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VIII International Scientific Siberian Transport Forum

TransSiberia 2019, Volume 2

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International Siberian Transport Forum—TransSiberia 2019

Preface

International Scientific Siberian Transport Forum—TransSiberia 2019—took place in Novosibirsk, Russia, on May 22–27, 2019.

The forum was organized by the Government of the Novosibirsk Region, the Ministry of Transport of Russia, the State Duma of the Russian Federation, the Legislative Assembly of Novosibirsk Region, and Siberian Transport University.

Leading experts in the field of transport from more than 15 countries met in Novosibirsk to exchange the latest scientific achievements, to strengthen the academic relations between the leading scientists of the European Union, Russia, and the World, and to create favorable conditions for collaborative research and implement collaborative projects in the fields of transport.

The authors from several countries submitted 575 qualified papers to TransSiberia 2019 conference. Of these, 214 papers were accepted. All papers passed a strict scientific, technical, and grammatical review.

Only papers of original research-type performing results of original studies are accepted.

The recommended size of a paper is 9–15 pages. The obligate condition for a scientific paper to submit is the accordance with IMRAD structure.

Within the framework of technical review, all papers are thoroughly checked for the following attributes:

(1) For compliance with the subject of the conference.
(2) For plagiarism, acceptable minimum of originality is 90%.

(3) For acceptable English language, all papers are reviewed by a native speaker.
(4) At the same time, papers are checked by a technical proofreader (quality of images, absence of Cyrillic, etc.).

Scientific review of each paper is made by at least three reviewers. If the opinions of the reviewers are radically different, additional reviewers are appointed. «Potential reviewers» recommended by authors are not used. Authors have a right to answer the remarks of reviewers and submit revised versions of their papers.

Live participation in the conference is an indispensable condition for the publication of the paper.

The conference included workshops and plenary sessions dedicated to the issues of road transportation, railroad transport, road engineering complex, air transport, public transport, transport and logistics complex, road safety, and passenger taxi.

Within the conference, the participants discussed a wide range of issues concerning digitalization and innovative development of transport, road network and road facilities, application of federal legislation in the field of passenger traffic, comfortable urban environment for low-mobility passengers, energy efficiency in transport, and other topics. The key agenda of discussions was the implementation of the national project "safe and high-quality roads" and the comprehensive plan for the expansion and modernization of infrastructure, including in the Siberian Federal District.

The members of our organizing committee express their deep gratitude to the crew of your journal. We appreciate your help in preparation of our TransSiberia 2019 conference volume.

The members of our organizing committee express their deep gratitude to the crew of Advances in Intelligent Systems and Computing journal for the publication of selected papers of the Siberian Transport Forum conference!

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Contents

Bridges, Roads, Tunnels, Construction of Transport Infrastructure Facilities

Wide Span Segmented Precast Concrete Girders

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Abstract. In Germany, most of logistic halls are constructed with precast reinforced concrete members. Nowadays, there is an increasing demand for logistic halls where the roof construction is to realize with a span of up to 60 m without any inner support. However, the production and the transport of 60 m long precast concrete members are only to perform under extraordinary difficulties. Therefore, it was necessary to develop another solution. The idea was to produce two separate precast concrete segments and to transport them to the site. At the site the segments are combined to the final girder by prestressing them together, resulting in a segmental girder with the requested span of 60 m. The paper provides information about the structural demands on the joint between the two segments and the carried-out experimental program.

Keywords: Segmental girder · Precast concrete · Prestressed concrete

1 Introduction

Caused by the demand for high user's flexibility, an increasing share of logistic halls is constructed without any inner load-bearing walls and columns. Therefore, slab and roof girders must be designed for a span of up to 60 m. This fact is a problem for precast concrete industry because the production and the transport of such long elements are very difficult and inefficient from point of economy. To get a gapless value chain, the precast concrete industry is interested in a practicable solution of this problem. In this context, the precast concrete company Betonwerk Heringen GmbH & Co. KG, belonging to the Austrian HABAU Group, and the Structural Concrete Institute (IfB) of Leipzig University of Applied Sciences worked together for the development of a new precast concrete girder system. The main idea was to divide the girder in two separate elements with a length of up to 30 m, each of them produced and pre-tensioned in the precast company. After hardening of concrete, the two separate elements are transported to the site. At the site, these elements are to combine to the final segmental girder. The joint between the two segments is to prestress by external tendons in a way that all safety demands in the ultimate limit states and the serviceability states are satisfied.

This procedure is a usual technique for the construction of bridges [1]. In published experimental investigations it was noticed that the segmentation is an appropriate technique for long-span structures enabling a very ductile load-bearing behavior [2].

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However, for the construction of long-span girders that are not part of bridges, there is only few experience. Therefore, a research program was carried-out at IfB focused on the structural behavior of the joint between the two segments.

2 Initial Situation

In the first step the initial conditions for the production of the girder had to be defined. For manufacturing reasons a T-section with a maximum height of 3.00 m was selected. The structural system of the final segmented girder is a single span beam with simple supports on precast concrete columns. After assembling of the two separate precast concrete elements a girder span of 60.00 m should be achieved.

Each of the two separate elements are produced and pre-tensioned in the precast concrete company. For the joint between the two elements a dry joint was selected. Dry joints own some benefits in comparison to other types of joints, see Fig. 1. When using a dry joint there is no need for adhesive bonding or casting concrete in the gap between the two elements, resulting in an easier and faster assembly work at the site.

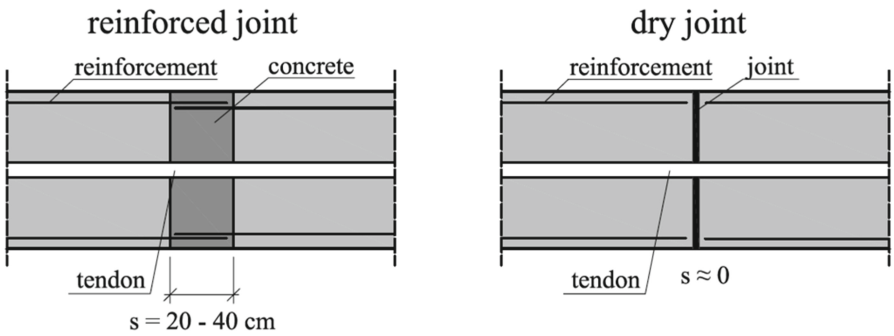

Fig. 1. Joint types between precast concrete elements.

The connection between the two segmental elements must be able to bear the acting bending moments, axial forces and shear forces. In principle, in a dry joint it is impossible to splice the reinforcement. Therefore, it was made the decision to use an external post-tensioning system to achieve a safe connection. The bar tendons cross the joint outside of the cross-section. In different heights, two bar tendons (always one at each side) are arranged. The number of bar tendons was dependent on the needed load-bearing capacity of the connection. For anchorage of the tendons, the web was widened to width of the slab near the joint resulting in a kind of corbel. The tendons pass the corbels in ducts and are anchored at the end of the corbels with steel plates, see Fig. 2.

Another question was how to profile the surface of the joint. As a result of preliminary considerations, the profiling was concentrated in the web. It was a particular challenge for the precast concrete company to guarantee the needed accuracy of the end face of the segmental elements later being part of the connection.

Fig. 2. Post-tensioning of the connection between the two precast elements.

The most important point of the performed experimental and analytical investigation was the design and optimization of the dry joint.

3 Experimental Investigations

The main part of the experimental program was the loading-test of connected specimens that were scaled to lower dimensions in comparison to the real segmented girder. An overview about the specimen geometry is provided in Fig. 3. In Fig. 3 only one of the both connected specimen is figured. The general test set-up is shown in detail in Figs. 4 and 5.

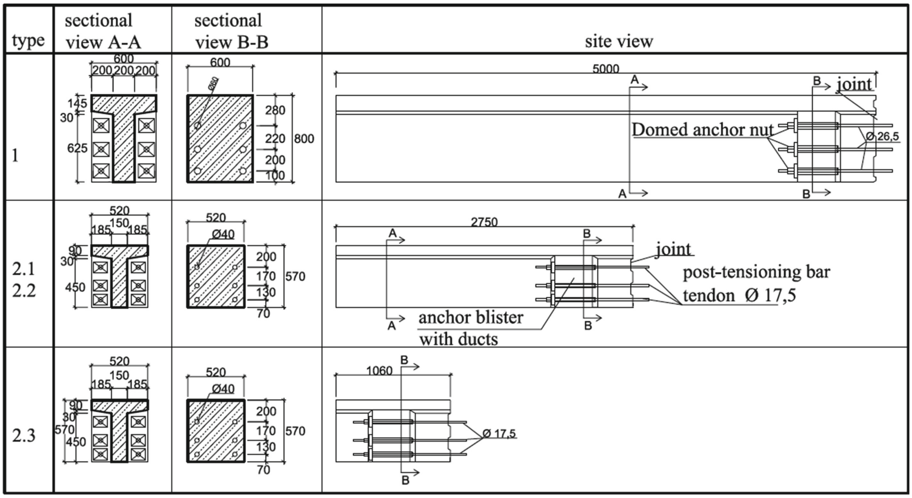

Fig. 3. Specimen geometry.

The pre-tensioned segmental elements were produced in the precast concrete company Betonwerk Heringen GmbH & Co. KG and transported to IfB in concrete age of 28 days.

In preparation of the loading tests, two precast concrete elements (type 1 according to Fig. 3) were adjusted at the lab and, subsequently, connected by external post-tensioning. As result of the post-tensioning process, the own weight of the girder system was activated. Then, the segmental girder was loaded in vertical direction. The load was applied by four hydraulic jacks with a capacity of 400 kN each. Arrangement of the load was equivalent to a four-point-bending test, whereby the load position was relative close to the joint, see Fig. 4.

Specimens type 2.1 and 2.2 were tested to find an optimal geometry of the specimen's end face at the joint side. Specimen type 2.3 was used for long-time experiments to get information about the influence of concrete creep on the load-bearing capacity of the connection.

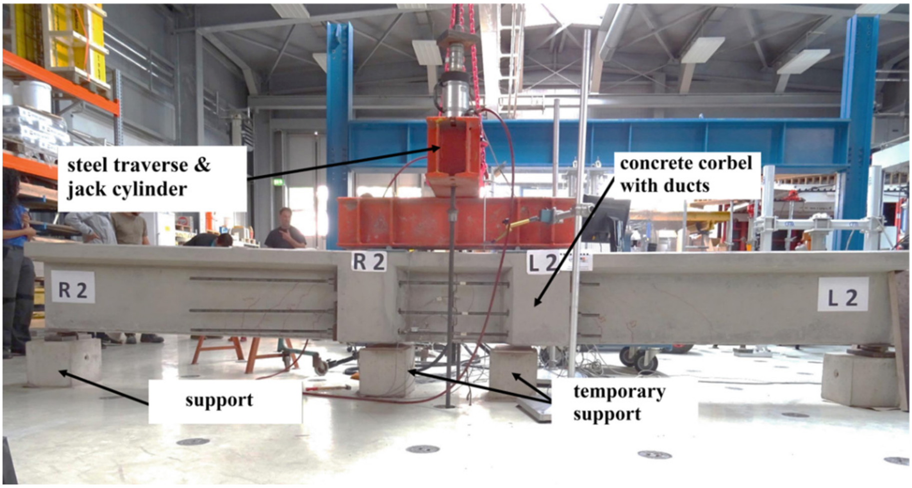

Fig. 4. View of two connected segmental elements in the loading test.

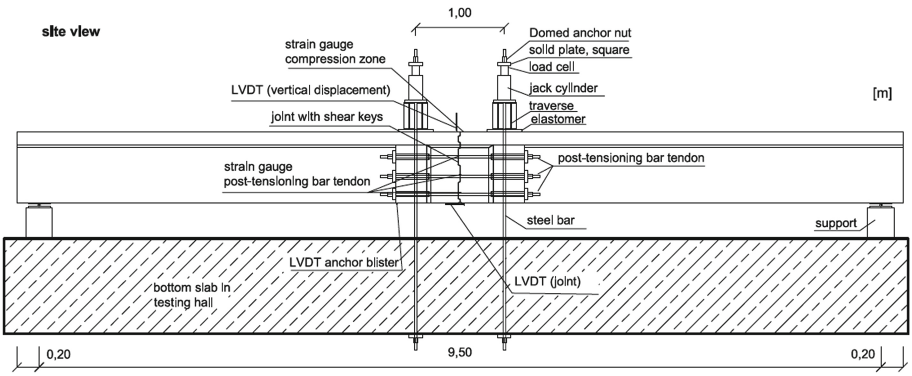

Fig. 5. Test set-up for four-point bending tests at specimens type 1.

The bending moment-deflection behavior of specimen types 1, 2.1 and 2.2 is provided in Fig. 6. It is obvious that there is a very ductile load-bearing behavior. At begin of loading process there is a quite linear load-deflection relation. For higher loads, it is apparent that structural behavior becomes clearly non-linear because there is a strong increase of deformation for only low load increase. Summarizing, it is to state, that the structural behavior is characterized by opening of the joint, big deflections and many bending cracks with small crack width in the web. In all cases, collapse was caused by failure of concrete compression zone, see Fig. 7.

Specimen type 1 did not reach the pre-calculated ultimate limit moment in the experiment. Reason was the insufficient bond of the pre-tensioned wires inside of the

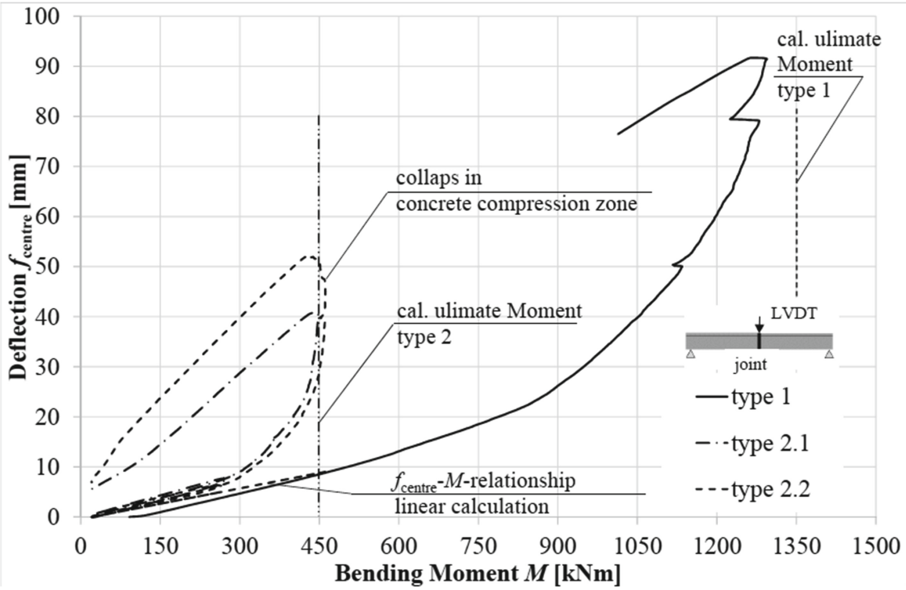

Fig. 6. Bending moment-deflection behavior of tested specimens.

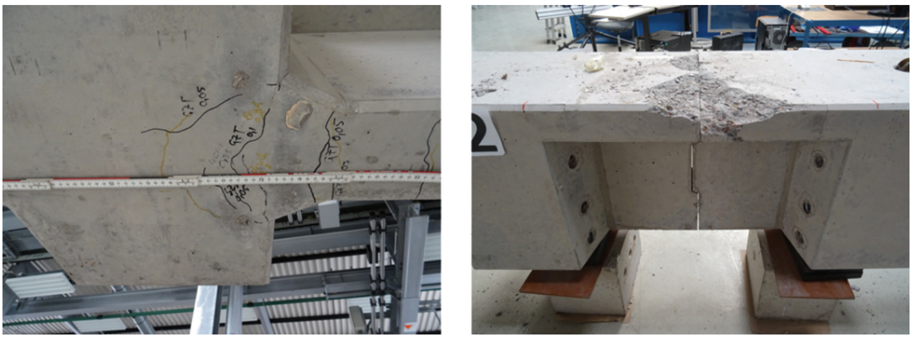

Fig. 7. Failed specimen, left: cracks at bottom side, right: failed concrete compression zone.

segmental elements. By changes in geometry and steel bar reinforcement this disadvantage could be avoided in the later produced and tested specimens 2.1 and 2.2. For those specimens the ultimate bending moment in the experiments slightly exceeded the pre-calculated one.

More details about the experimental program are described in [3, 4].

4 Simulations

For further optimization of the segmental elements, a Finite-Element (FE) analysis was carried out where FE-software ATENA was used. To get close-to-reality results, all requested concrete material properties (compression and tensile strength, modulus of elasticity, softening behavior) were measured in additional experiments with small specimens.

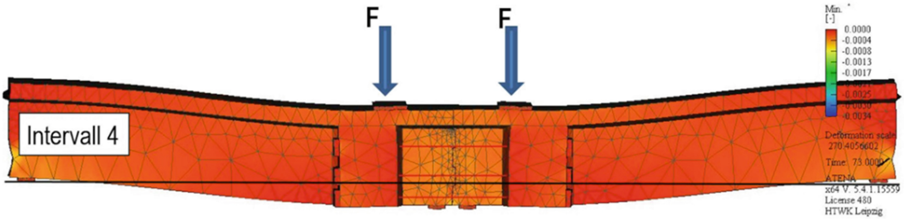

Fig. 8. FE-model used for simulation.

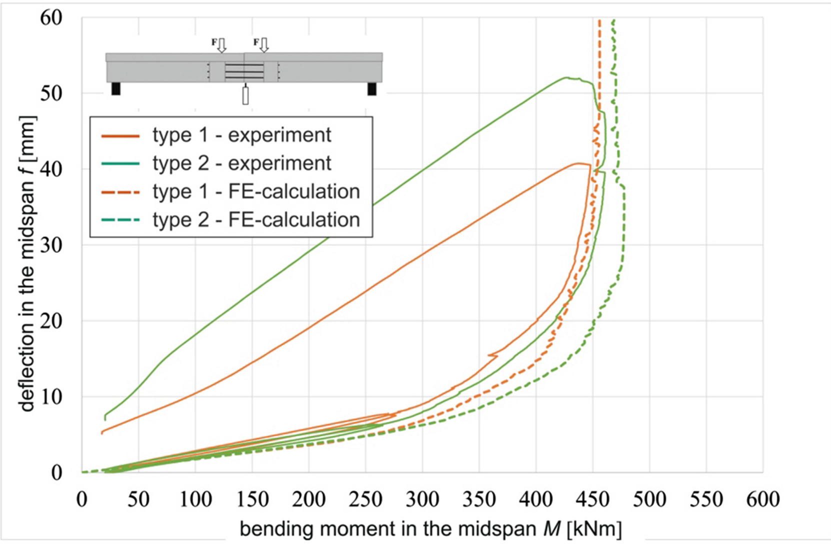

Fig. 9. Comparison between experimental results and FE simulations.

The applied FE-model is shown in Fig. 8 together with deformations for a situation where external vertical load is already applied. Comparison between experimental data and FE calculation indicates just very low differences (Fig. 9). This fact enables the usage of the developed FE-model for an intensive optimization of the segmental girder.

5 Summary

Segmental girders are a favourable construction system enabling very long spans. The carried-out experimental and analytical investigations are the basis for future application of segmental girders in building practice. Post-tensioning using external tendons is an appropriate method for connecting the segmental elements in a safe and economic way.

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Early Cost Estimates of Bridge Structures Aided by Artificial Neural Networks

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Abstract. Cost estimates are essential for construction projects success in terms of completion of a project on budget. The estimates that are delivered in the early phase of construction projects are of special importance. The paper presents results of research on applicability of artificial neural networks for early cost estimates of bridge structures. Number of multilayer perceptron networks were investigated as a core of regression models developed to support cost prediction. Basic parameters of bridge structures were used as input values, whereas real life construction costs played the role of expected output values. Data used in the course of the research consisted of information collected for 161 bridge construction projects completed in Poland. One neural network of best performance was selected to be the core of the model with the use of two-step procedure. This network's structure was 21-2-1 activation functions applied were hyperbolic tangent for hidden layer and linear for output layer. Performance of the model in the light of applied measures such as root mean squared error, mean absolute percentage error and assessment of absolute percentage errors distribution and expectations for early cost estimates is acceptable.

Keywords: Early cost estimates · Artificial neural networks · Bridge structures

1 Introduction

Bridges are very important components of the communication infrastructure in every country. Development of the infrastructure results in many new bridge construction projects. These projects need careful cost planning and budgeting. Early cost estimates, in other words cost estimates delivered in the early phase of a bridge construction project, have their own specifics. These estimates are based on general information about a project, basic characteristics and parameters of a construction which is supposed to be designed and built in the future. Collection of information including characteristics and parameters of bridge structures completed in the past along with the real life projects costs allow for development of models that aid early cost estimates. Artificial neural networks (ANN), as artificial intelligence tools, offer significant capabilities for such models: no need to assume analytical form of the relationship between the dependent and independent variables, ability to learn with the use presented data patterns and to generalize knowledge on this basis. ANN are reported to be used in early cost estimates for variety of construction projects. Some examples of such applications are models developed for: structural systems of buildings [1], residential

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buildings [2], sports fields [3], road tunnels [4], structural building projects [5]. Some other cost related problems where the use of ANN was investigated are: prediction of the tender prices of school buildings [6], estimates of site overhead costs [7, 8], or estimation for lifecycle costing of construction projects [9]. ANN applicability is also investigated in other fields of civil engineering – e.g.: classifying construction contractors [10], estimation of formwork labour [11], analysis of selected problems of geodesy [12], analysis of selected problems of structural and solid mechanics [13], predicting earthmoving machinery effectiveness ratios [14], predicting the maintenance cost of construction equipment [15].

The purpose of the paper is to present results of the research on the development of models that are expected to support cost estimates of bridge structures in the early phases of construction projects. The investigated and presented herein models are based on ANN of multilayer perceptron type (MLP). As the ANN simulator the author used TIBCO® STATISTICA™ software. The research presented herein is a continuation of the earlier author's work on the similar problems.

2 Assumptions for Model Development

Main assumption for the research was to develop a regression model, based on ANN of the MLP type. The theory of ANN, especially MLP networks, is widely discussed in literature [16–19] so the theoretical details in this paper were either omitted or reduced to absolute minimum.

2.1 General Concept and Training Data Presentation

If the variables are assumed as follows:

y – real life total construction cost of a bridge structure, dependent variable, expected output of a regression model;
x_j – cost predictors, selected characteristics of bridge structures, independent variables, input of a regression model;
then the aim of the research is to find a regression model that allows mapping $x_j \rightarrow y$. According to the assumptions for the research, the model was sought for in the form of a neural network which was supposed to implement the mapping implicitly.

For the purposes of the research database including 161 cases of road bridge projects completed in Poland between years 2005 and 2018 were used. Values of variable y stood for total construction costs of road bridge structures (given in PLN million) updated for year 2018. Cost predictors x_j represented basic information for bridge structures which can be identified on the early stage of construction project. Some of the independent variables were of a categorical type:

x_1 – type of a bridge structure – three possible values: 1. wharf (WH), 2. bridge (BR), 3. viaduct (VI);
x_2 – type of a structural solution – three possible values: 1. beam (B), 2. arched (A), 3. frame (F);

x_3 – type of material – three possible values: 1. prestressed concrete (PCT), 2. reinforced concrete (RCT), 3. steel (STL);
x_4 – type of intermediate supports – four possible values: 1. none (NO), 2. piles (PI), 3. solid-walled (SW), 4. Columns (CL);
x_5 – type of supports foundations – two possible values: 1. shallow (S), 2. deep (D);
x_6 – load class (according to rules and standards applied in Poland) – three possible values: 1. class A (A), 2. class B or C or D (BCD), 3. class E (E).

Some of the independent variables were of a numerical type:

x_7 – total length of a structure [m],
x_8 – width of a structure [m],
x_9 – number of spans.

Table 1 presents random sample of the independent and dependent variables values as recorded in the database (compare with the list above).

Due to the fact that the variables of a categorical type, $x_1 - x_6$, had to be coded as *1* of *n* the actual number of inputs (neurons in the input layer) equalled 21. Taking that into account along with overall number of training data, made some limitations for the complexity of investigated neural networks – especially for the number of neurons in the hidden layer.

Table 1. Random sample of the variables values

p	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	y
15	WH	A	PSC	W	D	BCD	292.7	10.5	8	21.329
27	VI	B	PSC	O	D	A	34.6	15.7	1	3.134
32	BR	B	PSC	O	D	BCD	25.0	8.7	1	1.907
66	BR	B	PSC	L	D	A	44.8	10.0	2	3.444
84	VI	FR	RCT	I	S	A	255.8	15.5	15	23.220
101	WH	B	PSC	W	S	A	90.3	15.7	3	9.735
149	BR	A	RCT	O	D	A	13.2	10.3	1	4.365

2.2 Assumptions for the Training and Selection of Neural Networks to Be the Core of Predictive Model

Figure 1 depicts the structure of investigated ANN. One can see that the way of coding of the variables of categorical type resulted in 21 neurons in the input layer. Input values were scaled appropriately in the preprocessing phase with regard to activation functions applied in the investigated ANN.

Considered activation functions were as follows: linear (LIN), logistic (LOG), hyperbolic tangent (TANH), exponential (EXP). Postprocessing aimed to convert the ANN output into the original values of y. Both preprocessing and postprocessing were done automatically by the ANN simulation software. (Please note that the models performance – especially errors measures are given in this paper for the original values of y - total bridge structures construction costs given in PLN million.)

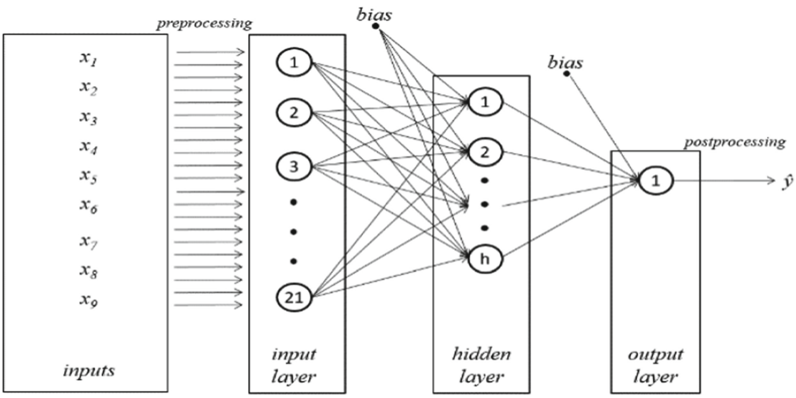

Fig. 1. Structure of investigated ANN

Overall number of data, which constituted patterns for the training and testing ANN, was divided into three subsets used for learning, validating and testing purposes – the subsets are referred later as *L*, *V* and *T* respectively. The division ratio *L*/*V*/*T* was as follows: 113/24/24. Division into the three subsets was made so as to ensure equivalence and representativeness of all data collected and used in the course of the research. Especially the representativeness of bridge structures present in the database and their parameters were of special importance.

Number of neurons in the hidden layer h was assessed according to the following equations [20, 21]:

$$h \approx \sqrt{NM} \tag{1}$$

where:

N – number of neurons in the input layer,
M – number of neurons in the output layer.

$$L \geq P = \sum\nolimits_k w_k + b \tag{2}$$

where:

L – cardinality of a subset used for the purposes of supervised learning,
P – number of ANN’s parameters regarding its’ structure,
w_k – number of synaptic weights in the *k*-th layer of ANN (excluding input layer),
k – number of layers excluding (excluding input layer),
b – number of biases in the ANN.

Compromising conditions given by Eqs. (1) and (2) number of neurons in the hidden layer varied between 2 and 4.

Overall number of the trained networks equalled 100. These networks varied in: the number of neurons in the hidden layer in terms of their structures, activation functions applied in neurons of hidden and output layer, initial conditions of training process (sampling of initial values of synaptic weights).

Error function, minimized during the training process, is given by the equation below:

$$E_{SOS} = \sum_{p} (y^p - \hat{y}^p)^2 = \sum\nolimits_p (e^p)^2 \tag{3}$$

where:

$e^p = y^p - \hat{y}^p$ – prediction error, difference between the real life value y^p and value predicted by model $\hat{y}^p$,
p – index of a pattern belonging to L subset.

One of the criteria of networks selection was correlation between real life values of the bridge structures total construction cost y and values predicted by model $\hat{y}$. In order to measure the correlation Pearson's coefficient R was used:

$$R = \frac{cov(y, \hat{y})}{\sigma_y \sigma_{\hat{y}}} \tag{4}$$

where:

$cov(y, \hat{y})$ – covariance between y and $\hat{y}$,
σ_y, $\sigma_{\hat{y}}$ – standard deviations for y and $\hat{y}$ respectively.

Two main error measures were considered to assess the performance of investigated networks: root mean squared error (*RMSE*) and mean absolute percentage error (*MAPE*). For the purposes of predictive performance analysis of the trained networks also the distribution of absolute percentage errors (APE^p) was assessed.

$$RMSE = \sqrt{\frac{\sum_p (e^p)^2}{n}} \tag{5}$$

$$MAPE = \frac{100\%}{n} \sum\nolimits_p \left| \frac{e^p}{y^p} \right| \tag{6}$$

$$APE^p = 100\% \left| \frac{e^p}{y^p} \right| \tag{7}$$

where:

n – cardinality of L or V or T subset,
p – index of a pattern belonging to L or V or T subset.

Values of *RMSE*, *MAPE* and PE^p were computed after the end of training process for L, V and T subsets respectively.

Selection of the best network was made with the use of the two step procedure:

- in the first step 10 ANN were initially selected on the basis of the following criteria: high enough *R* values and *RMSE* values which were convergent for *L*, *V* and *T* subsets,
- in the second step final choice of the best ANN, out of 10 initially selected in the first step, was based on assessment of *MAPE* values (as errors measures) and distribution of APE^p values that compromised low errors' values and good generalization capabilities.

The performance of the finally selected network was presented and discussed.

3 Results and Discussion

First step of the procedure allowed for initial selection of 10 trained ANN (out of 100). Characteristics of the 10 initially selected networks are presented in Table 2. What is interesting most of initially selected ANN had 2 neurons in the hidden layer, none of them had 4, so the simplest assumed structure appears to be most effective in the investigated problem. In the Table 2 one can see that the *R* values computed for *L*, *V* and *T* subsets were greater than 0.9 in all cases. *RMSE* values computed for *L*, *V* and *T* subsets for each network were convergent, moreover the differences between the ANN were not significant.

Table 2. Characteristics of 10 ANN selected in the first step

Times	MLP	Activation functions: hidden layer/output layer	R_L	R_V	R_T	$RMSE_L$	$RMSE_V$	$RMSE_T$
1	21-2-1	TANH/TANH	0.911	0.922	0.947	1.856	1.742	1.634
2	21-2-1	TANH/LIN	0.920	0.946	0.945	1.763	1.598	1.702
3	21-3-1	LOG/LIN	0.902	0.943	0.934	1.943	1.690	1.806
4	21-2-1	TANH/LIN	0.901	0.945	0.923	1.996	1.536	1.977
5	21-2-1	TANH/TANH	0.911	0.922	0.947	1.856	1.742	1.634
6	21-2-1	TANH/LIN	0.920	0.946	0.945	1.811	1.728	1.787
7	21-3-1	LOG/LIN	0.902	0.943	0.934	1.943	1.690	1.806
8	21-2-1	EXP/TANH	0.920	0.931	0.925	1.756	1.663	1.936
9	21-2-1	EXP/TANH	0.924	0.952	0.943	1.720	1.380	1.694
10	21-2-1	TANH/TANH	0.911	0.931	0.946	1.856	1.639	1.693

Table 3 presents MAPE values computed for the 10 ANN for L, V and T subsets.

Table 3. MAPE values for the 10 ANN selected in the first step

LP	1	2	3	4	5	6	7	8	9	10
MLP	21-2-1	21-2-1	21-3-1	21-2-1	21-2-1	21-2-1	21-3-1	21-2-1	21-2-1	21-2-1
$MAPE_L$	19.7%	16.8%	21.3%	27.6%	19.7%	18.9%	21.3%	25.2%	24.7%	21.0%
$MAPE_T$	20.2%	15.7%	21.3%	19.1%	20.2%	17.6%	21.3%	22.7%	19.5%	19.8%
$MAPE_V$	19.7%	16.7%	25.0%	28.2%	19.7%	17.1%	25.0%	27.2%	24.5%	24.1%

The charts presented in Figs. 2, 3 and 4 depict the distribution of APE^P errors, for L, V and T subsets consequently. The APE^P errors computed for each of the 10 ANN ordered in successive ranges:

$APE^P \leq 10\%$,
$10\% < APE^P \leq 20\%$,
$20\% < APE^P \leq 30\%$,
$30\% < APE^P \leq 40\%$,
$APE^P \geq 40\%$.

Percentage shares for each range are presented in the charts.

Analysis of *MAPE* values and distribution of APE^p errors allow for the final choice of ANN number 2 that is MLP 21-2-1 with TANH activation function in the hidden layer and LIN activation function in the output layer. *MAPE* values were smallest for this network. In terms of APE^p distribution all values were smaller than 40%.

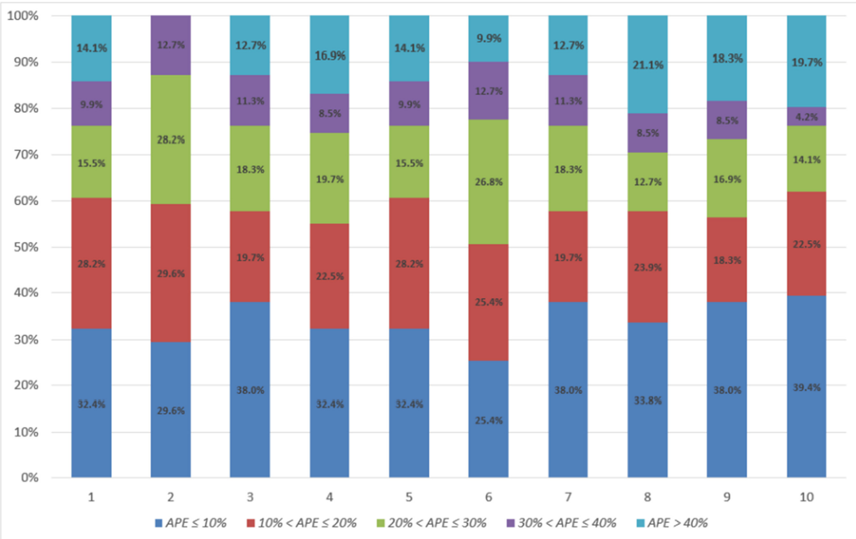

Fig. 2. Distribution of APE_p errors for L subset for the 10 ANN

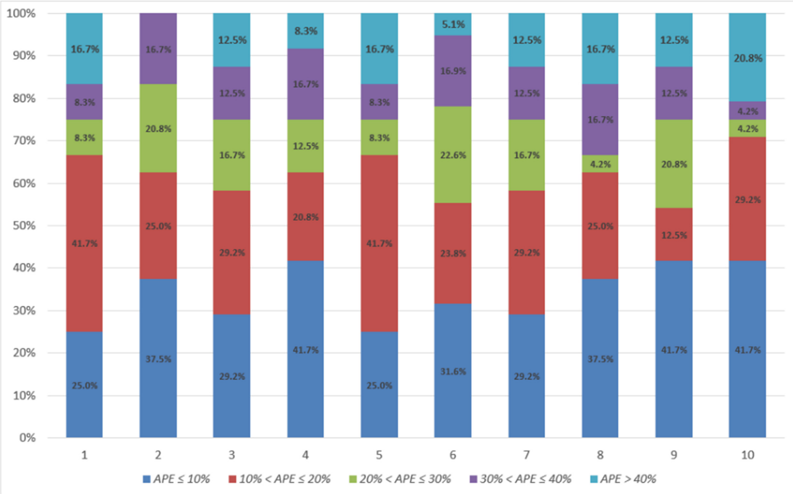

Fig. 3. Distribution of APE^p errors for V subset for the 10 ANN

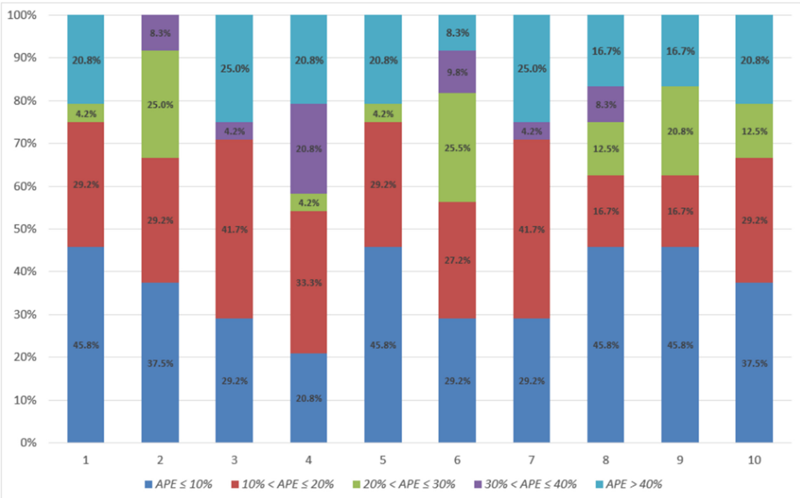

Fig. 4. Distribution of APE^p errors for T subset for the 10 ANN

Figures 5, 6 and 7 depict scatter plots of points which coordinates represent real life values of bridge structures construction costs y and model's output $\hat{y}$, that is costs predicted by the finally selected ANN. Figures 5, 6 and 7 present results obtained for L, V and T subsets respectively. One can see that the points are decomposed along the line of a perfect fit $y = \hat{y}$, in a similar manner for all three subsets.

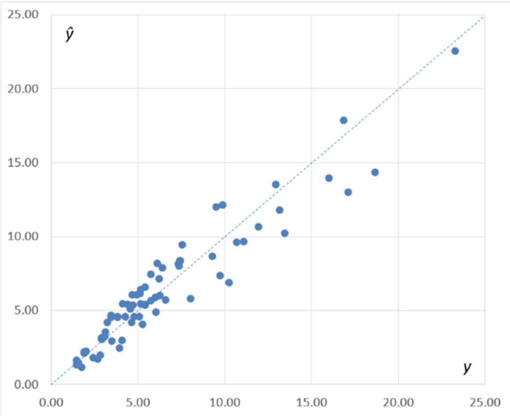

Fig. 5. Scatter plot of y and $\hat{y}$ values for the finally selected ANN for L subset

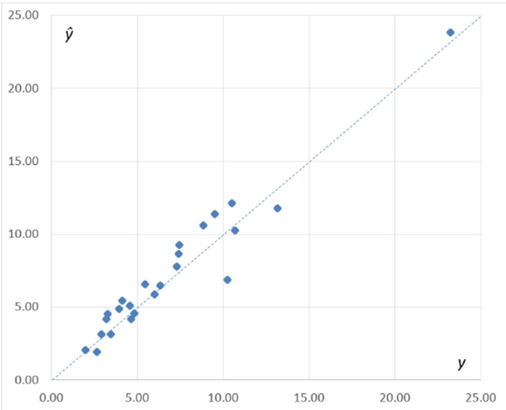

Fig. 6. Scatter plot of y and $\hat{y}$ values for the finally selected ANN for V subset

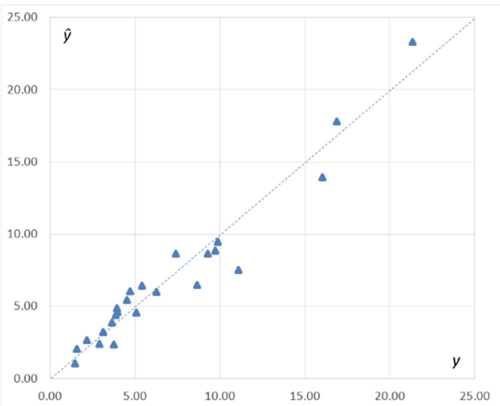

Fig. 7. Scatter plot of y and $\hat{y}$ values for the finally selected ANN for T subset

In Table 4 minimum and maximum values of APE^p are presented for the finally selected ANN for *L*, *V* and *T* subsets are set together. The cumulative percentage shares of APE^p in successive ranges are also set together in the Table 4 (these values can be compared with APE^p distributions presented schematically in Figs. 2, 3 and 4).

Table 4. APEp values obtained for the finally selected ANN for *L*, *V* and *T* subsets

APE^p		L	V	T
APE^p	min	0.39%	2.08%	3.34%
	max	37.81%	38.14%	36.99%
	$\leq$ 10%	29.6%	37.5%	37.5%
	$\leq$ 20%	59.2%	62.5%	66.7%
	$\leq$ 30%	87.3%	83.3%	91.7%
	$\leq$ 40%	100.0%	100.0%	100.0%

One can see that most of the APE^p values, (namely 87.3% for *L* subset, 83.3% for *V* subset and 91.7% for *T* subset) are smaller than 30%. General expectations about the accuracy for early estimates is that difference between the actual final cost and the estimated cost (in other words error of estimation) should be no greater than ±25%/30%. One can see that this condition is fulfilled by the model for most of the cases for all of the three subsets. The accuracy of model is acceptable however there is possibility of improvement of model's performance. This is going to be the goal of some future work.

4 Summary and Conclusions

The paper presents a study on the development of a model, based on ANN, that is supposed to aid early cost estimates of bridge structures construction. Altogether 100 ANN of MLP type were trained. The networks varied in their structures, activation functions applied and initial conditions of learning process. Single network of best performance was selected to be the core of the model with the use of two-step procedure. The finally selected network structure was 21-2-1 (two neurons in the hidden layer), activation functions applied were hyperbolic tangent for hidden layer and linear for output layer. For finally selected ANN obtained measures of performance were as follows:

- Pearson's correlation coefficient values between real life values of bridge structures construction costs y and costs predicted by the finally selected ANN $\hat{y}$ equalled 0.920, 0.946 and 0.945 for subsets used in learning, validating and testing respectively,
- root mean squared error values equalled 1.763, 1.598 and 1.702 for subsets used in learning, validating and testing respectively,
- mean absolute percentage error values equalled 16.8%, 15.7%, 16.7% for subsets used in learning, validating and testing respectively.

Performance of the model in the light of APE^p distribution and expectations for early cost estimates is acceptable. Taking into account number of patterns available for training and testing limited for now to 161 cases obtained results are satisfactory. Future research will cover the issues of collection of supplementary data to enrich the database and implementation of neural networks ensembles to be the core of model.

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The Study of the Effect of Heat Mains Laid in the Automobile Road Embankment Pavement on Its Base

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Abstract. The article provides a way to prevent deformation of linear structures in connection with the laying of the heat mains, which contributes to the formation of ice. The considered pavement design when laying the heating system is being erected on a section of the highway belonging to category III roads. The results of scientific research and engineering calculations of the parameters of rational road structures when laying a heating network are presented using the example of the Far Eastern section of the highway. Development is a generalization of the results of solving engineering, scientific and computational-applied problems. In the considered area, a heating network is laid, which will subsequently warm the outer surface of the asphalt concrete due to the heat generated by the pipes, which will cause ice formation on the outer surface of the asphalt concrete in the period with negative temperatures.

Keywords: Deformations · Freezing · Defrosting · Geosynthetic materials · Geogrid · Modeling · Heat insulation · Load bearing capacity · Stress-strained state

1 Introduction

The design includes a pseudo-plate device in crushed stone layers using an integrated biaxial geogrid, as well as laying a heat-insulating layer. In the process of analyzing the initial data and during the performance of the work, it was found that for the possibility of evaluating and comparing the indicators, it is necessary to provide theoretical and theoretical studies for several design options. When analyzing possible methods and means for determining rational design parameters, it will be advisable to use the FEM models and Termoground geotechnical software systems that can complexly simulate the operation of structures according to its stress state, as well as the ongoing thermodynamic processes in the annual freezing cycle - thawing. The performed numerical modeling of the construction using this geotechnical software package made it possible to assess the stability of structural deformations, as well as to limit the heating of the surface of asphalt concrete with the coolant.

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Laying heating mains in an embankment of roads in areas with seasonal freezing and thawing always has a high degree of risk associated with the occurrence of unacceptable deformations due to heating of the road surface in a period with negative temperatures [1]. This is especially true for linear transport facilities requiring an increased level of reliability and responsibility.

Such structures should provide permissible deformability and bearing capacity of the bases when exposed to promising moving loads in difficult geological and climatic conditions.

One of the rational solutions to the main issues associated with laying heating mains in regions with difficult geological and climatic conditions is the scientifically and technically sound use of the properties of modern geosynthetic materials that can ensure long-term stable operation of structures using local building materials [2]. At the same time, the properties of the applied geosynthetic materials must fully comply with the requirements of the conditions of their work in structures, as well as the condition of durability and quality. Developed design solutions must satisfy the requirements of regulatory documents in force in the Russian Federation on strength and frost resistance. In addition, the construction of the structure should provide bearing capacity when exposed to specified moving loads.

The complexity of the considered section of the highway on the street the Pioneer Street of Khabarovsk in the Khabarovsk Territory is associated with the presence of seasonal freezing and thawing and, as a consequence, changes in their temperature and humidity conditions, which require special treatment and design [3, 4]. In addition, due to the possibility of special circumstances, a high load on the roadway has been accepted for consideration (Fig. 1). Renault road train, 47 t payload, having 5 axles, 2 m track. The axle load is distributed as follows:

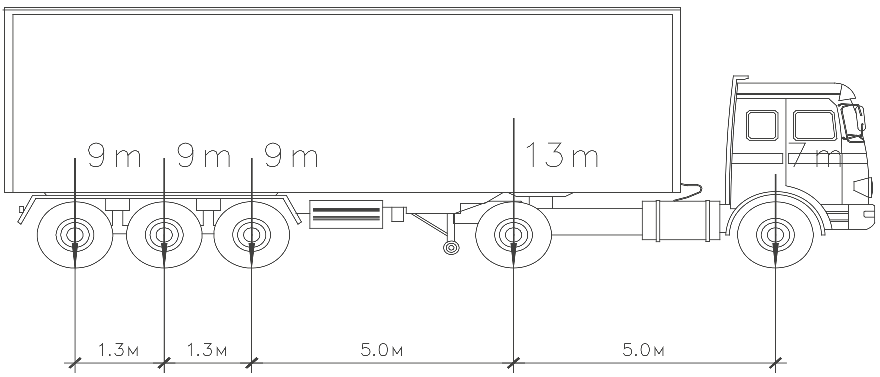

Fig. 1. Load distribution on trailer axles

When determining the required thickness of the insulating layer to prevent heating of the outer surface of the asphalt concrete due to heat generation from the pipes of the heat network and to prevent the formation of ice on the outer surface of the asphalt concrete in the period with negative temperatures, take the temperature of the coolant (water) T = 130 °C.

The permissible temperature of the heating of the outer surface of the asphalt concrete during the period with negative temperatures of the asphalt concrete is not more than minus 4 °C.

In this regard, it is necessary to develop a pavement coating design when laying a heating network to exclude the formation of deformations and frost on the road surface [5, 6].

2 Numerical Implementation of Thermophysical Modeling

An integral part of FEM-models is the Termoground program [7, 8], which allows us to study the processes of freezing, frost heaving and thawing in an annual cycle using the finite element method using numerical modeling in a spatial setting.

The general equation describing the freezing-thawing process for non-stationary thermal conditions in three-dimensional soil space can be represented as the following expression:

$$C_{th(f)}\rho\frac{\partial T}{\partial t} = \lambda_{th(f)}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + q_V \tag{1}$$

where is the specific heat of soils (frozen or thawed); ρ - soil density; T is the temperature; t is the time; $\lambda_{th(f)}$ - thermal conductivity of soils (frozen or thawed); x, y, z - coordinates; qv is the power of internal heat sources.

The main factor determining the reduced temperatures on the surface of the subgrade and adjacent terrain is the temperature of the atmospheric air and the conditions of its heat exchange with the surface, depending on the wind regime, solar radiation, evaporation, etc. [9, 10].

The calculated value of the monthly average air temperature is determined by the formula:

$$T_{np.} = T_{в} + \Delta t_r - \Delta t_e \tag{2}$$

where is $T_в$ – average monthly air temperature, °C; Δt_r и Δt_e – corrections to monthly mean air temperatures due to solar radiation and evaporation, °C.

3 Geotechnical Modeling of the Design of the Road

Geotechnical modeling of the pavement coating after laying a reinforced concrete slab over the laid heating main has been performed. A close to real picture of the location of the zones of propagation of elastic strains and dangerous zones with plastic strains was obtained (Figs. 2, 3 and 4). In mathematical modeling, numerical values and their distribution in the structure were obtained, as well as a direct indicator of deformations and their distribution in cross sections [11, 12]. The modeling of thermodynamic processes is due to the need to obtain a qualitative and quantitative picture of freezing-thawing in the structure in a year or more cycle.

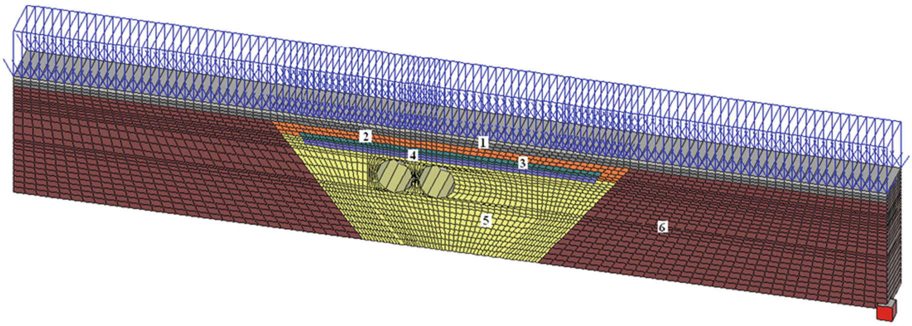

Fig. 2. Calculation scheme of the facility: 1 – three-layer asphalt concrete; 2 – breakstone M600; 3 – plate; 4 – polystyrene; 5 – sand and gravel composition; 6 – underlying pavement layer

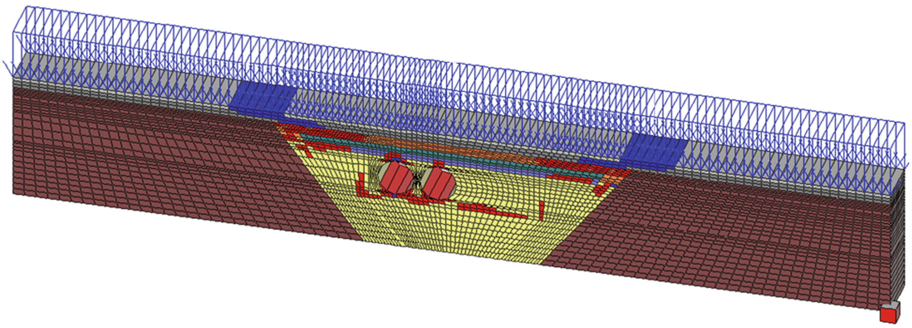

Fig. 3. Area of elastic and plastic deformations: blue color – elastic deformations; red color – plastic deformations

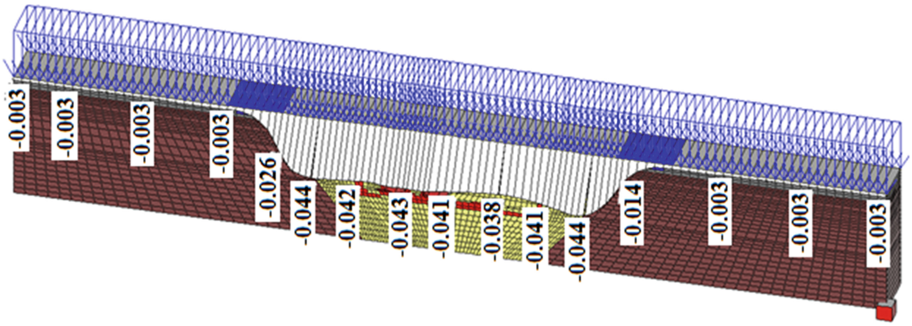

Fig. 4. Vertical deformations of the road surface, m

Numerical modeling of freezing-thawing of the structure was carried out monthly. The design scheme is presented in Fig. 5.

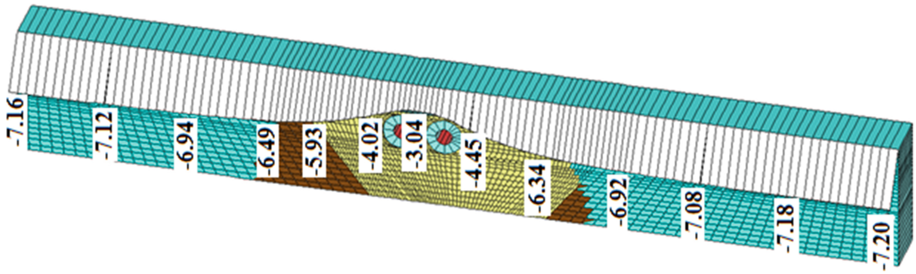

Fig. 5. Temperature plot on the surface of asphalt concrete during the period of negative temperatures (March), °C

As a result, it was found that the surface of the pavement is subject to uneven deformations due to the different stiffness of the base in the area under consideration [13].

An analysis of the results of geotechnical modeling of the structure showed that zones of plastic deformations are widespread everywhere in crushed stone and sand and gravel, in places of variable structural rigidity between reinforced concrete slab and existing road pavement, which indicates insufficient bearing capacity of the road structure.

To reduce or almost completely stop plastic deformations, as well as to redistribute stresses in order to prevent uneven deformations, interlayers should be provided to increase the bearing capacity of the base and redistribute stresses [14].

Such a layer can be crushed stone pseudo-plate, where the composite-forming element is an integrated biaxial geogrid [15].

To reduce the risk of uneven soil deformations from the thermal effects of the heating main, it is necessary to provide a set of measures to reduce soil thawing during periods with negative temperature of asphalt concrete (using heat insulators).

Geotechnical modeling of the condition of the pavement coating after laying a reinforced concrete slab over the laid heating main using geosynthetic geomaterials in crushed stone and heat-insulating materials was performed (Figs. 6, 7, 8 and 9).

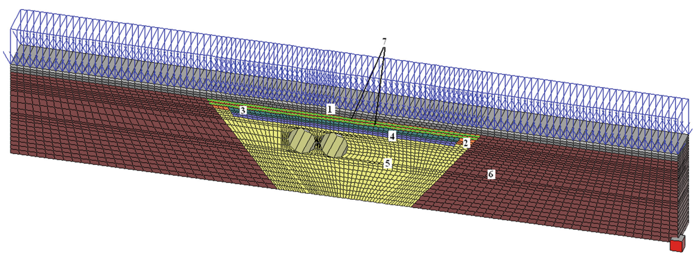

Fig. 6. Calculation scheme of the facility: 1 – three-layer asphalt concrete; 2 – breakstone M600; 3 – plate; 4 – polystyrene; 5 – sand and gravel composition; 6 – underlying pavement layer; geogrid

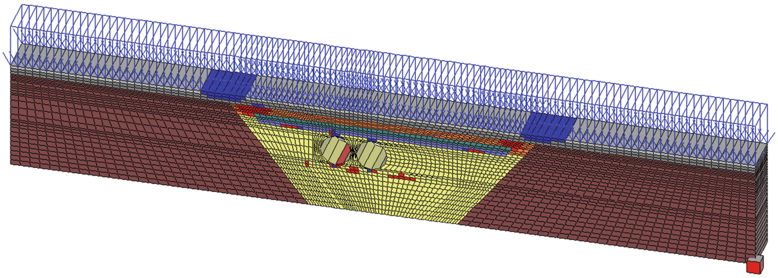

Fig. 7. Area of elastic and plastic deformations: blue color – elastic deformations; red color – plastic deformations

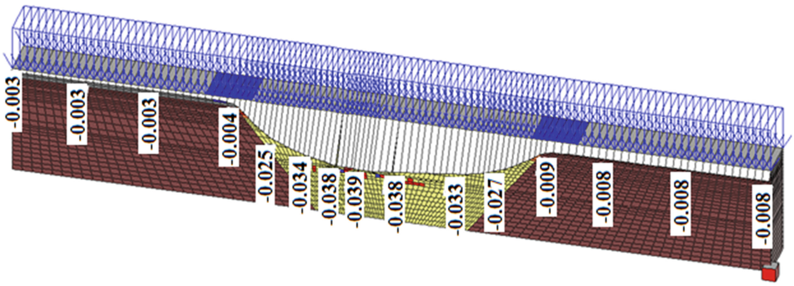

Fig. 8. Vertical deformations of the road surface, m

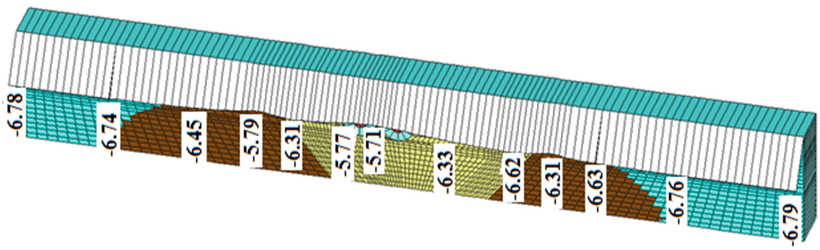

Fig. 9. Temperature plot on the surface of asphalt concrete during the period of negative temperatures (March), °C

4 Conclusions

1. The zones of plastic deformations in crushed stone and sand and gravel, in places of variable structural rigidity between the reinforced concrete slab and existing pavement, have significantly decreased, which indicates the effectiveness of the selected measures.
2. When considering the obtained vertical deformations of the pavement structure, it can be concluded that the surface deformations of the pavement have been reduced,

and the redistribution of stresses by the creation of a pseudo-plate has led to the elimination of subsidence in places of different structural stiffness.

3. When laying a heat-insulating coating, the temperature values of the outer surface of the asphalt concrete correspond to the permissible temperature of the heating of the outer surface of the asphalt concrete in the period with negative temperatures. The thickness of the insulating material determined by the calculation is 10 cm.
4. The use of modern geotechnologies and new geosynthetic materials in construction has a progressive trend today. They are in many ways a cost-effective and reliable alternative to traditional solutions. Therefore, comprehensive research in the field of the rational use of the capabilities of geosynthetic materials when they work in soil environments, the development of new structures and calculation methods, as well as the search for perfect approaches to solving such problems of modern geotechnics, are of high importance and relevance today.

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Application of RFID Technology on Construction Site – Case Study

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Abstract. Technological innovations are spreading in all sectors. The application of innovation to the construction industry is not straight forward, despite the importance of this sector in the development and growth of the wider economy. One of the innovative approaches to increasing the technical, technological, time, safety, quality and environmental efficiency of construction is the application of radio frequency identification (RFID) to the building sites. The aim of the paper is to point out the possibilities of using RFID technology for construction and to describe the advantages of its application. The case study was chosen as a research method. The research object was a construction of "Waste collection area" in Torysa village. Three variants of RFID technology (component types and its location) application for this particular construction site has been designed and then assessed. The cost parameters of the use of RFID technology for all variants were analysed and described benefits of its use in term of time, cost, quality, safety and environment point of view.

Keywords: Innovation · RFID technology · Construction site · Case study · Construction project management

1 Introduction

Currently, construction projects are becoming more complex and difficult to manage [1]. Also, the building and construction industry is one of the most important in modern economies. The higher the levels of innovation in the construction industry, the greater the likelihood that it will increase its contribution to economic growth. Unfortunately, in most countries, there is a perception that the industry is not generally innovative, and that there is much room for improvement. Government reports commissioned in recent years have identified such problems as poor rates of investment in research and development, fragmented supply chains, and lack of coordination between academia and industry in research activities [2]. The construction sector has failed to keep pace with productivity improvements seen in the manufacturing sector over the last 20 years [3]. With productivity in the construction sector lagging other sectors, there are hopes that the continued advancement of the fourth industrial revolution (also known as Industry 4.0) will spur on innovation and bring forward opportunities to improve efficiency.

New innovations in construction often involve the built environment, with the advent of built-in sensors and automation enabling engineering and construction

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companies to develop products and services that cover the all phases of life-cycle of buildingsa and infrastructure assets, integrating with energy management, repair and maintenance and wider smart building and smart city applications. One of the innovative solution in construction is Radio Frequency Identification (RFID) technology. Owing to its ability to identify and track objects, RFID is extensively used for diverse applications [4]. Notably, in industrial sectors such as logistic and supply chain management, manufacturing, RFID technology has been widely discussed. Because of its ability to identify and track objects, RFID is being used for diverse applications: (i) aviation, (ii) construction and facility management, (iii) health, (iv) retailing, (v) logistics or security, among others.

1.1 RFID Technology

Since the 1990s, RFID has been applied in the field of construction. RFID technology has been inserted in construction to make easier, and even automatic, a large variety of processes during the lifecycle of a construction. Before the construction starts, some operations related to the production of materials and components are automatically registered and controlled by means of RFID tags. This technology is based on exchanging information by means of electromagnetic signals [5]. An RFID system (see Fig. 1) is mainly composed of a transceiver (called the reader) connected to an antenna and a set of transponders or tags, where information is stored [6]. The reader communicates with a computer by means of an application, which manages the data stored in the tags. Antennas establish the communication between the readers and tags.

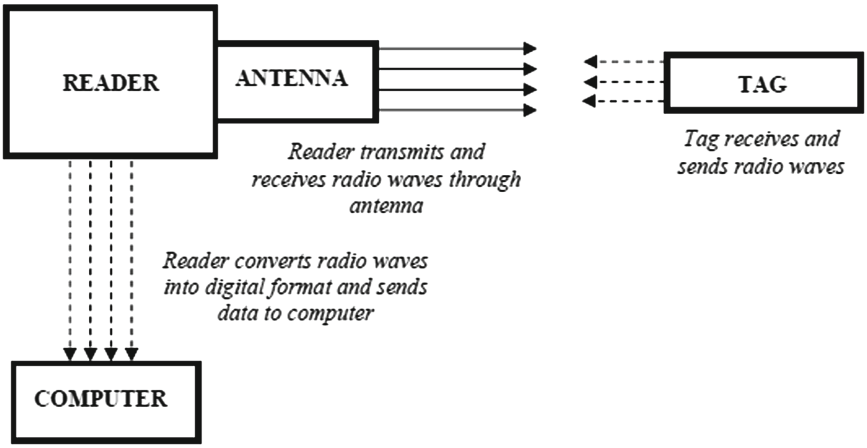

Fig. 1. RFID components [7]

1.2 RFID Technology in Construction

RFID technology can be integrated into all phases of life cycle of construction, but mainly into construction and operation and maintenance phase. During the construction process, thousands of materials and a crew of workers, equipped with tools and vehicles, are permanently changing their position in the jobsite. Controlling the location of resources and material helps to improve the productivity in building erection and to increase the safety of workers [4]. When a building is in use, an important number of maintenance and evaluation tasks are carried out. Diverse elements under inspection can be equipped with tags, aiming to monitor their condition or performance [4, 8].

The submitted paper deals with the RFID technology application in construction phase of building life cycle. Information is recognized as a new element for construction project management success. Project managers need to acquire real-time information about materials, men, and machinery so as to make prompt and informed decisions [9]. Author Lesniak et al. summarized a methods used to support decision-making in construction management [10]. RFID tags can be used for locating resources:

- materials,
- workers,
- equipment.

RFID technology offers the chance to locate materials in construction applications at a fast update rate and at an accuracy varying from one to a few meters. Since the 1990s, the possibility of taking into account RFID technologies for managing critical materials, equipment and vehicles has existed [11]. Not only the materials, but also other resources, such as workers or equipment, have to be controlled in the construction site. On many occasions, the evaluation of works has to be carried out by a supervisor. However, there are many employees moving at the same time around the job site. Aiming to control the operations executed by workers, they can be equipped with RFID tags that register the movements of the labour force and working time [12]. The poor quantity of tools or their misplacement in the workplace are related to undesirable interruptions. Workers have to look for the proper tool in the scene, this being a time-consuming task. In other construction scenes, the number of tools exceeds the necessary quantity to avoid delays. However, the addition of RFID tags to the equipment can be a useful strategy to optimize the budget [13]. On the other hand, the particular construction processes can be monitored by RFID technology:

- manufacturing and supply chain,
- concrete operations,
- precast production management,
- pipe spools,
- transport and delivery control,
- construction site.

Once the building construction is planned, different materials are moved from fabrication to the job site. In the last few years, RFID technology has been gaining importance in this supply of components, the decisions about the use of RFID systems in supply chains being an important issue. Jaselskis [11] proposed to incorporate RFID technology into delivery, billing and quality control for concrete. The steps of concrete mixing, loading time and delivery location would be monitored and notified to the job site and test laboratory. The fabrication of precast elements can be inspected and managed by means of RFID systems, as shown by precast production management system is developed to examine incoming materials and the production and logistic processes [14]. The transportation of materials from the factory to the construction site can be controlled by RFID technology. The control of these delivery jobs is therefore considered as a part of the constructive process. The continuous movement of materials and workers in the construction site, together with the advances in the works, make the monitoring of resources in the construction environment truly complicated. RFID technologies are not able to control every process carried out in the workplace. However, the combination of several technologies can automate the monitoring systems, helping measure the progress of every process. Thus, laser scanning and photogrammetry can be used for site representation, RFID and barcodes for collecting actual working hours and modelling for information purposes and updating planned data [15].

2 Material and Methodology

The aim of the paper is to point out the possibilities of using RFID technology for construction and to describe the advantages of its application. The case study was chosen as a research method.

2.1 Material of Research

The research object is a construction of “Waste collection area” in Torysa village, which consists of 7 construction objects (SO) (see Fig. 2): SO 01-production hall and warehouse, SO 02-steel shelter, SO 03-handling area, SO 04-waste storage, SO 05-fencing, SO 06-water-service pipe and SO 07-severage. The main construction object SO 01 is divided into a masonry construction and steel prefabricated part. The masonry part of the building is two-storey and steel hall is one-storey.

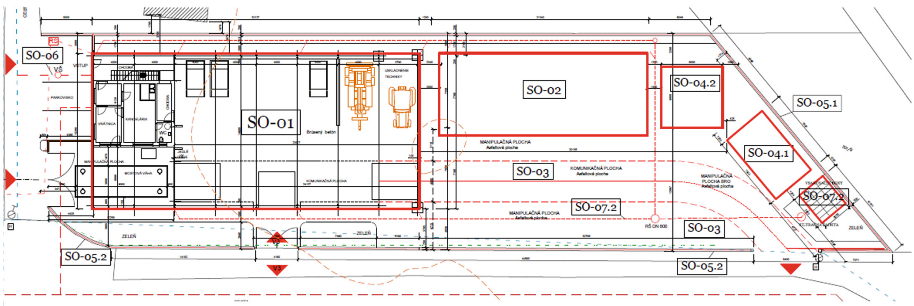

Fig. 2. Layout of construction site and construction objects, Source: authors

2.2 Methodology of Research

Research methodology was selected a case study which is defined as an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used [16]. Case study method enables a researcher to closely examine the data within a specific context. In most cases, a case study method selects a small geographical area or a very limited number of individuals as the subjects of study. Case studies, in their true essence, explore and investigate contemporary real-life phenomenon through detailed contextual analysis of a limited number of events or conditions, and their relationships.

The research initial step of RFID technology application on "Waste collection area" building site was an analysis of resources and construction processes which can be monitored by RFID technology. Then, there were selected the necessarily RFID components for monitoring of resources and processes (see Table 1).

Table 1. Resources and processes located by RFID tags and RFID components

Resources	Processes	RFID components
Material	Material supply chain	Reader & Antenna
Workers	Transport and delivery control	Tags & Hard tags
Equipment	Movement of workers	RFID software

Selection of RFID component types and its location on construction site presents a key steps for assessment of RFID technology using. Three variants of RFID component types and its location has been designed and then assessed (see Table 2). There were varied:

- different antenna types (by their distance and frequency range), their number and location,
- number and location of RFID readers.

RFID gate was proposed as a reader of RFID technology. RFID software "Clear-Stream RFID" has been used for all three variants.

Table 2. Variant of application of RFID components

Variant	RFID reader (pcs)	Antenna (pcs)	RFID hard tag (pcs)	RFID software
A	2	8	16	Clear Stream RFID
B	1	11	16	
C	1	5	16	

3 Results and Discussion

Possibilities of using RFID technology in construction site of "Waste collection area" was proved by the design of three variants RFID technology application by determining the number and location of RFID components. The cost parameters of the use of RFID technology for all variants were analyzed (see Table 3).

Table 3. Cost parameters of the used RFID technology [EUR]

Components	Variant A	Variant B	Variant C
Tags & assembly	1935	2126	1540
Reusable components	8717	7610	6503
Total	10652	9733	8043

Firstly, it was necessary to identify elements that can be reused. The RFID software, RFID reader and antennas present one-off costs. These elements can be reused on multiple construction sites. The RFID tags are for single use only. New RFID tags are required for each building site. Also, assembly of RFID components is not reused. From the economic point of view, the most preferred variant is variant "C" which consists of 1 piece of RFID reader – RFID gate, 5 pieces of RFID antennas - Zebra AN440, 16 pieces of RFID hard tags "Confidex Corona^{TM}", 1 piece of RFID software "ClearStream". Cost analysis has shown that variant "C" is the most advantageous because it includes only 1 RFID readers (gate) and 5 antennas. On the other hand, in this variant, the costs of the reusable components were in the slightest share.

The case study confirmed the findings of authors [4] about the advantages and limitations of RFID technology for construction site. Tags are light and easy to attach work and protective equipment, helmets, etc.; tags are small and wearable; facilitates maintenance and evaluation. The advantages of RFID technology application from point of the view of construction project management (CPM) are divided into 5 groups: (i) time, (ii) cost, (iii) quality, (iv) safety and (v) environment [17]. The construction project management requires cost calculation of construction projects including sustainable factors [18] and real-time information about construction resources, mainly when Just-In-Time method is adopted. RFID technology can be used to improve construction quality through a number of ways. For example, it can be used by indication the depth of piles as there were construction practices that piles did not actually penetrate to the designated depth. RFID tags can be planted into the pile ends and their radio signals will indicate the depth that the piles have actually penetrated into the ground. RFID can also help anti-counterfeit materials [17]. Construction safety is a key issue in modern CPM. RFID can be implemented to improve safety performance on site. Managing machines and tools efficiently is not only to manage them as assets but also to ensure the smoothness of scheduled construction works. The real-time visibility and traceability of machinery become more important when the construction site is big. All these approaches can also be applied to the studied site.

Moreover, authors Lu et al. and Meadati et al. [7, 17] had shown the integration of RFID technology with Building Information Modelling (BIM). BIM is envisaged to bring a paradigm shift in CPM through managing building information in a systematic way and fostering a collaborative working environment. RFID, with its real-time information with visibility and traceability, can bridge the interface between a BIM and a real project.

4 Conclusion

Application of RFID technology in Slovak construction practice can increasing technology, time, cost, safety and environmental performance by developing intelligent tools. RFID technology are also based on the principles of digitization and information sharing what is in context of Industry 4.0 principles. The aim of the paper is to point out the possibilities of using RFID technology for construction and to describe the advantages of its application. The case study was chosen as a research method. The research object was a construction of "Waste collection area" in Torysa village, which consists of 7 construction objects. Three variants of RFID technology (component types and its location) application for this particular construction site has been designed and then assessed. The cost parameters of the use of RFID technology for all variants were analysed and described benefits of its use in term of time, cost, quality, safety and environment point of view.

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Nature of Seismic Hazard of Mainlines' Functioning in the Conditions of Sredneamurskaya Lowland North Offset

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Abstract. The aim of the study is to compose equation of the microseismic field within the territory of the Sredneamurskaya plain development for average ground conditions. For this, an analysis of previously performed work was carried out, and tasks were set. The territory is located within the Sikhote-Alin fold system. The disjunctive tectonics of the region are determined by deep-seated faults of the northeastern strike, some of which are part of the largest Tan-Lu system, stretching from China. Faults of this system are characterized by a left-shear amplitude component. Deep faults that locate in close proximity are manifested only in geophysical fields in the form of the gravity field gradient zones and are not expressed morphologically. Active faults within the territory under consideration include the Kursk deep fault, with an area associated with 2.6–6.5 magnitudes earthquakes. The study of morphological forms showed that most faults have no signs of activity at the present stage. Despite the presence of a number of positive and negative neotectonic structures (uplifts and depressions), as well as deep faults revealed by geological and geophysical data there are no reasons to isolate individual seismogenic zones within the Sredneamurskaya Depression.

Keywords: Tectonics · Faults · Tectonic disturbances · Seismicity · Uplifts · Basins · Seismogenic zones · Seismic hazard · Macroseismic field

1 Introduction

Design, construction and operation of linear structures within Sredneamurskaya (Middle Amur) lowland are possible in the Amur valley within the boundaries of plots shown in Fig. 1. Area actively develops. Prospecting as well as design and construction of linear objects, industrial and civil buildings, are performed. The seismic hazard of structures is justifiably considered as the main factor in geodynamically active regions experiencing intense movements of the earth's crust.

The study of this issue for the region began actively from the 80s of the last century. The results are reflected in scientific works [1–3].

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The aim of the research was to evaluate the disjunctive tectonics of the Sredneamurskaya lowland, which is determined by deep faults of predominantly northeastern strike. Active faults within the considered territory include the Kursk deep fault. All active faults in geophysical fields manifest as the form of gravitational field gradient zones, despite these structures have no morphologically expression. An important issue is the allocation of individual seismogenic zones within the Sredneamurskaya Depression. Studies have shown that taking into account specific geodynamic conditions the assessment of seismic hazard in the regions an important aspect.

Following the above, the main target is to derive macroseismic field equation and the dependence of peak soil accelerations.

2 Research Methods and Results

2.1 Tectonic Zoning

In accordance with the actual scheme of tectonic zoning [4] the Sredneamurskaya lowland is located within the Sikhote-Alin folded system.

The northwestern part of the region belongs to the Badzhalo-Gorinsk structural-formation zone (Boktor subzone), the rest - to the West Sikhotealin (Priamursk, Vandansk, Priussuriysk subzones).

Structural and formation zones are delimited by the Harpy deep fault.

The masonry structures mentioned above are the basis of the Cenozoic depressions—the Sredneamurskaya and Verkhnekurskaya (Upper Kursk). The depressions are part of the East Asian rift system [4].

The Sredneamurskaya depression was formed as a result of complex motions of different orientations (spreads, faults, uplifts, and, apparently, dislocations) along numerous subvertical faults that are combined into a system of grabens and horsts.

The Verkhnekurskaya depression substantially coincides with the Verkhnekursk-graben, which is a morphological expression of the part of the Kursk deep fault-spread zone [4].

2.2 Disjunctive Tectonics

The basic style of the disjunctive tectonics of the region is determined by deep faults of the northeastern strike. Some of them, in particular, the Kukan deep fault, are included in the largest Tan-Lu system, stretching from the territory of China. Faults of this system are characterized by a left-shear amplitude component.

Most of the north-eastern strike faults belong to the East Asian rift zone. Such are the Kursk and Harpy deep faults and the numerous disjunctives that make up and accompany the systems of these deep faults.

All these faults, irrespective of the time of occurrence (the Kursk deep fault, for example, continuously develops from at least the Triassic), are characterized, first of all, by the sliding component, the magnitude which reaches tens of kilometers, which accounts for the development of the Cenozoic grabens, the formation of which was completed in the early Pliocene.

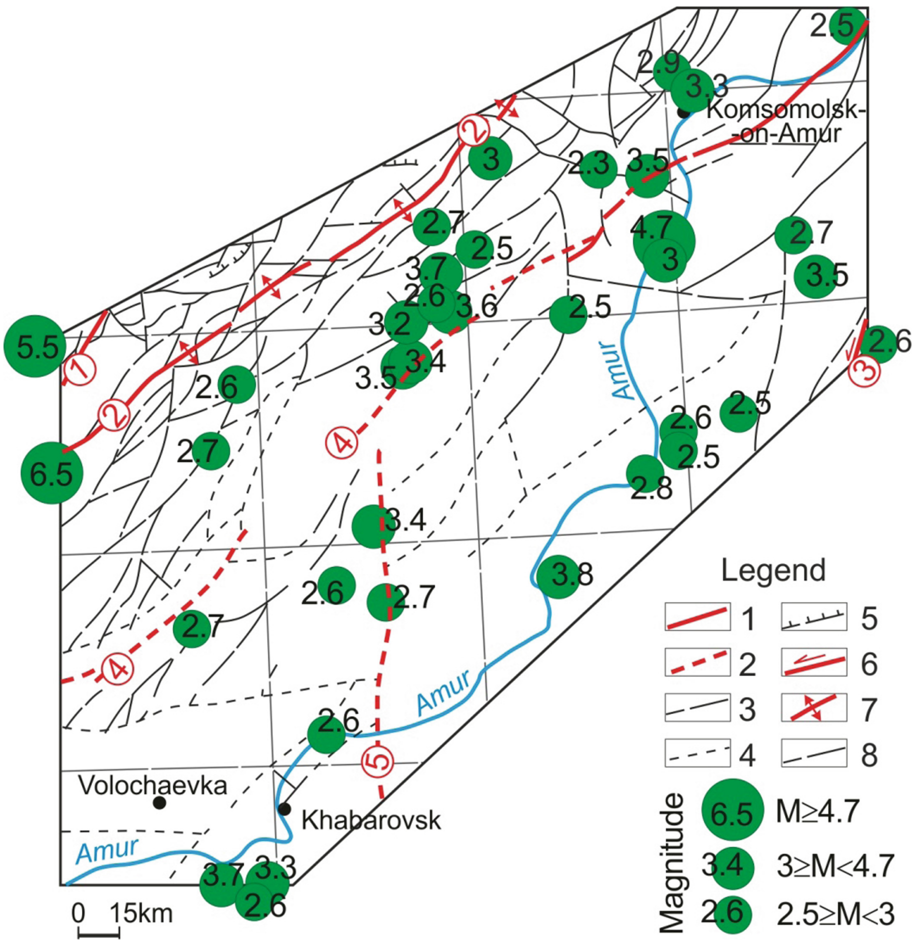

Fig. 1. Tectonic structure and earthquake epicenters of the research area: 1 – Deep faults defined by geologic data (1 – Kukansky, 2 – Kursky, 3 – Sikhote-Alinsky); 2 – the same defined primarily by geophysical data (4 – Kharpiysky, 5 – Dabadinsky); 4 – other types of faults defined by geologic data; 5 – thrust faults; 6 – left shifts; 7 – strike-slip faults; 8 – steep faults with uncertain kinematics, primarily normal and reverse faults

Many faults of this system also have a small shear amplitude component. Thrusts are rare, they are all ancient (Triassic and Jurassic) and are associated with the formation of Mesozoic olistostrome complexes. Submeridional and northeastern faults close to them in orientation are rare.

Among them, the Central Sikhotealin deep fault with a left-shear amplitude estimated to be up to 1000 km is well studied.

The Dabandinsk deep fault is marked out by geophysical data and the results of the interpretation of distance research materials. Its kinematics is unknown.

2.3 Active Tectonic Faults

Active faults within the territory under consideration include the Kursk deep fault, with an area of which 2.6–6.5 magnitudes earthquakes are associated.

The activated part of the Kursk fault covers the width of the Kukan and Verkhnekursk depressions and Forberg type near-fault linear narrow uplifts bounding them from the southeast.

The activated part of the Kursk Fault is a reverse fault with a bearing azimuth of 110–120° and an angle of 75–80°.

Judging by the operating discontinuities and their orientation, the discontinuous violation has a left-side displacement component. This is confirmed by the kinematics of the movement of the wings of the Kukan paleoseismogenic structure, to which the Kursk fault zone belongs, and by the analysis of fracturing according to Danilovich A.N. [2].

Neotectonic activation in the Kursk Fault zone was reflected quite intensively, manifesting itself in the formation of distinct morphologically pronounced ledges, gently sloping ditches and through valleys on the watershed promontories of the left tributaries of the river Kukan and in the basin of the left and right tributaries of the river Kur.

In some areas, the fault zone is opened in the landslides' walls and valleys of temporary streams. Here, the host rocks are highly fragmented, up to kakirites, which give a small-fragmented gravel during destruction. Visible vertical movement along the system of subparallel fractures is at least 300–400 m. The magnitude of the horizontal displacement is supposedly not less than vertical.

An assessment of the potential seismicity of the Kursk fault included in the Kukan structure is not in doubt and is determined by the magnitude of M = 6.5 [5].

Based on the length of the fault renewal zones, there is a close correlation between the length of the gap formed during the earthquake and the magnitude of the earthquake expressed by the equation [6]:

$$\mathrm{lgL} = (1.01 \pm 0.02)\mathrm{M} - 6.18, \qquad (1)$$

where

L - the length of the seismogenic fracture,
M - magnitude of an earthquake.

If based on the relationship between the sizes of paleoseismic dislocations and the magnitude, then the length of the fault renewal zones at the crustal center with M = 6.5 should be 2–3 km. [7, 8]

The Kukan paleoseismic dislocation, to which the Kursk fault belongs, was expressed in seismogenic digging of the fault at a distance of about 7 km with formation of dips on watershed slopes.

Based on the equation of Solonenko [3], the magnitude of this earthquake could be M = 6.8–6.9.

Thus, for the considered activated part of the Kursk lineament, it is advisable to accept and further use the value of $M_{max} = 6.5 \pm 0.3$.

2.4 Studies of Geomorphological Forms

To clarify the tectonic structure of the development territory and to study geomorphological forms of the region the authors carried out a route survey along and across lineaments.

The main goal was to clarify neotectonic plan and to confirm or disprove the presence of tectonic faults active at the present stage.

Plots of the territory were divided according to the conditions of their entry into large neotectonic elements of the study territory [1].

The northern part, in the region of Komsomolsk-on-Amur, is partially located within the Miaochansky uplift, where the amplitudes of the newest movements reach 1000 m.

The track runs on the periphery of the indicated uplift and in this part is either in the conditions of valley grabens or passes along a hilly-steep surface, as shown in Figs. 2 and 3.

Fig. 2. Plot of valley graben within the Miaochansky uplift

Fig. 3. A section of hilly-rugged terrain within the Miaochansky uplift

The sides of the valley grabens have a gentle slope, and hilly-rugged surfaces represent low-amplitude plicative deformations without fault ledges, ditches, and gravitational displacements of rock masses indicating neotectonic activity.

Further, for a distance about 200 km (appr. from railway station Elban to railway station Litovko) is a traceable superimposed depressions system of Sredneamurskaya lowland - Ust-Harpinsk and Lithovsk graben type depressions, sometimes located on the periphery of the small horst uplifts.

Near the village Elbanit is observed Harpiysk fault, determined mainly by geological- geophysical data. Neotectonic structural forms indicating its emergence to the surface were not detected during the survey (Fig. 4).

Route observations made in the valleys of rivers and streams, did not find any signs of current activity of the fault modern relief.

Fig. 4. Section of the Sredneamurskaya Depression in the Harpiysk Fault Area

Similar situation is marked on the portion of Dabandinsk depth fracture as well as along the Harpiysk fault line zone, determined by geophysical data (Fig. 5).

Fig. 5. Section of the Sredneamurskaya Depression in the Dabandinsk Fault Area

In the process of observation, the Ukur river valley, the eastern slopes of the Gorbylak ridge, the upper stream of Selgon river were examined.

The massif is strongly dissected by erosion. Grabbed protrusions and other relief forms indicating non-tectonic activity were not found (Fig. 6).

No signs of fault activity at the present stage were found. The ubiquitous distribution of Neogene-Quaternary sediments, signs of mountain topography degradation (eroded watersheds, gentle slopes), small longitudinal river slopes, numerous meanders, and the absence of floodplain terraces indicate the neotectonic passivity of the site.

Another major structural element, within the influence of which the active development of the territory is carried out, is the Vandan uplift, which is a residual hills massif.

Fig. 6. A section of the route in the area of the Vandan uplift

2.5 Selection and Justification of the Attenuation Equation for Seismic Hazard Assessment

The choice of the model of attenuation of soil movements presents the greatest difficulty in conducting probabilistic calculations of seismic hazard. Due to the lack of instrumental records of soil motions for shocks with intensity $I_{MSK} > 5$, it is very difficult to construct an empirical regional attenuation equation for accelerations.

Justification of the maximum possible magnitudes is given in the previous section. M_{max} for the only dangerous lineament structure - the Kursk fault is 6.5 ± 0.2, for the Kursk-Kukan and Sredneamurskaya area zones - 5.0 ± 0.2 and 4.5 ± 0.2, respectively.

Therefore, the calculation of seismic hazard can only be carried out either using the equations of attenuation of soil movements obtained for other regions of the globe, or to calculate for the macroseismic intensity of shocks using the regional attenuation equation for a territory comparable in size to the Asian continent [5, 9, 10].

Thus, the equation of attenuation of peak accelerations for the Asian continent, widely used in China, has the following form [11]:

$$\ln A = 0.1497 + 1.9088M - 2.049M^2 - 2.049\ln\left[R + 0.1818\exp(0.7072M_S)\right], \quad (2)$$

where:

A - the peak acceleration of the soil, cm/s^2;
M_S - magnitude of an earthquake by surface waves;
R - the shortest distance from the observation point to the gap in the outbreak, km.

The equation corresponds to "hard rock" type soils. At present, strong motion damping models developed by Abrahamson & Silva and published in a special issue of the journal "Seismological research Letters" [12] in 1997 are widely used in world practice.

$$\ln Sa(g) = f_1(M, r_{rup}) + Ff_3(M) + HWf_4(M, r_{rup}) + Sf_5(PGA_{rock}), \quad (3)$$

where:

Sa - the spectral acceleration, g;
M - the moment magnitude M_w;
r_{rup} - the closest distance to the discontinuity plane;
F - type of fault;
HW - a dummy variable for hanging wall sections;
S - a dummy variable depending on the type of soil;
$f_1(M, r_{rup})$ is the basic attenuation equation for fault-shear events recorded on rocky soils;
$f_5(PGA_{rock})$ - function of soil conditions (Fig. 7).

$$f_1(M, r_{rup}) = a_1 + a_2(M - c_1) + a_{12}(8.5 - M)^n + [a_3 + a_{13}(M - c_1)]\ln R \quad (4)$$

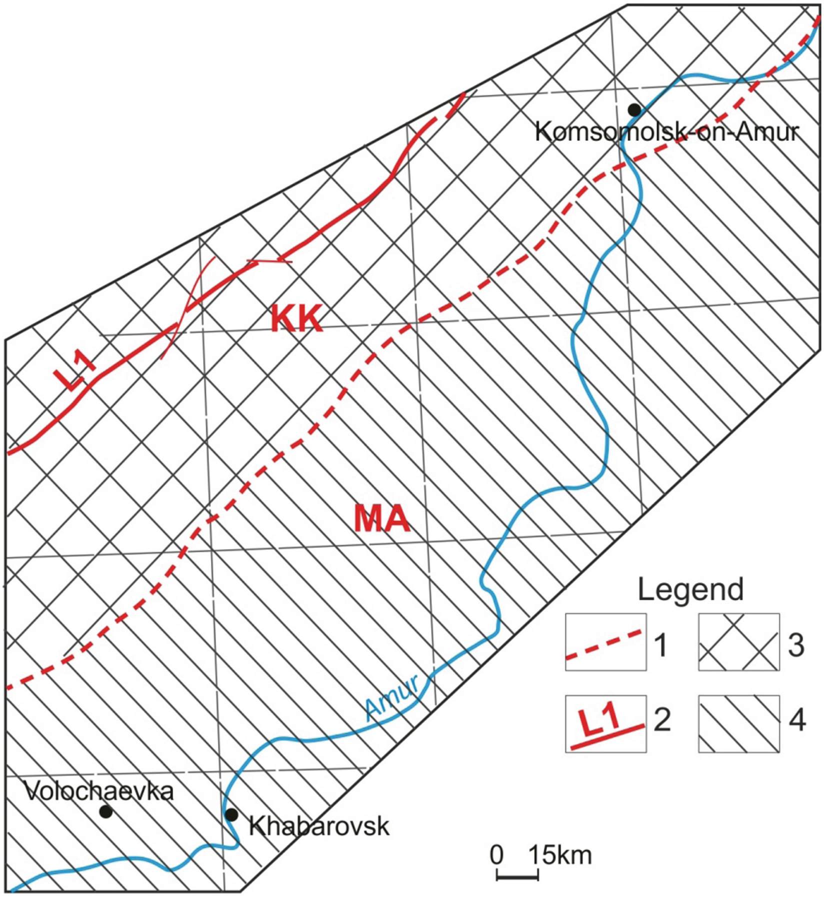

Fig. 7. Seismotectonic model of the research area: 1 – Borders of specific seismic regions; 2 – Kursky lineament (M_{max} = 5.0 ± 0.2); 3 – Kursk-Kukan zone KK (M_{max} = 5.0 ± 0.2); 4 – Middle Amur zone MA (M_{max} = 4.5 ± 0.2)

where: $R = \sqrt{r_{rup}^2 + c_4^2}$; a_1, a_2, a_{12}, a_3, a_{13}, c_1, c_4 - coefficients depending on the period of oscillations;

$$f_3(M) = \begin{cases} a_5 & \text{at } M \leq 5.8 \\ a_5 + \frac{(a_6 + a_5)}{c_1 - 5.8} & \text{at } 5.8 < M < c_1 \\ a_6 & \text{at } M \geq c_1 \end{cases} \quad (5)$$

where: a_5, a_6 are coefficients depending on the period of oscillation;

$$f_4(M, r_{rup}) = f_{HW}(M) f_{HW}(r_{rup}) \quad (6)$$

where: $f_{HW}(M)$, $f_{HW}(r_{rup})$ are the distribution functions of the "hanging wall" effect depending on the distance to the gap plane;

$$f_5(PGA_{rock}) = a_{10} + a_{11} \ln(PGA_{rock} + c_5) \quad (7)$$

where:

a_{10}, a_{11}, c_5 - coefficients depending on the period of oscillation;
PGA_{rock} - expected peak rock acceleration, g.

To apply this model to the conditions under study, there are a number of limitations, the most significant of which are as follows:

Type of used magnitude. In the model appears moment magnitude M_w, while used to calculate the frequency of occurrence local directories contain magnitude M_L. For the study area, there is no necessary data for the conversion of M_L to M_w, and the use of dependencies obtained in other regions of the globe only adds uncertainty.

The predicted parameter of the attenuation equation is spectral acceleration. In this case, the basic equation of the model predicts peak PGA accelerations for rocky soils with the possibility of transition to loose soils, and estimates of soil conditions are largely integrated (coefficient S in formula (2) assumes a value of 0 for rocky soils, and a value of 1 for loose ones). In this case, it seems difficult to switch to soils corresponding to category II of Russian Seismic Code SP 14.13330.2018.

It is known that seismic risk estimates are very sensitive to the attenuation equation in the region of large magnitudes and short distances. For example, in the Abrahamson & Silva model above, the "hanging wall" effect is only taken into account for distances from the fault plane up to and including 25 km.

If the attenuation equation is a product of two functions, a function of R and a function of M, then it can be considered acceptable when the size of the source emitting energy is much more smaller compared to R and unsuitable when the size of the focus is of the same order as the hypocentric distances or exceed them. Such equations have long been known in the practice of engineering-seismological studies and in general terms are as follows

$$A = \frac{x\exp(aM)}{R^b}, \quad (8)$$

An example is the expression obtained by Davenport [13].

$$A = \frac{0.279\exp(0.80M)}{R^{1.64}} \quad (9)$$

As well as Esteva and Villaverde [14].

$$A = \frac{5.7\exp(0.8M)}{(R+40)^2}, \quad (10)$$

3 Results

The macroseismic field equation converted using the relationship between MSK -64 scores and peak ground accelerations will take the form that does not differ in form from the above dependences, but has the advantage that it is valid for medium ground conditions, i.e. Category II SP 14.13330.2018.

$$A = \frac{0.0078\exp(0.98M)}{R^{0.947}} \quad (11)$$

We also note that according to Shebalin N.V. [6] for earthquakes with a magnitude of $M_L \geq 6.0$, it is necessary to take into account the ellipsoidal configuration of the isoseist extended along the strike of the seismic generating fault.

4 Discussions

Given that in the Kursk lineament zone, the expected size of the foci, even with the strongest calculated events ($M_L = 6.8$), will not exceed 7 km (and on average they can be 2–3 km), then Eq. (11) can be applied taking into account the ellipsoidal possible isoseist configurations along the Kursk Fault.

To select the optimal equation for the attenuation of strong ground motion, we performed peak acceleration calculations using the 4 given models [11, 12, 15, 16]. Calculations lead to ambiguous results, this is due to the difference in magnitudes used, as well as the fact that the above equations correspond to different soil conditions. Formula (2) corresponds to soils of the “hard rock” type, Eqs. (3) and (5) correspond to soils of the “rock” type (which approximately corresponds to soils of category I according to SP 14.13330.2018).

Expression (11) corresponds to “average” soil conditions (category II according to SP 14.13330.2018) and operates with magnitudes of the type $M_{LH,}$ traditionally used by domestic seismologists and included in the catalogs of earthquakes of the past years that we used in this work.

5 Conclusions

1. There is no reason to isolate individual seismogenic zones within the Sredneamurskaya Depression, despite the presence of a number of positive and negative neotectonic structures (uplifts and depressions), as well as deep faults established by geological and geophysical data. Despite the fact that the Harpyisk and Dabandinsk deep faults located in the immediate vicinity are manifested in geophysical fields in the form of the gravity field gradient zones, these structures are not morphologically expressed. In addition, the seismicity that could be associated with them in the case of their modern activity does not differ from the background seismicity characteristic of the Amur-Sungaria domain zone. The same applies to the remaining formations along the route. The main contribution to the seismic hazard of the territory is made by the Kursk fault closest to them, which is active at the present stage, and the background seismicity diffusely distributed within the Amur-Sungaria domain zone.
2. The following conditions influenced the final selection of the attenuation equation:

   – insufficient knowledge of the mechanisms of earthquake sources of the main seismogenic structures (such as the Kursk fault) does not allow to identify the type of movement for using Eq. (3). Incorrect choice of the parameters of the mechanisms of the sources or active faults can lead to an error in the results obtained of more than 100%
   – correspondence of magnitudes in the used seismic statistics and the attenuation equation.
   – correspondence of the equation to the predicted soil conditions.

Equation (11) uniquely corresponds to the 2nd and 3rd conditions. The greatest uncertainty will be introduced by condition 1, which, nevertheless, can be partially compensated by taking into account the direction of seismogenic structures, assuming different attenuation coefficients of seismic waves along and across the structures.

Based on the foregoing, the expression (9) was adopted as the attenuation equation, which, with the current state of knowledge of the seismic process on the territory of the Sredneamurskaya Lowland, is the most optimal.

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Soil Research for Strengthening Railroad Bed Design in Cold Regions of Far East

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Abstract. The paper covers the results of phenomena and process researches that influence deformations in soil bases in the annual cycle. The target research focuses on deformations in an embankment under operation in severe natural climatic, engineering and geological conditions. The causes of a road exploitation in permafrost areas with cryogenic deformations are presented. It is necessary to reduce the length of sections under the slow order that has been introduced due to unpredictable deformations in the embankment, while the sections are located in complex natural, climatic, geological and engineering conditions. In addition, it is necessary to provide a planned strengthening of the embankment, thus preventing appearance of deformations, and carry out a reconstruction of the embankment on the sections expecting an increasing volume of coal. A cause-effect analysis of processes and phenomena in soils fosters justification of designs and their better selection for improving mechanical strength characteristics that accord with natural restoring processes in soils (drainage and strengthening). A rational justification of the roadbed strengthening and a testing introduction are mandatory requirements for the roadbed design that provides the technical system bearing capacity with developed and patented technical solutions.

Keywords: Permafrost · Anti-deformation measures · Water encroachment into areas · Cryogenic deformations · Complex technological design solutions

1 Introduction

The roadbed strengthening is always in the focus of attention in cold regions when projecting engineering structures. It is especially important for the Russian Federation as its 65% of territory lies on permafrost, primarily located in Siberia and the Russian Far East, with about 80% in the Far Eastern region and the rest part being a subject of cryogenic deformations.

The Eastern polygon of the Baikal-Amur Mainline (BAM) consists mostly of high-temperature permafrost. In this condition, one of the main reasons for great amount of the roadbed deformations is the water-thermal disbalance as a result of warming natural

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factors and technogenic influence on weak soils of the roadbed subgrade (especially in low embankments and plane levels): climatic, static and vibro-dynamic loads, filtering impact, etc.

Global warming conditions bring quality changes to permafrost regions that results in their transformation into areas of deep seasonal freezing characterized by different cryogenic (frost) deformations at temperatures of zero/minus one degrees Celsius. An annual alternating impact of deep (up to 4–5 m) seasonal freeze-thaw processes on over-saturated soils provokes such cryogenic deformations as permafrost mounds, icing, suffosion processes, etc. [1–8].

However, the geomorphological and hydro-geological conditions of the area play an important role. The surface relief that stops the drainage and causes a water stagnation results in a poor diversion of water from the roadbed due to river bed silting and a malfunction of drainage structures, thus causing overmoisturization and thawing of frozen soils. Besides, the embankment itself becomes a barrier weakening overwatered soils, thus preventing a complete ground water run-off from the high side of the relief.

2 Mechanism of Appearance and Development of Processes and Phenomena in Soils of Embankment Base in Severe Climatic Conditions (on Example of BAM)

A technogenic impact on natural soils, such as embankment filling, fires, floods, etc., leads to different from usual temperature and humidity conditions. It breaks the thermodynamical equilibrium of the natural and man-made system resulting in the roadbed deformations [2, 4, 6].

2.1 Causes of Thermo-Dynamical Equilibrium Deviation in Natural and Man-Made System and Its Following Restoration in the Course of Its Natural Stabilization

With the depth of seasonal thawing in natural conditions of 0.8–1.5 m and the embankment height of 2–2.5 m, the upper line of permafrost sets at about 10–15 m from the embankment top. This layer is an active zone. Annually, during the initial period of 10–15 years after construction, an uneven settlement of embankments constitutes the values from some centimeters to the first tens centimeters depending on the soil subsidence category. According to multi-year researches, there are stages in the natural and man-made system transition from one condition to another. They are three all in all.

The thermo-dynamical equilibrium does not set up until the natural and man-made system eventually goes through these stages. It is the normalization of temperature and humidity regime in the system coming harmonically into coherence with the natural temperature and humidity conditions that provides the equilibrium. When a transitional layer between a naturally thawing subgrade and the roadbed has formed (it takes 15–20 years in the conditions of the Eastern polygon of the BAM) at the depth of 5.5–6.0 m from the top of the roadbed, a new quality appears: the roadbed begins working as having a weak subgrade in the condition of deep seasonal freezing. It is important to notice that freezing processes at this period are of a changed character and have different ways of their manifestations (Fig. 1).

The freeze-thaw process in soils is accompanied by a formation of three zones: thawed, thawing and frozen. These zones are characterized by such reverse processes as a thermal settlement and heaving, shrinkage and swelling, absorption and pressing out of pore water, heaving due to segregated icing and settlement due to plastic deformations. All the mentioned processes in the subgrade soils take place at definite temperature and humidity conditions, and their impact on the technical system as far as formation of its total settlement is the following.

Positive deformations take place in a summer period and are connected with soil swelling and segregated icing in a frozen area. Heaving due to the soil swelling can be observed until the end of July, while the maximum heaving (up to 20 mm) in the embankment due to segregated icing takes place in the third decade of August, that is the time of complete thawing of the embankment (when a zero isobathytherm comes to the permafrost line). It occurs because of soil swelling as a result of liquid absorption that appear in ice-water transition phases.

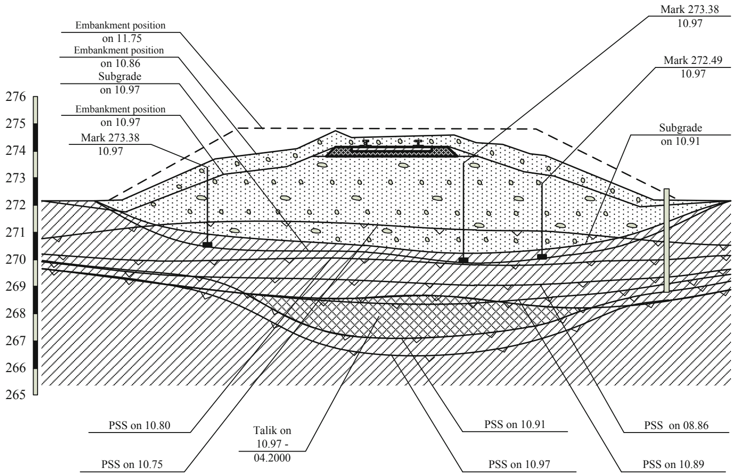

Fig. 1. Formation of unfrozen talik zone in annual cycle

The settlement that takes place due to liquid and fine particles pressing out can be observed from the second decade of November up to December. It occurs under a massive hydrostatic pressure in subgrade soils between freezing layers as a result of liquid migration to the freezing front and its increased volume. This settlement constitutes up to 20% of the total seasonal one.

Osmosis in May-June influences the dewatered after winter subgrade allowing it to absorbs the liquid and the soil particles that have been pressed out before under the above mentioned forces. According to the authors' research, these fine particles take part in forming the temperature regime of the subgrade. Entering into a reaction, clay particles form a temperature-resistant structure. This process goes under a definite temperature. Intensive deformations in the embankment continue until an unfroze in an annual cycle talik zone is formed under the line of seasonal freezing in the subgrade.

2.2 Impact of Vibro-Dynamic Factor on Technical System Conditions

The most essential and negative impact on weak soils in subgrades and slopes of the embankment is produced by the vibro-dynamic factor because of its massive, regular and rhythmical character.

It is a common knowledge that the natural ground has a three-phase porous structure consisted of soil particles, water, air and vapor. A relative content of different phases and their qualitative features as well as their interrelation character ultimately determine the main characteristics of soils. The vaporous water in the ground stays in its dynamic equilibrium with other types of water (the bound water, in particular) and vaporous water in the atmosphere. In certain conditions, for example, when the temperature goes down and the vibration impact is increasing, the vaporous water is condensed turning into the capillary water. Condensation of water vapors is quite significant.

In loosen areas of slopes and the subgrade, a mechanical destruction of bonds between particles that lead to changes in pore spacing and all-phase soil temperature (including the vapor-and-liquid one) takes place under the vibro-dynamic loading. This brings a redistribution of soil particles and a disbalance between liquid and vapor followed by a temperature and a pore pressure increase in the technical system weak subgrade soils resulting in their elastic-plastic deformations in the contact areas of weak and firm soils (Fig. 2). Liquid in a vapor state does not produce a direct influence on soil construction qualities. However, a vapor liquid displacement from areas with a higher vapor tension to the ones with a lower tension (from warmer to colder areas) and the followed condensation of liquid on particle surfaces leads to a moisture increase and a liquid concentration in some areas of a soil massive. The soil strength and stability considerably decrease in the place of contact of weak and firm soils when the moisture increases above the molecular maximum capacity. Having a considerable content of unbound water, the soils acquire clamminess, eventually becoming plastic. A continuous vibro-dynamic impact leads to worsening of the soil conditions and results in the technical system settlement and sliding of slope blocks, thus decreasing the system's bearing capacity and creating a threat to the railway traffic safety (Fig. 2).

The soils of a technical system are characterized by a relative stability with a constant temperature and the pore pressure at the thermodynamic equilibrium.

When the vibro-dynamic load influences an unstable section, the technical system goes out of the thermodynamic equilibrium and becomes a stress and strain system. At first, a displacement of soil particles and vapor takes place due to mechanical vibrations in the technical system. This is determined by the soil temperature increase in the upper layers of the system because the energy of vibrations turns into the thermal energy of soil-and-water substance. The maximum temperature deviation is shown in Fig. 2. In addition, an increase of temperature of the vapor-liquid phase in the upper layers of the system increases the vapor tension that makes vapor move into deeper cold layers of the system soils. There, the vapor thermal condensation takes a form of hygroscopic water with a high liquefying power.

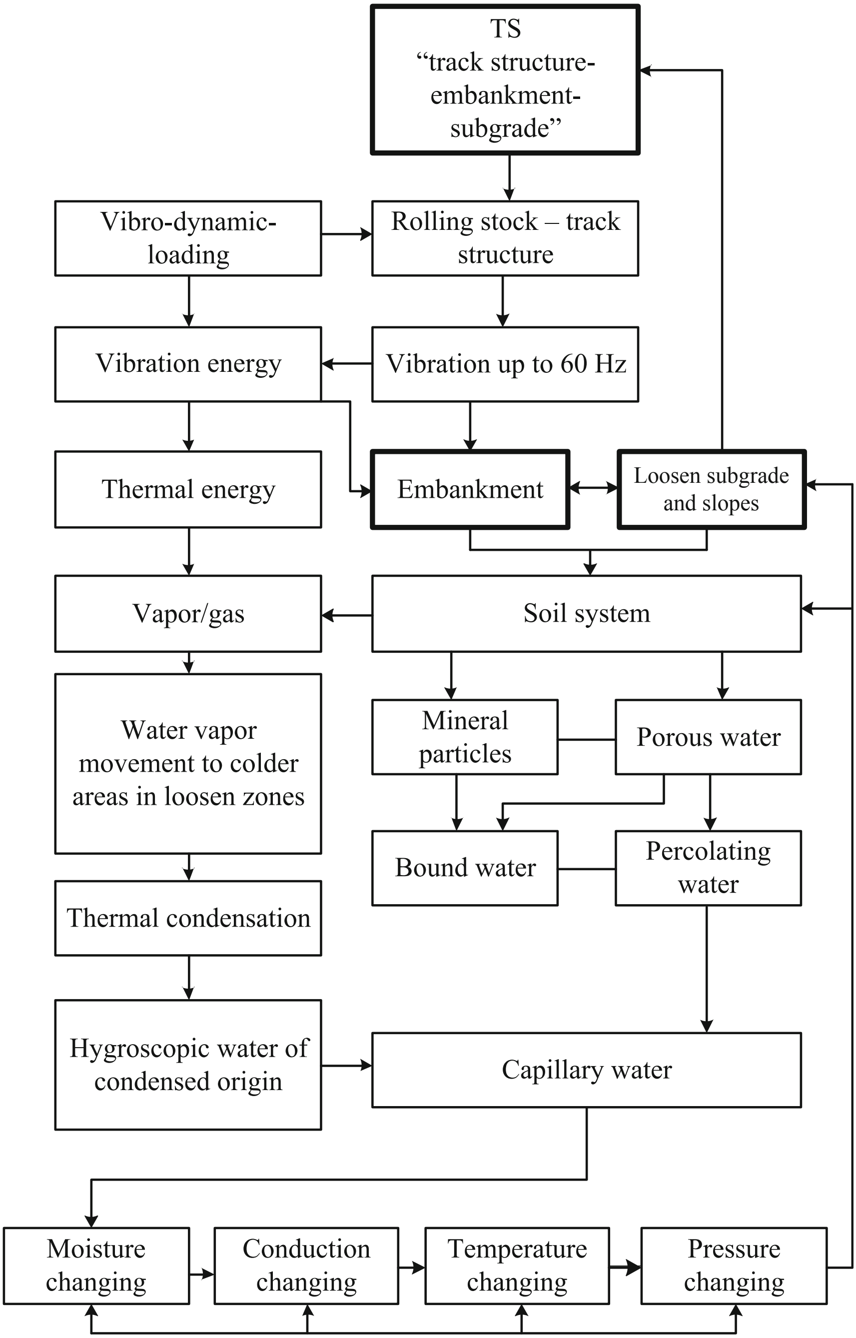

Fig. 2. Scheme of impact produced by vibrational oscillations on soil condition in technical system "track structure-embankment-subgrade"

Due to an increasing amount of water in the technical system subgrade and because of its high liquefying power, an increasing pressure in soil pores takes place that changes the parameter characteristics of the soil-and-water substance. Solid particles break down, thus the soil is changed in its consistency and its features become weaker. In the contact areas of weak and firm soils in the subgrade, some shearing forces appear under loading impact in the technical system. The soil particles experience strains resisting a shift. A weak elastic-plastic soil starts yielding in the contact zone in the horizontal direction to less compacted foot (field) zones.

The plastic yield of weak soils in the technical system subgrade reveals itself in foot zones and is connected with changing parameters of the air-vapor phase. Soil yielding goes from a less warm subgrade zone to the more warm foot zones. It is accompanied by a temperature decrease during the vapor-liquid phase in soils that can be seen from the temperature graph in Fig. 3.

After that, the technical system works for a restoration of its usual thermodynamic equilibrium equalizing its temperature and moisture regime. It takes place due to the osmotic suction regardless of the vibro-dynamic operating loading impact. A reverse process appears that works for bringing a squeezed part of soil back to the technical system subgrade, while the temperature and pressure start to rise due to the osmotic power.

In unstable soils, only a part of the vapor-liquid phase soils can restore. Another part and solid soil particles that cannot move back stay in the foot zone. It happens because solid particles have changed their initial position, i.e. shifted, and their places are taken by the other ones, from upper layers, thus the system has settled. The temperature changes and the pore pressure values in unstable systems are considerably higher under the vibro-dynamic load than those before a train pass-through. This fact is proved by theoretical calculations. These tasks are solved according to a quantitative assessment of strength, bearing capacity and stability of elements of the “track-subgrade” system. There are some common features of possible deformations in soils that are connected with the character of seasonal freezing and the subpermafrost water regime. The seepage deformations of soil, such as suffusion and uplift, that can change the structure up to its complete destruction appear under the hydrodynamic pressure of artesian aquifer flow and are defined by the amount of soil fraction and the ratio of soil diameters as well as the virtual slope value.

3 Ground Waters. Causes of Cryogenic Deformations

The embankment itself being a barrier on the way of ground and surface water run-off determines the deformation features of the embankment and its subgrade.

Any obstacles on the way of groundwater run-off and malfunctions of surface drainage advance a development of dangerous icing processes, heave-and-settlement deformations, ice billows (hydrolaccoliths) in the roadway, aufeis (mechanical) suffusion (washing out) of the subgrade soil, and other cryogenic deformations [6–8].

Some of the general features of possible soil deformations connected with the seasonal freeze-thaw are given in Fig. 3a and b.

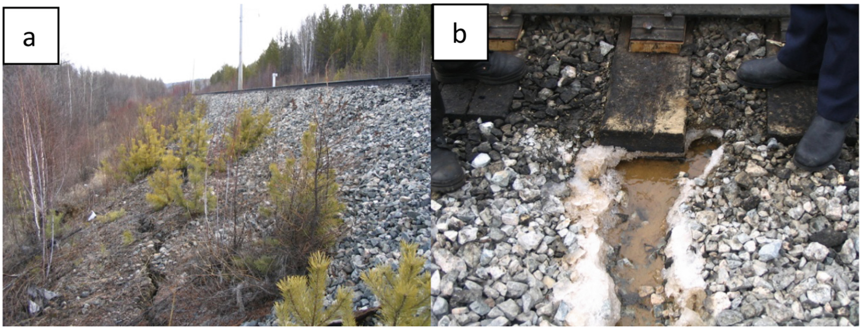

Fig. 3. Hydrolaccolith formation in roadway: a – crack of 0.5 m in slope; b – water seepage from icing mound at daytime (March)

Figure 4 shows a cryogenic process due to a water pressure injection in the rail seat replacing a heave mound as a result of aufeis mechanical suffosion.

Fig. 4. Injected ice in collapse sinkhole of rail seat (in May)

Suffusion and uplift that can change the structure up to its complete destruction appear under the hydrodynamic pressure of artesian aquifer flow and are defined by the amount of soil fraction and the ratio of soil diameters as well as the virtual slope value. If the value of artesian aquifer flow above the top of seasonal permafrost is within 2 m (often naturally presented), the aufeis uplift influences the layer of seasonal permafrost of up to 0.5 m.

The especially dangerous case is a gushing spring disclosure when cutting. Free pressure of the spring above the cutting site at the beginning of winter can be quite considerable. In this case, aufeis and frost mounds of a massive size are developed on the cutting site. Thus, if some special technical solutions that provide elimination of the hydrostatic head of underground water in the embankment area are not designed in the

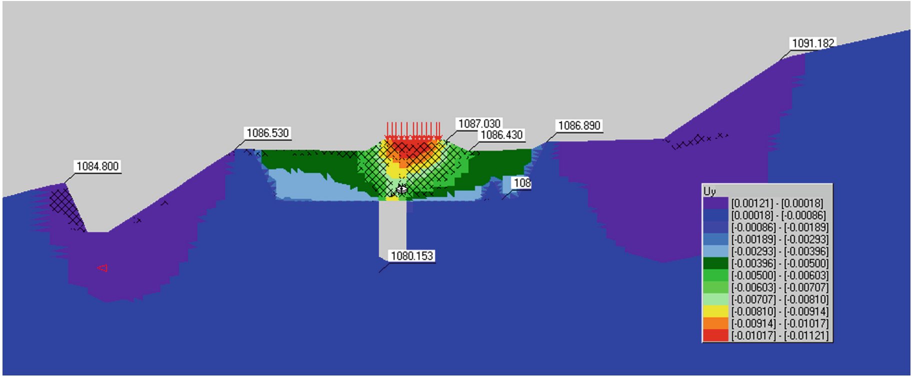

Fig. 5. Results of traffic load modelling on reinforced embankment subgrade (levels of vertical component of displacement vector, u_y)

Fig. 6. Installation of deep warmed drainage in conditions of underground water strikes and thermal karstification

project, the appearance of frost deformations is possible, and they are comparatively more dangerous than multi-year settlements that occur due to the permafrost degradation on thawing soils of third and fourth category of thermal stabilization [10, 14].

The following scheme is applied to solve the problem:

– calculation and assessment of stress and strain conditions of the current system elements to find out the impact of cryogenic processes on the elements as far as their strength, bearing capacity and stability;

– calculation and assessment of stress and strain conditions of the elements according to common design solutions to provide a target strength, bearing capacity and stability.

Originally, solutions of model problems are carried out within the designed schemes for a representative cross-section. In the solution process, the main factors playing role in the interaction of the system elements and its subgrade are analyzed. Next, when having the analysis of the model design results, the other cross-sections on the given sections of the railroad go through the model design solution (Fig. 5).

It is necessary to determine the impact of different factors on the technical system "track structure-embankment-subgrade" to forecast its state and justify designed solutions for eliminating the deformations (Figs. 6 and 7).

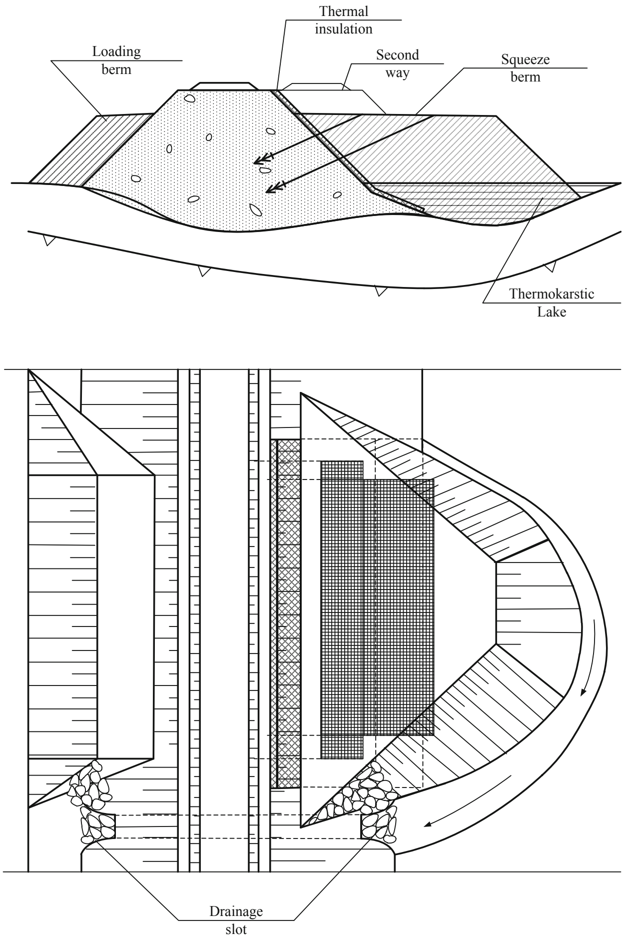

Fig. 7. Embankment reinforcement on sections with thermal karstic lake

4 Conclusions

1. The most important problem in track facilities maintenance is to provide the embankment stability. Despite a great amount of research done and published results as well as standards adopted some issues connected with impacts of certain destabilization factors have not been solved.
2. The authors have studied continuous deformations and their causes in permafrost in the southern areas on the sections with small longitudinal slope and difficult engineering and geological conditions. In the course of research, the construction and exploitation problems are found out to appear in the geotechnical system "embankment-subgrade" that are characterized by deep seasonal freezing conditions.
3. As the researches show, the deformations in a long-operated railroad embankment constructed on high-temperature permafrost soils, including the Vostochny polygon of the Baikal-Amur Mainline, are connected with disturbance of natural geomorphological and hydrological conditions that influences the temperature and moisture regime and causes changes in soil processes in the natural-technogenic field "soil structure-permafrost subgrade".
4. The researches show that the embankment itself is a barrier on the way of ground and surface run-offs. This determines the deformation features in the embankment and its subgrade as well as aufeis, heave-settling deformations, ice mounds and suffusion of weak soils from the subgrade.
5. To avoid potential mistakes and exploitational losses it is necessary to increase a scientific research level of technological design solutions made for permafrost conditions. In this connections, the offered samples for searching and choosing rational, technological and effective technical solutions on strengthening the embankment in the permafrost and cryogenic conditions are actual for eliminating the causes of the problems.

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New Designs of Drainage and Discharge Facilities for Dewatering Endorheic Sections in Cold Regions

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Abstract. The target research are actual problems of the embankment maintenance on weak soils including thawing permafrost. The objectives of the research given in the paper is first, to determine the causes of deformations in the embankment on endorheic sections, and second, to offer patented innovative technical solutions for stabilizing the embankment when strengthening both current railroad lines and constructing the new ones on weak and thawing permafrost soils. This supplies an introduction of advanced traffic technologies. They provide increased axle and per unit length loads as well as using trains of increased weight in areas with weak and permafrost soils. Some methods are given as the research results on diagnostics and forecasts of deformations in the embankment on endorheic subgrades.

Keywords: Thawing permafrost · Weak soils · Endorheic subgrades · Innovative technical solutions

1 Introduction

High modern requirements for the technical conditions of the track structure and the embankment stability in the track facility that are aimed to provide safe and continuous traffic demand considerable material and labor costs.

The target research is the embankment on weak soils including thawing permafrost. The research objective is to find out the causes of the embankment stability malfunction and to provide increased axle and per unit length loads as well as using trains of increased weight in areas with weak and permafrost soils using innovative methods.

To achieve this goal it is necessary to reduce the length of sections under the slow order that has been introduced due to unpredictable deformations in the embankment, while the sections are located in complex natural, climatic, geological and engineering conditions. In addition, it is necessary to provide a planned strengthening of the embankment, thus preventing appearance of deformations, and carry out a reconstruction of the embankment on the sections expecting an increasing volume of coal and ore.

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To implement the above mentioned measures a number of problems should be solved:

– a systematic analysis of construction and exploitational issues for the geotechnical system "embankment-subgrade" in southern areas of permafrost;
– collection and analysis of experimental data received from the results of multi-year natural observations made by researches of the Far East State Transport University in experimental sites on the Far Eastern and the Yakutian Rail Roads;
– an annual and multi-year survey of changes in the thermal and moisture regime and its influence on processes of settlement in weak soil subgrades as well as the factors that provoke the changes [1, 2].

The research results are used to develop an ultimate method for the settlement forecast in weak soils and permafrost subgrades and recommendations to provide stability of the embankment in these conditions.

2 Main Research Objectives

More than a quarter of the embankment on The Far Eastern Rail Road is exploited in severe physical and geographical conditions. According to the researches, an impact of vibro-dynamic processes on the embankment condition and its deformability increases with the increase of the length of trains, their weight and the axle loading. This also leads to the growing maintenance cost and requires its forecast assessment for making adequate decisions. Thus, these complex measures can be taken on the basis of diagnostics and monitoring of the embankment.

The issues of a systematic approach to exploitational problems of the geotechnical system "embankment-subgrade" have been highlighted but still have not been solved. There are a lot of variants answering "what?", "where?" and "why?", while there are only few of "how?" and "what with?". Moreover, "why?" is not always correct; "how?" is multi-variant and "what with?" is few and poorly reasoned.

In the course of their work, the authors specified a systematic analysis of constructional and exploitational issues for the geotechnical system "embankment-subgrade" in southern areas of permafrost and deep seasonal freezing. The main objective is the research of continuous deformations and their causes on endorheic swamp areas on permafrost as well as on the sections with a low longitudinal gradient and complex geological-engineering conditions.

The researches are resulted in the general principle of drainage technical solutions for making a project of a new construction and a reconstruction (strengthening) of the embankment on weak and permafrost soils.

3 Research Methods

The southern zone of permafrost, the Khani – Tynda – Komsomolsk-on-Amur – Sovetskaya Gavan' section of the Baikal and Amur Mainline (the Vostochny polygon) is characterized by a great variety of natural conditions. A great number of different physical and geological phenomena create a lot of deformations. The permafrost on the Vostochny polygon is mostly continuous on the swamp area from the stations of Khani to Herby; then goes insular permafrost up to Dzhamku station; further to the East, stretches a deep seasonal frozen area; and then goes sporadic permafrost up to station Gorin.

The Far Eastern State Transport University (FESTU) has been studying the embankment stability issues since 1960s. Every time, when accomplishing scientific research works to study deformations, the structures designed on experimental basis are installed where the regime observations are carried out. Moreover, the observation results obtained on the structures during the embankment construction period (1976) are always used. This engineering analogue method has been used in the BAM eastern section, Yakutia and Sakhalin. The structures of the Vostochny polygon (BAM) were reequipped in 1990s, and a considerable experimental material has been collected.

During the engineering and geological survey on the section, some geodesic works are done first. Then, after the field materials have been processed, the analysis of natural data takes place. Next, a comparative assessment of the obtained results is carried out by analyzing the graphs of different configurations: an annual or multi-year cycle taking into account other factors (Fig. 1).

Fig. 1. Peat swamps with sag ponds, the Vostochny polygon

The paper gives a comparative analysis made on the basis of engineering and geological survey and the regime observations on experimental analogous structures at different exploitation periods on the railway lines Izvestkovaya – Urgal, Tynda – Dzhamku, Berkakit - Tommot [3, 4].

The main structure includes three analogous structures of different exploitation periods: the construction year of 1975, the construction year of 1984 and the construction year of 1940 plus additional draw-out track of the 1985 fill. This main structure is located on the turn-out tracks of the Urgal eastern interchange of BAM and on the second bottom of the Bureya River which is a peat-and-hillock swamp.

The traditional method of determining a general pattern of the embankment stabilization is based on making a comparison and finding a connection between the experimental structure results and the results of analogous structures of different exploitation periods (engineering analogue method). The selection of the experimental structures is ruled by an assessment of the frozen ground condition in the subgrade and its deformability.

Multi-year natural surveys of the regime in the experimental embankments on permafrost subgrades with soils of the 3rd and 4th categories of thermal moisturization help specify:

– settlement intensity and the total settlement in the embankments of different exploitation periods at natural thawing;
– character of the embankments behavior from the moment of thawing to their total freezing;
– soils behavior in the subgrades and foot zones of the embankments in the annual and a multi-year cycles;
– temperature regime in soils of the embankments and their subgrades in the annual cycle;
– effect of thermal insulation materials for the embankment stabilization;
– impact of deformations on the plan and profile of railway lines.

The main reason of lacking stability in linear structures on permafrost is the territory inundation and overwetting.

The operating practices on the permafrost embankment and the multi-year researches of the FESTU show that the embankment deformability on endorheic sections is definitely directly connected with a poor drainage quality and an inadequately low quantity of drainage structures.

4 Behavior Research Results for Structures of FESTU

The analysis of multi-year regime observations has resulted in diagrams of thawing and the subgrade settlement on the Vostochny polygon swamps.

Recent experimental researches and the analysis of long-term observations allow to track the mechanism of deformations in an annual cycle and develop the method of their forecasting in soils of the 3rd and 4th categories of thermal settlement in ordinary conditions [5, 6]. They also give a picture of main processes that affect this mechanism. The research of thermal and mass-exchanging processes, the physical and chemical ones, etc., that takes place in the subgrade under the influence of external factors, such as natural and climatic or/and technogenic and accidental, was carried out with different diagnostic equipment. Knowing the causes of settlement processes and their dependence on the changes helps renovate an already developed method for forecasting in these conditions as well as making justified design solutions for stabilization.

Malfunction of drainage systems or their absence, especially at endorheic areas and areas with poor run-off, leads to continuous deformations in the embankment. The changes in the soil freezing conditions in the subgrade leads to changes in the landscape and in the adjacent flood-prone territory. The soils losing their strength become subjects for a destructurization and deformations, such as plastic deformations, clay soil uplifts, pumping, etc., even more actual at an increased traffic load. As a result, the problem keeps urgent in the embankment's further exploitation.

According to the drainage conditions, the embankment is considered to be located in the good/poor run-off conditions or the endorheic ones. The parameters of the above mentioned are given in Table 1.

Table 1. Embankment drainage assessment

Drainage conditions	Territory characteristics	
	Mean slope	Surface and subsurface runoff
Good runoff	More than 3%	Surface runoff is provided; no ground waters or they do not influence the subgrade soil moisturization
Poor runoff	From 1% to 3%	Conditions for surface runoff are poor; evident water logging
Endorheic	Less than 1%	Practically endorheic (enclosed) area; ground or continuously presented (over 30 days) surface waters that influence soil moisturization

Therefore, when the problem of the embankment stabilization on the permafrost sections is focused only on a reconstruction of the drainage system, the solutions do not produce a necessary effect, while the permanent structure requires a considerable capital investment; and the maintenance and operational costs affected by traffic restrictions and environmental requirements are high. So, it is necessary to introduce the technological designs that on the one hand, eliminate deformations, and on the other hand, meet the operational and environmental requirements.

5 Solutions of Drainage Problems

The settlement process continues during the whole period of the structure exploitation if the right decisions are not made and targeted anti-deformation measures are not taken. Moreover, in permafrost conditions, the processes go on in a more complicated way in weak soils, thus requiring an accurate forecast for the occurrence of deformations and their development.

As there is no method for forecasting the appearance and development of the embankment settlement, the maintenance cost for stabilization of settling sections is increasing. It is closely connected with unjustified anti-deformation measures that must be technically correct when assigned only after the deformation causes have been determined. If not, the ballast materials for keeping the track within a serviceable limit state are not used rationally.

The most important factors that affect deformations in the high-temperature permafrost subgrades are the soil temperature and moisture that, in their turn, depend on natural, climatic, technogenic and occasional factors. After having determined their roles in the settlement processes, it is possible to correct the conventional method of forecasting, thus allowing to make justified design solutions for eliminating the negative processes.

The point is that a systematic control of the embankment condition is not conducted, thus there is no objective data base of deformations in it and, consequently, it is difficult to make a forecast for its stabilization.

The research results serve as original data for a development of an ultimate method of diagnostics and prognosis of the embankment settlement on weak and permafrost soils. Some measures are also offered to provide the embankment stability in these conditions.

Some methods of diagnostics and prognosis are realized with a developed device SDG-M; there are four patents and a utility model.

One of the ways to receive the prognosis and determine the causes of deformations is an experimental sample of a stationary unit for observing a deformated embankment. It is installed by engineers of FESTU at 2374 km on the Tynda section, Besstuzhevo station, the Far Eastern Rail Road, as a part of a complex control system in the Northern Longitudinal Railway organized by JSC "Russian Rail Road" [7] (Fig. 2).

Fig. 2. Experimental sample of stationary unit for observing a deformed embankment, Vostochny polygon, Far Eastern Rail Road

The received prognosis data are analyzed and the causes of the embankment deformations are determined to assign the reinforcement measures including the drainage. Below, there are new structural solutions for the embankment.

5.1 Cross-section of the Counter Dam (FESTU Patent #2392385) [8]

One of the target embankment sections is the one at 25 km of the Denisovsky-Chulman block-section located on the right bank of the Chulman River to the north-west of Nerungry Town. The section is filled with rock and equipped with rock berms.

A survey of the swampy section at 25 km of the Yakutian Rail Road made by the FESTU engineers with the above mentioned diagnostics and prognosis ways shows that deformations appear due to the melting of ice, 2–3 m thick, in the embankment subgrade as a result of its inundation. The extrusion of weak saturated soils of the subgrade and an artesian mechanical suffosion (removal of soil particles in runoff through the soil) cause settlements of weak subgrade soils. The embankment section is in an unstable condition, and the deformation process has been irreversible since the construction (1987). At the time of observation (2009), the settlements are of 150–200 mm. The width of the subgrade top is less than required, sleepers having bare butts. A structure of counter berms of variable cross-section is constructed (Fig. 3).

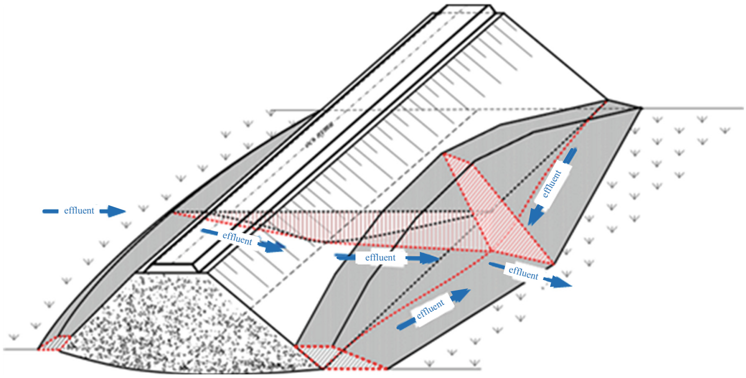

Fig. 3. Counter dam of sectional changing area

The earthwork structure on a weak subgrade includes the embankment (1) and prisms of sectional changing area – the (2, 3). The prisms serve for the runoff and the drainage in the subgrade in longitudinal and transversal directions. They are constructed of a draining soil and are located on both high and low sides of the embankment. The prism on the high side (3) is of lighter weight (the static weight) than the prism on the low side (2) of the embankment. In every prism, a trapezoidal cross-section of a maximum area is placed in the maximum settlement zone, while a trapezoidal cross-section of a minimal area is placed in the zone of stable soils.

5.2 The Drainage Structure on Permafrost (Patent (FESTU) #2567248 RF) [9]

The innovation can be applied in construction and reconstruction of the roadbed in linear structures at the sections with transversal water-flow and longitudinal drainage structures on weak permafrost soils.

A water-flow structure on permafrost consists of a drainage unit made of containers with sorted rock soils and placed on a planned natural subgrade perpendicular to the roadbed. It is installed on the bottom of the runoff course outlet at the high side of the adjacent territory in the direction of its low side, the drainage section being wrapped with a geosynthetic material around the perimeter.

To achieve the technically required objective it is offered to place containers in consequence when they overlap each other starting from the second one, the center of gravity being shifted to the far end. The size of the overlap is calculated according to $\Delta L = (0{,}1–0{,}15)L$, where ΔL is the overlap size of the consequent container on the end of the preceding container; L is the length of the container. The container weight is calculated according to the ratio $P_{i+1}/P_i = (0{,}05–0{,}10)P_i$, where P_i is the weight of the preceding container; P_{i+1} is the weight of every consequent container (Fig. 4).

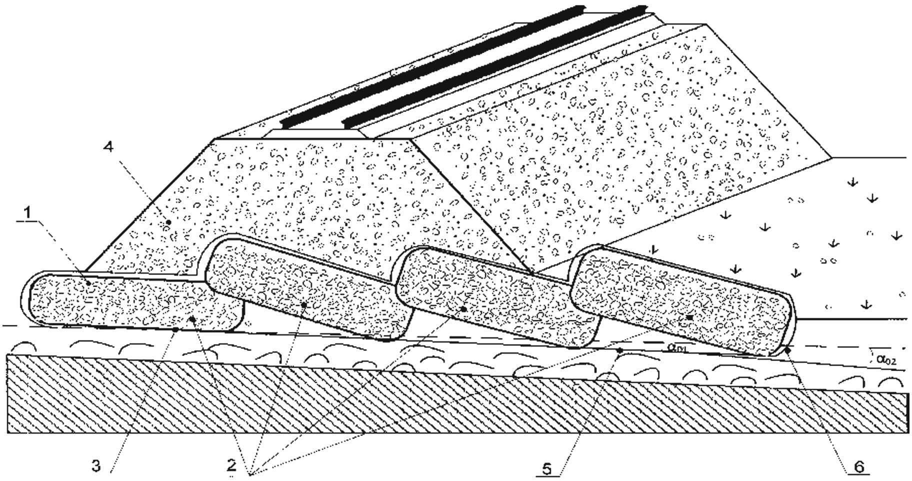

Fig. 4. Construction of longitudinal gradient with draining blocks (tubes) at endorheic sections

Drainage systems provide a longitudinal discharge of ground waters in the freezing period at the sections with cryogenic deformations. Ice heaving deformations often account for destabilization of the roadbed in the severe natural climatic, frozen ground, geological and engineering conditions. In most cases, it happens because there are no artificial structures between the road way and small local gullies, hollows and depression cavities located on the areas with poor runoffs. Due to a low longitudinal gradient (less than 1.5%), these areas are characterized by a malfunction of longitudinal drainage ditches along the embankment, and the surface and ground waters run off to the foot area of the embankment along the depression areas such as gullies, hollows and depression cavities. In summer period, water naturally filters through the roadway making no significant influence on the integrity of soil mass. In the period of temperatures below zero, the thermal and moisture regime changes as a result of uneven freezing in foot zones and narrowing of a water flow clear opening that acquires pressure. Thus, usually in November, when the pressure increases, the soil particles are washed out through draining soils of the subgrade and the roadbed where it comes close to gullies, hollows and depression cavities. On the other hand, when a complete freezing takes place at the foot zones on the low side, the increased pressure makes the roadway hollows be filled with water that increases in volume and makes heaves. Therefore, the earthwork structure deforms showing settlements in the subgrade, ice mounds and heaves in winter as well as collapse sinkholes, slope wash-outs, etc., in spring.

Stabilization of earthwork structures which embankments and subgrades are composed of degrading soils can be achieved using different drainage structure, draining embankments of sorted rock soils, ditches, anti-ice “warming” and “freezing” belts as well as small water discharge facilities.

5.3 Discharge Facility for Surface and Ground Waters (PJSC “Russian Rail Roads” Patent) [10]

Discharge facilities for surface and ground waters concern a construction of earthwork structures in thawing permafrost conditions and are used for water discharge through the roadbed from lower areas.

A technical result is prolonging the operational life of a structure over its standard term, providing stability of the roadbed preventing deformations in the roadway by free filtration of ground waters through the roadbed soils, from its high side to the low one. The discharge facility for surface and ground waters has a longitudinal trench along the roadbed slope. There is also at least one transversal trench perpendicular to and connected with the longitudinal one, both on the high side of the embankment. On the low side, there is a transversal trench perpendicular to the slope. The transversal trenches on both high and low sides are laid in one cross-section in low parts of the relief on both sides.

The transversal and longitudinal trenches are made to the depth of the seasonal freezing layer and are filled with the draining soil. Every transversal trench is covered with a thermal insulation (Fig. 5).

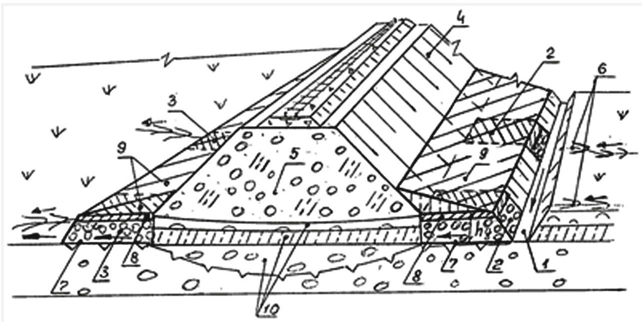

Fig. 5. Discharge facility for surface and ground waters in pre-winter period

5.4 Discharge Facility for Surface and Ground Waters (Patent (FESTU) #2618108 RF) [11]

The discharge facility for surface and ground waters concerns a construction of earthwork structures in severe natural climatic, geological and engineering conditions and is used for construction and reconstruction of linear structures on the sections of washouts and filtration of ground waters through the roadbed that mostly occur on permafrost and at deep seasonal freezing on rail- and motor roads, pipe mainlines, embankments and dams (Fig. 6).

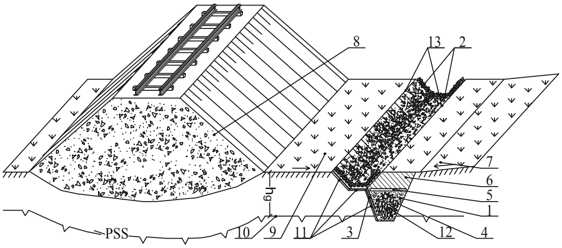

Fig. 6. Double-draining system on permafrost

5.5 Introduction of Innovations on Operational Sites

The first introduction of the counter dam of variable cross-section was made by FESTU in 2002 on a BAM interstation block Tuyun-Stlannik. In 2009, the Scientific Research Lab engineers of FESTU developed the reinforcement design for 25 km of the embankment, the heat insulation double-draining system with a catch ditch, as a part of order implementation from the Yakutian Rail Road, which was installed on the 116 km section of Neryungry-Tamrak line in 2006.

In 2015–2016, within framework of the agreement between the Yakutian Rail Road and FESTU, four sections of the road embankment in the Sakha-Yakutia Republic were surveyed. The sections of 11–12 km, 28 km, 58–59 km on Berkakit-Tommot-Yakutsk line and a section on Neryungry-Tamrak line have had traffic speed limit restrictions of 25–40 km/h which are now improved with the above described innovations. FESTU has developed some other successful projects with the innovations.

6 Conclusions

1. The research methods used during multi-year theoretical and experimental, laboratory and field works are applied to solve the target problems. A combination of scientific knowledge on theory and practice of the embankment design for operational and constructed transport facilities is adopted, and the methods received, directly or indirectly, improve the projecting of the embankment to provide safe and continuous railroad traffic in the Zabaykalye regions and the northern regions of the Russian Far East.
2. The scientific novelty covers new structural and technical solutions for draining the territories around the embankment of operational lines when developing reinforcement designs (reconstruction) and construction of new lines in the conditions of the southern areas of permafrost.
3. The researches have resulted in the following:
   - the causes of continuous deformations in permafrost areas are analysed;
   - new structural and technological solutions for stabilization of earth engineering structures are developed for projecting the embankments for new and operational sites taking into account the determined regularities;

– new multi-functional and anti-deformation structural and technological measures are offered and put into operation for the embankment stability of new and operational railroads;
– the method of the embankment design in the conditions of the southern areas of permafrost is improved on the basis of effective project solutions and the design variants accounting functional-system approach.

4. The practical implications of the work cover development, patenting and introduction of the technical solutions. The patented structural and technological solutions being combined with and improving the traditional principles of providing the stability are meant to be used in making other project for the embankment reinforcement (reconstruction) of both operational lines the ones under construction in a given region (eastern section of the Baikal-Amur Mainline, Zabaykalskaya Rail Road and Yakutian Rail Road) that decrease the capital and operational costs.

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Asphalt Concrete Mix Temperature Change Dynamics During Compaction

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Abstract. Usually, in studies, the temperature is assumed to be the same over the entire considered area during the roller pass. This assumption negatively affects the compression ratio achieved, namely, some areas may be under-compacted. At the point of contact with roller mix temperature is determined only by the time interval from the paver starts laying until roller run over the considered area. This time interval can be represented as a sum of: interval from the moment the mixture was laid to the moment a paver finishes work on the lane section; interval from the moment compaction of lane section starts to the moment a roller run over the considered area; time break from the moment when paver completed laying to the moment when roller starts compaction of the lane section. The obtained expressions set connection between the roller drum coordinate on a lane section and time when this position is reached. The obtained expressions allow us to calculate the asphalt concrete mix temperature at the moment of the roller contact with the coating area located anywhere in the lane section. The temperature value determines mixture deformation properties and, therefore, it's density in specified area. In this way it is possible to calculate the distribution of the achieved compression ratio over entire area of the lane section and track the distribution dynamics with roller passes number increase. The study of the coating cooling rate will provide specific recommendations to achieve the required coating flatness along the entire lane section length.

Keywords: Pavement · Roller · Compaction · Asphalt concrete mix · Temperature · Dynamics of cooling · Time interval

1 Introduction

Compacting is the final operation of the asphalt concrete road pavement construction. Quality of the specified operation effects on the coating durability. Temperature is one of the main asphalt concrete mix parameter that determine its physicomechanical properties. Therefore, when considering the impact of a road roller with an asphalt concrete coating during compaction, it is necessary to know mixture temperature in the contact area. Usually temperature is considered the same over the entire area of the lane section during roller pass. However, in reality, this temperature will be different, since the lane section has a considerable length and it takes time to move the roller along it. An additional temperature difference is made by the paver for the same reasons.

When the roller contacts with different coating areas of lane section the interaction conditions will vary, as a result, different compression ratio will be achieved on the same roller pass.

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2 Materials and Methods

Numerous empirical equations are proposed to describe the process of asphalt concrete mix temperature changing, the essence of which, as a rule, can be described by the following expression [1–15]

$$T = f(T_{in}, h, \rho, T_a, V_w, t). \quad (1)$$

Expression (1) includes the following parameters as independent variables:

1. T_a – air temperature, V_w – wind speed, that is, parameters reflecting environmental conditions,
2. h – coating thickness,
3. ρ – mix density,
4. T_{in} – initial mix temperature,
5. t – time interval required to change the mix temperature from T_{in} to the final value of T.

Modern pavers allow to achieve a compression ratio of 0.9–0.92 when laying asphalt concrete mix. Therefore, further compaction doesn't cause mixture density ρ and coating thickness h significant change. We will consider them in expression (1) as constants. The density is assumed to be $0.98\rho_{st}$, where ρ_{st} is the density of the asphalt concrete mix sample compacted in the standard way. As h we take the thickness of the finished coating h_f.

In addition, if we assume that the external factors are constant during the compaction process, and as the initial temperature we take the mix temperature in the paver hopper ($T_{in} = T_0$), then expression (1) takes form

$$T = f(t). \quad (2)$$

Thus, we will assume that the mix temperature in the area of roller contact with the coating is determined only by the time interval t from the moment mixture was laid out by the paver within the contact area until the roller run over this area.

For further calculations, we choose the law of mix temperature change, proposed in [16], which, taking into account the accepted assumptions, looks like

$$T = (T_0 - T_a)e^{-\frac{3.7e^{0.0588\,V_W}}{0.98\rho_{st} c h_f} t} + T_a, \quad (3)$$

where c – mix heat capacity, kcal/kg $\cdot\,^\circ$C;

T_0 – mix temperature in the paver hopper, °C;

V_a – wind speed, m/s;

h_f – finished coating thickness, cm;

ρ_{st} – density of asphalt concrete mix sample compacted in a standard way, g/cm^3;

t – time interval, h.

Consider a typical technique for asphalt concrete pavement manufacture with a mechanized set of road machines. The paver spreads one lane section of hot asphalt concrete mix with a width *W* and a length *L* (Fig. 1). After the paver vacated lane section, it begins to be compacted with a set of road rollers. The movement of any rollers, according to recommendations, occurs sequentially across all bands of the lane section, starting from the first. Roller passes each lane zone twice, since maneuvering on the lane section to be compacted is undesirable. After last lane zone compacted, the rolling sequence is reversed - from the last zone to the first. At any time of compaction process one roller is working on the lane section.

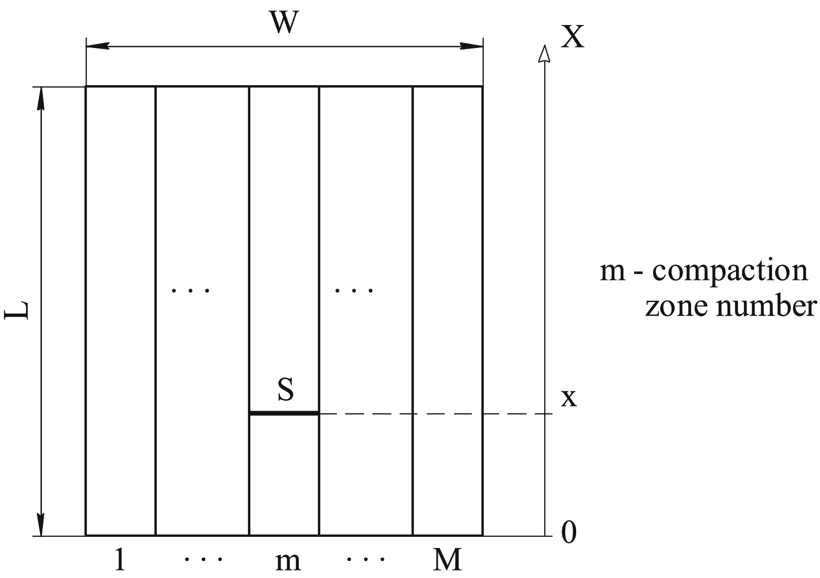

Fig. 1. Lane section compaction scheme by road roller

We introduce the axis of movement of the roller *0X*, the positive direction of which coincides with the roller movement on the first pass. On the surface of a zone *m*, we select an elementary area *S* having the coordinate *x* (Fig. 1). Asphalt concrete mix temperature at the area's contact with the drum of any roller is determined by the time interval Δt from the moment paver puts the mixture layer within considered area until the roller run over it. For any roller of the set, the interval Δt can be represented in the form of three terms

$$\Delta t = \Delta t_p + \Delta t^* + \Delta t_r, \tag{4}$$

where Δt_p – time interval from the moment of laying the mixture in the area *S* zone until the paver work completion on the lane section;

Δt_r – time interval from the lane section compaction start moment to the moment of roller's drum run over the area S;

Δt^* – pause, if there is one, between the moment of paver work completion and the moment of lane section compaction start by the considered roller.

Certainly, for any roller, the pause includes the total operating time on the lane section of all previous rollers of the set. In addition, if any of the rollers begins to delay compaction after lane section release by the previous road machine, then the pause Δt^* also includes the total time of all previous rollers indicated delays and the delay of the considered roller, if present.

Consider the paver work on the lane section. The paver moves along the positive direction of the $0X$ axis with a certain speed V_p. Time t is counted from the moment the mixture was layed.

The mix temperature is the same along any line parallel to the start of the lane section, but differs for various lines. Consider a line passing through the area S and, therefore, having the coordinate x. For this line, as well as for the area S, we can write

$$\Delta t_p = \frac{L - x}{V_p}, \tag{5}$$

By setting the value $t = \Delta t_p$ in Eq. (3), it is possible to calculate the corresponding temperature value for any x and, thus, to obtain the mix temperature distribution over the lane section area at the time of paver work completion.

Next, we will analyze roller operation on the lane section. On first pass roller movement coincides with the X axis positive direction. Time t is counted from the moment the compaction begins. The number of lane section zones M is

$$M = \left(\frac{W}{\alpha B}\right)^{UP}, \tag{6}$$

where B – roller drum width;

α – coefficient taking into account overlay of zones during compaction.

Hereinafter, the $()^{UP}$ index means that the fractional calculation result is rounded to the nearest larger integer. Time for the roller to pass through the zone is

$$t_{pass} = \frac{L}{V_r}, \tag{7}$$

where V_r – roller speed.

We introduce the concept of "compaction cycle". We call the compaction cycle the roller pass over the entire area of lane section alternately across all zones. After last lane section zone is compacted, the cycle repeats with a change in the sequence of zones changing to the reverse. Since, according to the technology, the roller compacting each zone twice, one compaction cycle includes $2M$ roller passes along the zone and the number N of roller passes along the same track always twice the number of compaction cycles P

$$N = 2P. \tag{8}$$

The compaction cycle period is

$$t_c = 2Mt_{pass}. \tag{9}$$

We denote K is the number of roller passes in zones along the axis $0X$ in any direction. We count the passes starting from the first zone. Then current pass number is determined from the expression

$$K = \left(\frac{t}{t_{pass}}\right)^{UP}. \tag{10}$$

Suppose at some point in time t, which corresponds to the roller pass along the lane section with number K, the roller drum is in contact with the elementary area S, which has an x coordinate and is located on a zone with m number (Fig. 1). Then compaction cycle number P corresponding to the considered time t will be equal to

$$P = \left(\frac{t}{t_c}\right)^{UP}, \tag{11}$$

or

$$P = \left(\frac{K}{2M}\right)^{UP}. \tag{12}$$

Zone number m is determined by the formula

$$m = \left\{\frac{Mt_{pass}\left[(-1)^P + 1\right] + (-1)^{P-1}[t - t_c(P-1)]}{2t_{pass}}\right\}^{UP}, \tag{13}$$

or

$$m = \left\{0.25\left[(-1)^P + 1\right](2M+1) + 0.5(-1)^{P-1}[K - 2M(P-1)]\right\}^{UP}. \tag{14}$$

The expression relating selected time moment t and coordinate x corresponding to this moment has the form

$$x = L - (-1)^{K-1}\left\{L - V_r\left[t - t_c(P-1) - t_{pass}\left((-1)^P + 1\right)(m-1) - 2t_{pass}(-1)^{P-1}(m-1)\right]\right\}, \tag{15}$$

or

$$t = \frac{1}{V_r}\left[L - \frac{L-x}{(-1)^{K-1}}\right] + t_c(P-1) + t_{pass}(M-1)\left((-1)^P + 1\right) + 2t_{pass}(m-1)\,(-1)^{P-1}. \tag{16}$$

In Eqs. (15) and (16) in accordance with the accepted countdown

$$t = \Delta t_r \tag{17}$$

3 Results and Discussion

The obtained relations allow us to calculate asphalt concrete mix temperature at the contact moment of the roller with coating area located anywhere in the lane section. This temperature value determines mix deformation properties and, therefore, the compression ratio in the specified area. In this way it is possible to calculate the distribution of the achieved compression ratio over the entire area of the lane section and track its distribution dynamics with the roller passes number increase.

It is convenient to use Eqs. (11), (13), (15) to find on the lane section the contact place of the roller with coating, if the time interval from the start of lane section compaction by a roller to the contact moment is known. If, on the selected roller pass, it is necessary to determine the temperature of a contact area, position of which on the lane section is known, then it is necessary to use Eqs. (12), (14), (16).

Consider the process of asphalt concrete mix temperature changing in the contact area using the example of compaction of the lane section by a roller, which starts immediately after the paver leaves lane section and performs two compaction cycles.

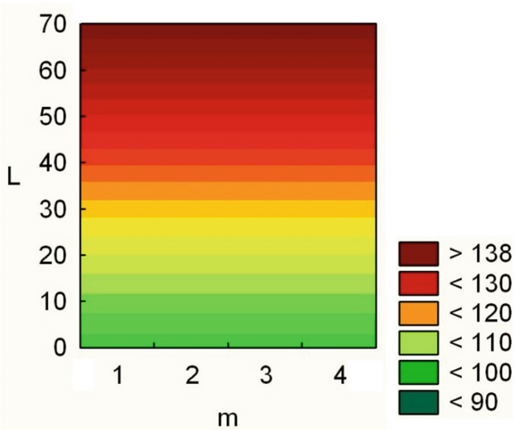

Fig. 2. Mix temperature distribution on the area of lane section at the time a paver is finished

The calculation is made with the following input data:

W = 3.5 m; L = 70 m; B = 1.1 m; α = 0.9; V_p = 144 m/h; V_r = 5000 m/h; h_f = 5 cm; ρ_{st} = 2.35 g/cm^3; $c = 0.5\text{kcal}/\text{kg} \cdot {}^\circ\text{C}$; T_0 = 140 °C; T_a = 20 °C; V_w = 3 m/s.

The calculation results are presented in Figs. 2, 3, 4 and 5. In Fig. 5 the time is counted from the moment of the lane section compaction start by a roller.

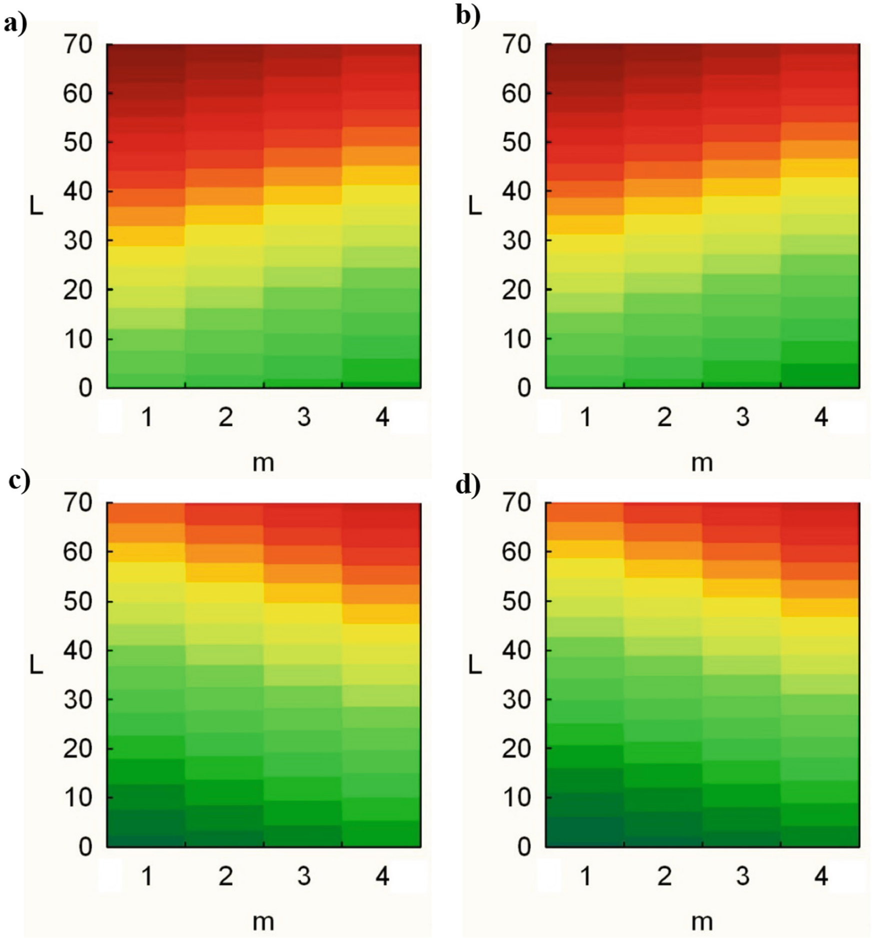

Fig. 3. Distribution of a contact zone mix temperature on the area of lane section at the first four roller passes along the same track: (a) first pass; (b) second pass; (c) third pass; (d) fourth pass

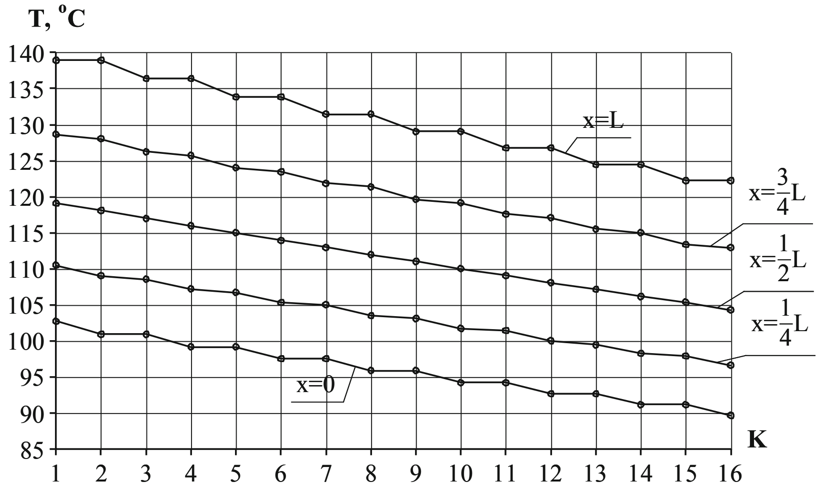

Fig. 4. Mix temperature in a contact area with the roller at any roller pass along the zone for various contact area positions within a zone

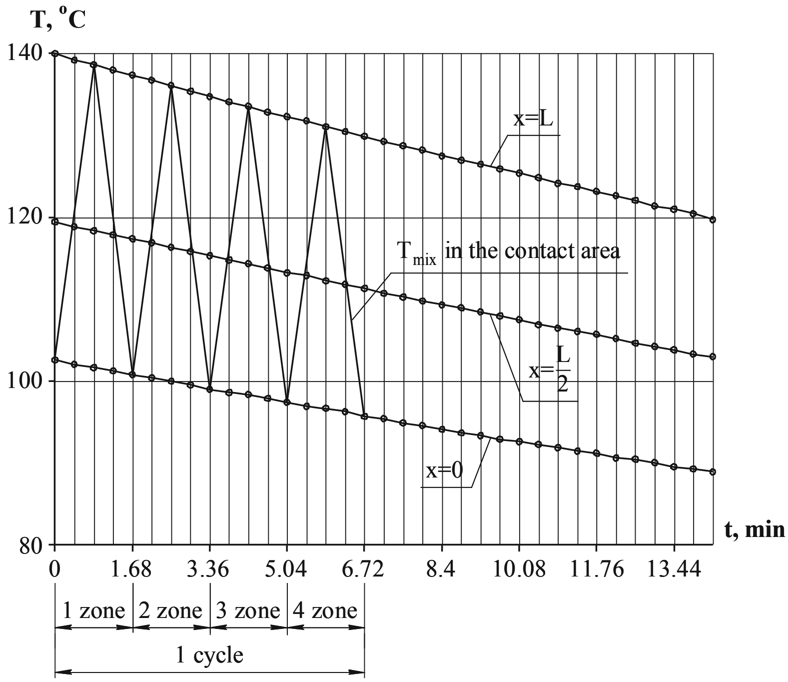

Fig. 5. Mix temperature change in the contact area of a roller with a coating for one compaction cycle, depending on the mix temperature change within the lane section over time

4 Conclusions

Studies results analysis allows us to draw the following conclusions:

1. During one roller pass along the lane section area, there is a significant mixture temperature difference in the contact zone of a roller with the coating both along the lane section length and in width. At the same time, the lowest temperature corresponds to the beginning of the last zone.
2. In mathematical modeling of asphalt concrete pavement compaction process with the mechanized set of road machines, it is necessary to take into account the above temperature difference. For example, the condition fulfillment of the compaction start by the roller, based on the mix strength properties, must be checked for the area located at the end of the first zone of the lane section, since this coating area is always the hottest during one pass of the roller over the lane section area.

On the contrary, condition fulfillment of coating compaction effectiveness by the roller must be checked for the coating area having a minimum temperature. This area is located at the beginning of the last zone of the lane section.

3. The unequal compression ratio of different sections of the lane section at one roller pass is due to a mix temperature difference in the contact area of these sections. The use of the reverse sequence of changing zones reduces the difference in compaction along the lane section surface when passes number increase.
4. During compaction, there is always a temperature difference along the length of a lane section. Therefore, at each roller pass the end of the lane section is denser than the beginning. To reduce this difference in compaction, it is recommended to perform next pass along the same track with a decrease in its length relative to a colder edge of lane section by the value of a drum diameter.

In addition, to achieve the required coating flatness, the final passes of the last roller must be performed along the entire length of the lane section.

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Geodetic Monitoring for the Construction of Railway Bridge Piles

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Abstract. This paper considers issues of geodetic monitoring for the construction of railway bridge piles. A system for scheduled control of the designed position of railway bridge piles erected by employing large diameter shell-type piles has been developed. The paper suggests an automated monitoring system for determining the coordinates of the major axes of the shell, assessing accuracy and making decisions on correcting the positioning of the structure under construction. This system includes the following sequence of operations: determining actual coordinates of checkpoints, automated real-time adjustment using root-mean-squared error ellipsis; and determining the center of the shell and the turns of the axes. A method for determining the inclination of the shells from one station through comparing actual measured difference of vertex angles with the design values and provided a 3D model of determining the inclination of bridge piles is also presented in this paper.

Keywords: Bridge pile · Monitoring of spatial positioning · Pile shell inclination · Root-mean-square error

1 Introduction

Under the conditions of present-day digital economy, the prompt obtaining of geospatial data and geo-analysis gains in importance [1]. Geodetic monitoring over the geometric parameters of the bridge piles under construction is a complicated and crucial issue. The permits to conduct works are determined by various bridge construction normative documents and standards.

The major purpose of monitoring is to find the compliance of actual data with the design specifications. The choice of the geodetic measuring instruments and working methodology depends upon the structure of the construction object, the topography and climatic conditions of the location and the construction period.

Classical and up-to-date methods of geodetic supervision over the construction of bridge piles are set forth in works [2, 3]. When erecting unique bridges, i.e. the Golden Horn Bridge (Zolotoy Bridge) (Vladivostok, Russia), the spatial location control was accomplished with systems consisting of GNSS receivers, base stations, electronic tachymeters, and tilt meters (inclinometers). The entire complex of equipment and software ensures spotting the coordinates of the object's checkpoints on a practically real time basis. Such expensive equipment is used, as a rule, for the construction of the off-class bridges [4] and unique engineering facilities [5].

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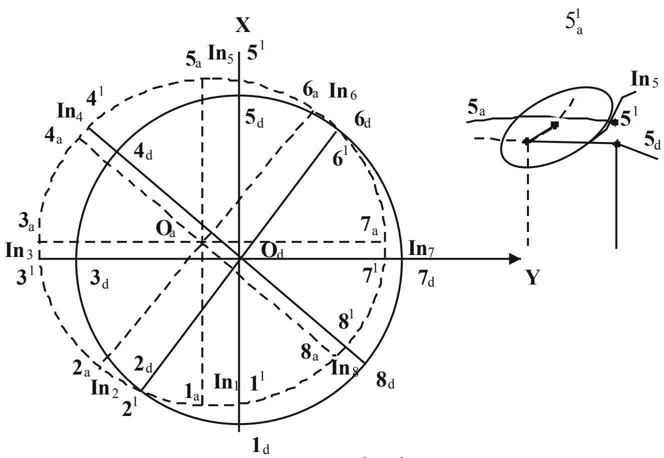
In present day bridge engineering practices, a considerable part of the foundations is built of metallic and reinforced concrete shell-type piles [6]. The diameters of the casings vary from 0.8 m to 10 m.

Therefore, the geodesic supervision of major, intermediate and minor bridges requires development of supervision methods that allow engineers to acquire and to process up-dated and valid data, and to make engineering decisions to correct the planned-high-altitude position of the bridge piles. Other considerations to be taken into account are the technology of building foundations employing shell-type piles and modern methods of implementing land geodetic work.

2 Technology and the Accuracy Assessment of the Method for Monitoring Spatial Positioning of Piles of Railway Bridges

To perform the complex of geodetic work, we have developed a method of staking bridge piles of/using cylindrical shells and a method of monitoring verticality [7].

The operation schedule of staking includes building up a staked grid, spotting the coordinates of checkpoints and calculating the staked angles. To implement this operation schedule, eight checkpoints are established initially placed on the external and the internal surfaces of the shell-pile. The optimal number of checkpoints is chosen based on several criteria: specific placement of technological equipment on the shell; reliable control over the shell under the most unfavourable conditions of locations of geodesic stations; and the determination of the verticality of the shell (Fig. 1).



$1d$–$8d$ – designed position of the points; $1a^1$–$8a^1$ – actual position of the points;
$1a$–$8a$ – position of the points after adjustment;
In_1–In_8 – displacement of the points with new positioning regarding the designed directions in an arc;
1^1–8^1– position of points on the designed directions

Fig. 1. Monitoring planned positioning of shell riles

The process of geodetic monitoring of the shell-type pile (or its section) positioning comprises the following stages:

- the positions of the pile centers and the checkpoints are determined by the electronic tachymeter or GNSS receiver (RTK mode). After that checkpoints are fixed on the island with grooving-and-tonguing;
- the assembly of the shell-type pile begins with the installation of supporting rings by lining up the checkpoints on the surface of the shell and the artificial island. The installation of the supporting ring is controlled from the station located on the base line/axis of the bridge; in cases of zero visibility the process is controlled from the center of the already erected pile. When manufacturing shells, the surface of the rings should have fastenings for reflectors.
- the coordinates of the points are determined and the adjustments are performed by the on-site computer. The operator (geodesist or foreman) can make a decision on the amendments to the planned design position of the structure.

The specific feature of erecting bridge supports employing reinforced concrete or metal shell-piles is that the latter possess reasonable rigidity. This means that they can be considered conditionally nondeformable. Under such conditions the positioning of the axes of these rings, i.e. spotting the coordinates of the major axes crossings and their turn in regard to the design positioning gains special significance, as these cylindrical rings are then used to place different insertions, and supporting pads for vibrating pile drivers, etc.

The issue of the optimal positioning of engineering objects of various shapes (round, spherical, or rectangular) is considered in many works on geodesy [8, 9]. The method suggested allows a simplification of the optimization algorithm as well as the correct resolution of the problem for the site-work.

To control the determination of the major axes of the shell, the accuracy assessment and decision-making on the corrections to the location of the structure, an automated system for monitoring the planned-and-designed positions of the shell's axes was developed.

The sequence of operations for monitoring the planned positioning is as follows. After the shell-pile penetration reaches the design reference mark, actual coordinates of the checkpoints ($1a^1$–$8a^1$) are determined by the geodetic measurement instruments (tachymeter).

For each of the points obtained a root-mean-square errors (RMSE) ellipsis is built up on the computer in the visual image mode. The elements of the RMSE ellipsis are calculated according to well-know formulae.

Then in the graphic presentation mode, the operator relocates (inscribes) the designed circumference under the condition that all eight point are not beyond the scope of the RMSE ellipsis and obtains new adjusted coordinates of the points (*1a–8a)*.

The minimal deviation of the shell center from the designed position is also accepted as an additional criterion. As a result, we have an opportunity to determine the values (In_1–In_8) for the displacement of points. In this way, the turn of the axes and the center deviation from the designed position are determined.

The assessment of accuracy in evaluating the shell center displacement and turn of the axes is performed according to the formulae for calculating standard RMSE, taking into consideration the fact that errors in the values of displacement L and turn α_L will depend upon the errors m_x и m_y in determining the coordinates of the points

$$m_L^2 = \frac{4L_x^2 \cdot m_x^2 + 4L_y^2 \cdot m_y^2}{L_x^2 + L_y^2}, \; m_{\alpha_L}^2 = \frac{L_y^2 \cdot m_x^2 + L_x^2 \cdot m_y^2}{\left(L_x^2 + L_y^2\right)^2}, \tag{1}$$

where m_L, m_{α_L} is the RMSE of evaluating the shell center displacement and turn of the axes.

Based on the suggested monitoring system we have performed mathematical modeling for different data (distance between the piles, diameter of the shell, and the RMSE ellipsis parameters). The data obtained (m_L = 5 mm, m_{α_L} = 8 mm) prove that the developed system for monitoring planned-and-designed position of the shell meets the requirements of the normative documents on geodetic works in bridge construction.

3 Determining the Inclinations of the Bridge Piles

When building bridges, determining the pile inclinations is an important element of monitoring. Inclinations (tilts) are determined in different ways [10]. The choice of the optimal way depends upon the technical parameters of the structure under construction, local conditions and the requirements for accuracy. When building bridge supports on shell-type piles, the process of inclination determination should be a part of the operational inspection and it should accompany the control of the planned position. The control is conducted, as a rule, from the same station.

We have developed an express method for immediate detection and elimination of inclinations while assembling cylindrical shells and set forth its basic principles in work [11]. Figure 2 presents the essence of the method.

As a cylindrical shell is a rigid structure, it is not deformation-prone and when it inclines its vertical axis tilts at an angle γ_x (angular dimension of the inclination constituent), the horizontal axis of the shell declines at the same angle. The projection of the vertical axis OO_x in its inclined state on the horizontal plane in the base of the cylindrical shell, produces the linear value of the inclination constituent ($In_x - S_x$), determined by the formula

$$S_x = H \cdot \frac{\gamma_x}{\rho}. \tag{2}$$

where H is the height of the shell.

The height value of the inclination (In) is deduced by projecting the center of the structure O at the inclined position of the horizontal plane on the vertical plane passing through the corresponding marked points.

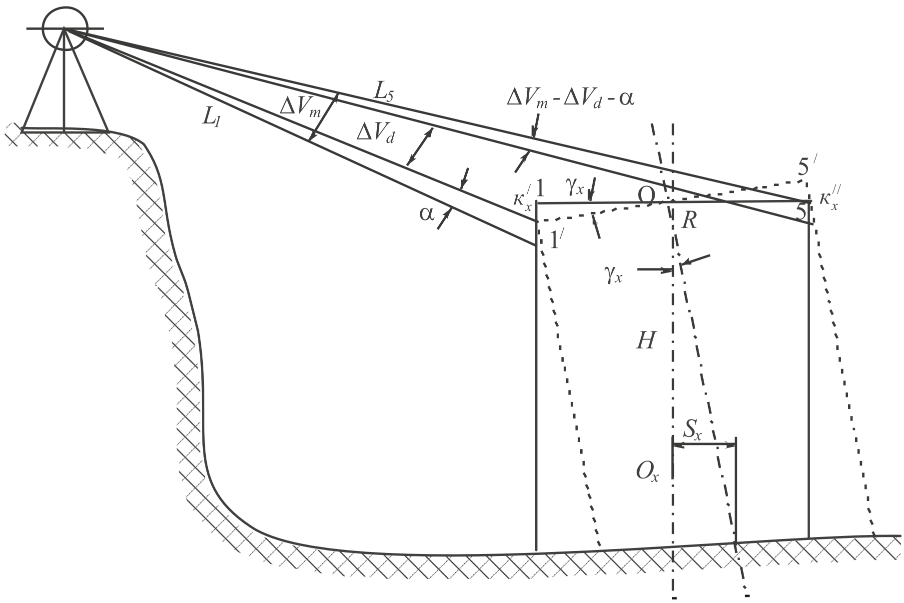


Fig. 2. Determining the inclination of the cylindrical shell

Value *In* is determined from the expressions:

$$In_x = \frac{(L_1 + L_5)}{2} \frac{(\Delta v_m - \Delta v_d)}{\cos v \quad \rho};\; In_y = L_{3,7} \frac{\Delta v_m}{\cos v \quad \rho}, \tag{3}$$

where In_x and In_y are height constituents of the inclination; Δv_m is the measured difference between vertex angles; Δv_d is the designed difference between vertex angles (as $L_3 = L_7$, *a* $\Delta v_d = 0$); and L_1–L_7 is the distance to inspection points.

The overall value of the inclination *In* is deduced by the formula

$$In = \sqrt{In_x^2 + In_y^2} \tag{4}$$

Thus, the angular, the linear and the height values of inclination are deduced on the basis of the measured difference between vertex angles and precomputation (design values).

The issues of precomputation, accuracy assessment and taking into account refraction in trigonometric levelling employing electronic tachymeters are considered in works [12–14].

The RMSE $m_{k,x,y}$ of determining the inclination constituents are deduced from the equation

$$m_{k,x,y} = \sqrt{m_L^2\left(\frac{\Delta v}{\rho\cos v}\right)^2 + m_{\Delta v}^2\left(\frac{L}{\rho\cos v}\right)^2 + m_k^2\left(\frac{L}{2R}\right)^2}, \quad (5)$$

where m_L, $m_{\Delta v}$, m_k are the RMSE in measuring lines, vertex angles difference and constant of refraction.

The developed method for determining the inclination allows us to neglect the earth's curvature corrections and refraction as the measurements are performed at the same height above the water surface and the indications are taken within a short period of time. Analysis of the formula (5) shows that at vertex angles up to $\pm 10^{\circ}$ the declivity angle of the directional ray in relation to the horizon and inequality of distances to the checkpoints do not practically impact the value of inclination.

Planned displacements of cylindrical shells do not exceed admissible values by 5–10 cm and do not impact the accuracy of determining the inclination, as we need to know the lengths of the lines from the base to the checkpoints within an accuracy of 1–2 m. Thus, is we accept mk,x,y = 5 mm, $m_{\Delta v} = 5''$, $\Delta v = 300''$, $v = 20°$, $L = 100$ m, and use formula (5) to calculate RMSE, necessary for the length of the line, we will obtain mL = 1.5 m.

When sinking large-diameter shell-piles in the process of erecting bridge supports, there appears a necessity to both determine and to immediately correct the inclination. In this case, the value of angular and linear inclinations do not contain information for correction of the inclination and it is only the vertical value of inclination that makes it possible to calculate the efforts of the vibratory drivers that are installed on top of the shell and to promptly eliminate the inclination.

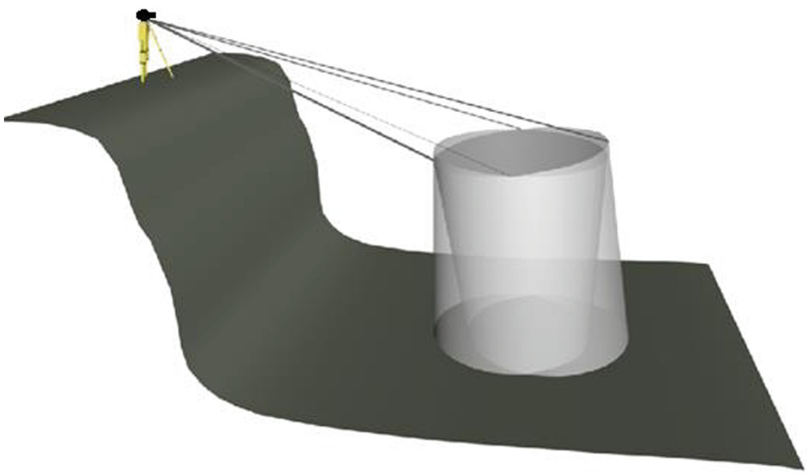


Fig. 3. 3D model of determining inclination

Technologies for information 3D modelling of buildings and structures BIM (Building Information Modeling) are deployed by the construction industry in the world. Paper [15] shows the major trends of the development of 3D modelling technologies for transport structures. Among them is the project IFC-Bridge aimed at the 3D designing of bridges. Based on the method for determining the inclination on the measured difference of vertex angles, a 3D model of an object, presented in Fig. 3, was created. Employment of spatial models makes possible making immediate real-time engineering decisions aimed at corrections in positioning structures.

Looking ahead, 3D modeling technologies are going to become an integral indispensable part of the designing process and bridge construction.

4 Conclusions

1. We have developed a system for monitoring geospatial data for construction of the bridge piles.
2. We suggest a productivity enhancing method for determining the bridge pile inclinations from the same station.
3. We have performed the calculations on the assessment of the accuracy of geodetic measurements that prove the efficiency of the suggested technology.
4. We have shown the prospects for the developed methods of geodetic monitoring in bridge construction and 3D modelling.

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Improvement of the Calculation of the Floating Bridge Hinge System of the Two Supporting Ferry

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Abstract. The regulatory method for calculating the load capacity of floating bridges of a hinged scheme from two-support ferries does not take into account the effect of the cross beams on the joint work of the main beams. To take into account the effect of transverse beams on the joint operation of main beams, it is proposed to introduce the coefficient of longitudinal load distribution between transverse beams. To determine the coefficient, a finite element model of the floating bridge span was built. While the test of the crossing deflections of beams, fibre linear tensile strain were measured, the lower chords of main girders in the monitored cross sections and the deflections of the ice cover. Controlled sections were selected on the principle of occurrence of maximum forces in them. It is advanced and confirmed by test methods calculation to cargo-carrying capacity floating bridge joint scheme from two-supporting ferry on base of the account of the influence of the transverse beems to collaboration main beems by been entering the corrective factor in formula accounting bending moment.

Keywords: Floating bridge · Load capacity · Pontoon · Combined crossing · Coefficient of transverse installation · Dynamic coefficient · Coefficient of longitudinal load distribution · Line of influence

1 Introduction

The regulatory method for calculating the load capacity of floating bridges of a hinged scheme from two-support ferries does not take into account the effect of the cross beams on the joint work of the main beams [1–3], therefore the aim of the work is to improve this technique.

2 Materials and Methods

The object of the study is the ice crossing, reinforced by metal pontoon structures from two-support ferries (hereinafter, the combined crossing) across the Ussuri river which is located near the village of Pokrovka in the Bikinsky District of the Khabarovsk Territory on the border with China.

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The combined crossing is arranged by the guidance and subsequent freezing of the metal pontoon structures of the floating Chinese-made road bridge into the ice cover of the river immediately after the end of the freeze-up. The technical category of the road is IV. Floating bridge scheme is 7.0 + (20.32 × 2 + 3.0) × 10 + 20.32 × 2 + 7.0 (20.32 m – full length of bridge spans; 3.0 m – length of insertions into every two bridge sections; 7.0 m – ramp length). Dimension of the roadway Г – 9.0 m, full length of the combined crossing is 491.04.0 m. Bridge deck is not covered. Artificial roughness was established by grafting anti-slip bars of 10 × 12 mm with a step of 15–20 cm over the entire width of the roadway dimension. Span structures № 1–22 ($L_o = L_{full.}$ = 20.32 m) are made of welded I-beams. Beam height is 0.51 m, 10 beams with a step of 1.0 m are located in the cross section, the lower belt is 1.4 × 18 cm, the upper belt is in the form of a metal sheet included in the work of 0.1 × 100 cm.

In the longitudinal direction, the span structures on the two-support ferries are combined in a hinged-cantilever system with coupling devices in the form of vertical lugs with a horizontal retractable pin on the pin (bolted hinges), forming a ribbon bridge [4]. In each span across the bridge, the beams are united by three transverse beams with a step of 2.8 m and a height equal to the height of the main beams and four auxiliary cross beams with half the height between them (step 1.4 m). The dimensions of the belts of high transverse beams are 1 × 20 cm, the auxiliary transverse beams are 1 × 10 cm. The roadway of the bridge is made of metal sheet 1 cm thick and the main beams of the superstructure are rigidly connected with two pontoons. Overhang of the main beams of the pontoons is 1.0 m. The transitional part is single-console (ramp), supported on a natural basis.

Support beams № 1–44 are pontoons of individual design with the load capacity of 50 tons each (similar to the Russian deck barge № XVII), navigation grade “P”. Waterline area - 104.2 m^2. The length of the waterline is 20.84 m. The length of the pontoon carriageway is 20.32 m. The pontoon’s length is 19 m. The pontoon’s width is 5 m. The width of the carriageway is 9 m. The distance between the axes of the pontoons (l) is 13 m. The height of the pontoons is 1.5 m. The admissible draft is 0.9 m. The draft is 0.42 m. There are no sidewalks. The general view of the crossing is shown in Fig. 1.

3 Results

The calculation of the road hinged cantilever bridge from two-support ferries is performed according to [2, 5].

A central bearing of the superstructure on supports is accepted.

Waterline area

$$A_0 = \frac{Q_\Gamma}{\gamma(t_\Gamma - \mathrm{t}_n)} \tag{1}$$

where:

$Q_\Gamma = 50$ m – carrying capacity of floating support (pontoon), according to technical documentation, deck barge № XVII is the Russian equivalent in RNM-79;

Fig. 1. General view of the ice crossing reinforced with metal pontoon structures

$t_\Gamma = 0.90$M – design draft of the floating support; t_п = 0.42 m – the draft of the floating support in the empty state;

$\gamma = 1$ t/m^3 – volume weight of water

$$A_0 = \frac{Q_\Gamma}{\gamma(t_\Gamma - \mathrm{t}_n)} = \frac{50}{1(0.90 - 0.42)} = 104.2\,\mathrm{m}^2.$$

The positive part of the influence line of the bending moment (i.l.M, Fig. 2) has a length

$$x_1 = \frac{2L_0 l}{L_0 + l} \tag{2}$$

$$x_1 = \frac{2L_0 l}{L_0 + l} = \frac{2 \cdot 20.32 \cdot 13}{33.32} = 15.86\,\mathrm{m}$$

$v_1 = 107.92\,\frac{\mathrm{kN}}{\mathrm{m}}$ - the intensity of the distributed load H-14 for a length of 15.86 m.

Greatest ordinate i.l.M:

$$m = \frac{2L_0 l}{2(L_0 + l)} \tag{3}$$

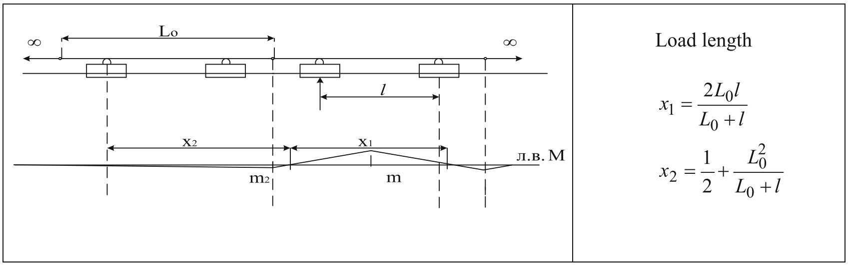

Fig. 2. Influence lines (i.l.) in the middle of the river part of the articulated-cantilever bridge of two-support ferries: a – bridge design diagram; b – i.l. bending moment in the middle section of the ferry span

or

$$m = \frac{x_1}{4} = \frac{15{,}86}{4} = 3.97\,\text{m} \tag{4}$$

From where

$$\text{M} = 0.5(1+\mu)\text{mx}_1\upsilon_1 = 0.5 \cdot 1.15 \cdot 3.97 \cdot 15.86 \cdot 107.92 = 3907.2\,\text{кNm}$$

where: $(1+\mu) = 1.15$ is the dynamic coefficient.

Minimum ordinate of the negative portion of the i.l.M in the hinge

$$m_2 = -\frac{L_0(L_0 - l)}{4(L_0 + l)} \tag{5}$$

or

$$m_2 = m - 0.25L_0 = 3.97 - 0.5 \cdot 20.32 = -1.11\,\text{m} \tag{6}$$

The length of negative portion i.l.M:

$$x_2 = \frac{l}{2} + \frac{L_0^2}{L_0 + l} \tag{7}$$

or

$$x_2 = L_0 + \frac{l}{2} - 2\,\text{m} = 20.32 + \frac{13}{2} - 2 \cdot 3.97 = 18.88\,\text{m} \tag{8}$$

$\upsilon_2 = 93.37\ \frac{\text{kN}}{\text{m}}$ is an intensity of the distributed load H-14 for the section with a length of 18.88 m.

From where

$$M_2 = 0.5(1+\mu)m_2x_2\upsilon_2 = 0.5 \cdot 1.15 \cdot (-1.11) \cdot 18.88 \cdot 93.37 = -1125.12\,\text{kNm} \quad (9)$$

The coefficient of transverse installation for the most loaded, extreme beam is determined by:

- when the height of the main farms (main beams or girders) is less than 1.5 m

$$K_{TI} = \frac{1}{n} + 1.86\frac{ez_K}{\sum_{i=1}^{n} z_i^2}4\sqrt{\frac{\sum_{i=1}^{n} z_i^2}{nL_{O\Pi}^2}} \quad (10)$$

where:

e – the magnitude of the transverse displacement of the temporary load from the axis of the bridge,
z_k – the distance from the axis of the bridge to the outer run (or hinge)
z_i – is the distance to the i-th run.
n – is the total number of runs in the cross section of the superstructure
$L_{o\Pi}$ – the length of the area of the waterline of a separate floating support (or hinge of ribbon bridge)

$$K_{TI} = \frac{1}{n} + 1.86\frac{ez_K}{\sum_{i=1}^{n} z_i^2}4\sqrt{\frac{\sum_{i=1}^{n} z_i^2}{nL_{O\Pi}^2}}$$
$$= \frac{1}{10} + 1.86\frac{2.25 \cdot 4.5}{2 \cdot (0.5^2 + 1.5^2 + 2.5^2 + 3.5^2 + 4.5^2)}4\sqrt{\frac{82.5}{10 \cdot 20.84^2}} = 0.185$$

where: $L_{on}\frac{A_0}{B} = \frac{104.2}{5} = 20.84$ m – waterline area length

The calculated bending moment in the extreme, most loaded run is:

$$M_{np} = M_p K_{TI} + M_M/n, \quad (11)$$

where M_M – bending moment in a girder run

M_p – the moment from the moving load, taken large in absolute value from the moments M and M_2, obtained when loading, respectively, the positive and negative part of the i.l.

The local bending moment arises from the action of the own weight of the superstructure (P) and the temporary load, taken as the equivalent load (ν) from the calculations of the maximum value (Mp). The local bending moment (Mm) is calculated by the formula for a three-span beam on rigid supports, and the calculated span between the axes of the supports is taken as the calculated span of the local bend.

M_M – defined from: $q_{constant} = 16.11\,\text{kN}$ – load on its own weight of the span and from $v_1 = 107.92\,\frac{\text{kN}}{\text{m}}$ – the intensity of the distributed load H-14 from the calculations of the maximum Mp, for the calculation of a three-span beam on rigid supports with a calculated span of l = 13 m.

$$M_{np} = M_p K_{TI} + M_M/n = 3907.2 \cdot 0.185 + \frac{1161.52}{10} = 839\,\text{kNm}$$

To take into account the effect of transverse beams on the joint operation of main beams, it is proposed to introduce the coefficient of longitudinal load distribution between transverse beams, Δ, determined by the finite element method according [2] to the method described in, by the beam grinder method, or by the method of elastically settling supports [6].

To determine the coefficient - Δ, a finite element model of the floating bridge span was built. A quadrangular shell FE with six degrees of freedom at the node was taken as the main FE. Such FE allows to take into account both the state of plane stress of the beams and the bending of the plate. The beams were divided by the height into several rows in the form near to square. The dimensions of the finite elements into which the slab was divided were determined by the possibility of joining with the FE of the beam. From the known value of the influence line (formula 4), the magnitude of the displacements was determined by the kinematic method in the extreme beam. After that, in the same cross section where the influence line was constructed, the found displacements were set in the continuum model of the span, and the surface of the influence of the bending moment was constructed. The calculations were performed using the LIRA software package (Figs. 3, 4 and 5).

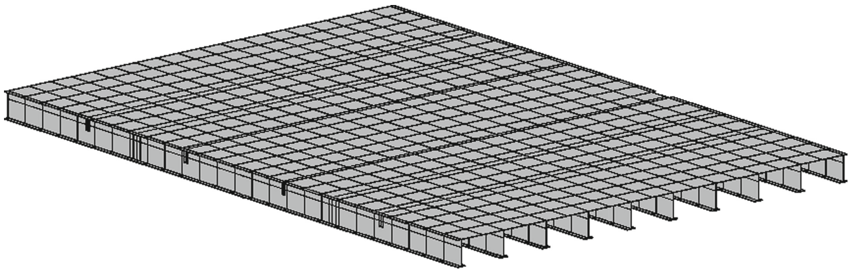

Fig. 3. Finite element model of the floating bridge span

Then:

$$M_{np} = M_p K_{TI} \Delta + M_M/n \tag{12}$$

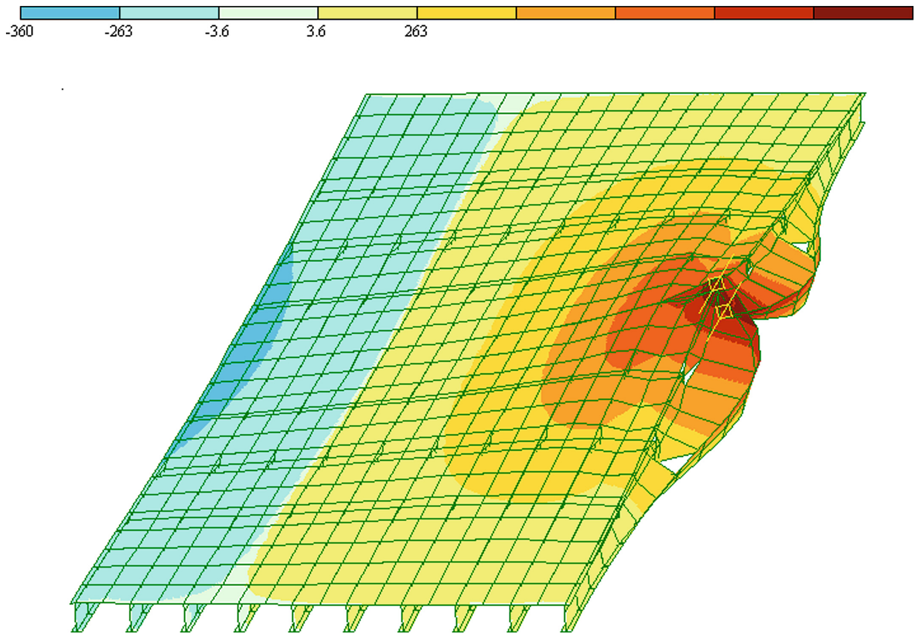

Fig. 4. The surface of the influence of the bending moment in the middle section of the continuum model of the span of the floating bridge

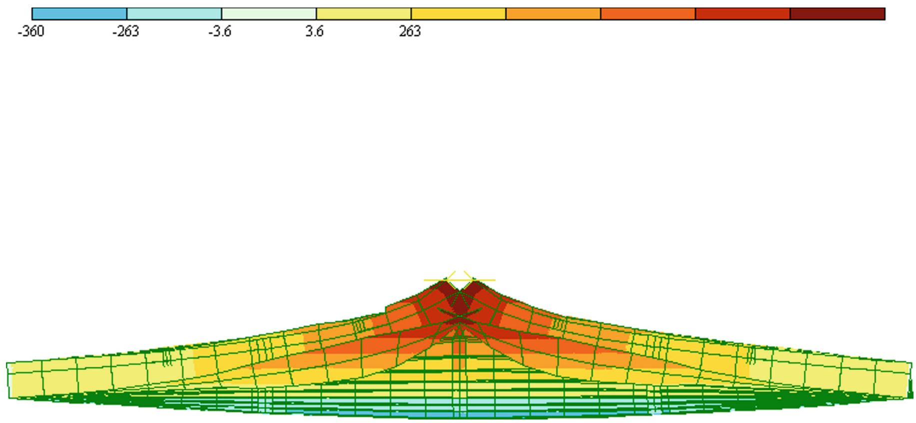

Fig. 5. The surface of the influence of the bending moment in the middle section of the continuum model of the span of the floating bridge (longitudinal cut)

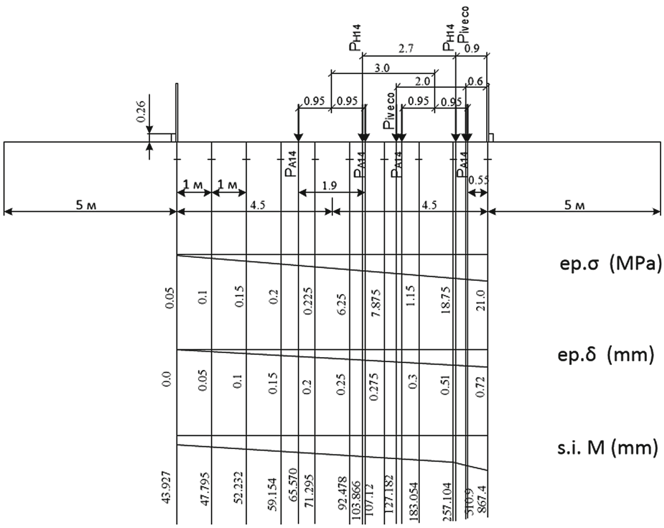

Fig. 6. The transverse loading circuit of the floating bridge: ep.σ – the diagram of normal stresses in the lower belt of the main runs from the test load; ep.δ – the diagram of deflections of the main runs from the test load; s.i.M – the trace of the influence of the bending moment in the calculated cross section to determine the coefficient Δ.

Given the proposed ratio

$$\varDelta = \frac{\max(s.\mathrm{i.M})}{\max(l.\mathrm{i.M})} \tag{13}$$

Where *max(s.i.M)* = 867.4 mm (Fig. 6) – the maximum ordinate of the surface influence of the bending moment in the design section of the beam;

Max (l.i.M) = 3970 mm – maximum ordinate of the line of influence of the bending moment in the same section of the beam (found above).

$$\varDelta = \frac{\max(s.\mathrm{i.M})}{\max(l.\mathrm{i.M})} = \frac{867.4}{3970} = 0.218$$

$$M_{np} = M_p K_{TI} \varDelta + M_M/n = 3907.2 \cdot 0.185 \cdot 0.218 + \frac{1161.52}{10} = 273.7\,\mathrm{kNm}$$

The coordinate of the center of gravity of the cross-section of the extreme beam:

$$y_C = 36.14\,\mathrm{cm}$$

The axial moment of inertia of the cross-sectional area of the outer beam:

$$J_x = 59794.5\,\text{cm}^4$$

Axial moment of resistance of the cross-sectional area of the extreme beam:

$$W_x = \frac{J_x}{y_C} = \frac{59794.5}{36.14} = 1654.5\,\text{cm}^3$$

Strength condition according to SniP 2.05.03-84*(SR 35.13330.2011) [7]:

Without coefficient Δ:

$$\sigma = \frac{M_x}{W_x} = \frac{83900}{1654.5} \cdot (10) = 507.1\,\text{MPa} > m \cdot \sigma_T = 1 \cdot 235 = 235\,\text{MPa}$$

Given the coefficient Δ:

$$\sigma = \frac{M_x}{W_x} = \frac{27370}{1654.5} \cdot (10) = 165.4\,\text{MPa} < m \cdot \sigma_T = 1 \cdot 235 = 235\,\text{MPa}$$

4 Discussion

In order to verify the accuracy of the calculation of the coefficient - Δ, and to estimate the actual work of the floating part of the combined crossing, static tests were carried out [8, 9]. The IVECO car, with a total weight of 33 tf, was taken as a test load. To estimate the actual work of the extreme runs, the load was set asymmetrically relative to the axis of the crossing [10, 11]. The deflections of the beams in the span number 3 were recorded defibomers 6 PAO. Linear fiber deformations in the sections of the main

Table 1. Calculation of load capacity of the floating bridge

Data item	H14	A14	Iveco
$\sum q \cdot w$, kNm	3397.5	986.5	
$\sum P \cdot y$, kNm		344.8	651.4
K_{TI}	0.185	0.156	0.209
$K_{TI} \cdot (\sum P \cdot y + \sum q \cdot w)$, kNm	628.54	207.83	136.14
Coefficient of transition to standard loads	0.217	0.655	–
$\sigma(M_M)$, MPa	70.2	70.2	70.2
[σ(Mp)], MPa	144.1	144.1	144.1
σ(Mp(experimental)), MPa	96.77*	32.06*	21.0
Δ - correction coefficient	0.218	0.218	0.218
σ(Mp(theoretical)), MPa	82.8	27.4	18.0
(1 + μ) · σ(Mp(theoretical)), MPa	95.22	31.51	21.7
Construction coefficient	0.7	0.23	0.15

*the values are determined through the transfer coefficient from the test load.

Table 2. Deflections in the middle span of the extreme beam

Load	Experimental, mm	Theoretical, mm	
		K_{TI} (theoretical) = 0.209	K_{TI} (experimental) = 0.259
Iveco	0.72	0.624	0.773

beams were measured using hour-type indicators (mesur) with a division value of 0.01 mm on the basis of 420 mm and Huggenberger strain gauges mounted on the lower shelf of the main beams [12]. Indicators were installed only in the span number 3 on the beams B6, B8, B10.

Tables 1 and 2 show the results of testing and calculating the span of the bridge section of pontoon structures. In Table 2, the theoretical deflections of the extreme beam are determined taking into account the dynamic coefficient $(1 + \mu) = 1.15$ [13, 14], the coefficient Δ and the coefficient of transverse installation (Кti).

Comparison of theoretical and experimental values of temporary load stress showed the proximity of the results, which indicates the correctness of the inclusion of the coefficient Δ in the formula of the calculated bending moment.

5 Conclusion

Methodology has been developed for taking into account the effect of transverse beams on the joint operation of the main beams of the metal pontoon structures of the hinge structure of floating bridges by introducing a correction factor Δ into the formula for the calculated bending moment.

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Measurement Method of the Reflected from Highways Noise in Urban Buildings

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Abstract. The main purpose of the article is to justify the choice of methods for calculating the reflected noise that occurs in the main building from highways and railways. Methods using a diffuse model of sound reflection from noise barriers are considered. The methods are based on the use of the Kuttruff integral equation and homogeneous Markov chains. It is shown that the use of the integral equation, if necessary to ensure the required accuracy of the calculation of reflected noise leads to certain difficulties associated with the need to create, store in computer memory and process large amounts of information. More convenient in this case is the calculation of reflected noise based on the Markov chain method. In relation to the posed problem, a probabilistic model of homogeneous discrete Markov chains is considered. An algorithm for solving the problem using this model is given. The accuracy of the Markov chain method relative to the method based on the Kuttruf integral equation is estimated. It is established that the simplifications made in the Markov chain method have a small effect on the accuracy of determining reflected noise levels. The discrepancies do not exceed ±1.5 dB for the situation considered in the article. Moreover, the use of the Markov method significantly simplifies the preparation of the initial data and reduces the calculation time. For these reasons, the method is recommended to be used when calculating the reflected noise generated within the large primary areas with a free layout of multi-storey buildings.

Keywords: Highways · Near highway building · Noise pollution · Markov chain · Equation Kuttruff · Calculation

1 Introduction

One of the main sources of noise pollution in urban areas is automobile and rail transport. For this reason, noise reduction in the near highway buildings is an important environmental task of modern urban settlements. Noisiness occurs as a result of the direct arrival of direct sound from the highway and the formation of the reflected noise component as a result of multiple reflections of sound from the surfaces of buildings and from other objects located on the territory [1].

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For the calculation of direct sound, there are quite reliable methods described in the normative and reference literature [2, 3]. Based on them, when choosing planning solutions for near highway construction, simple engineering calculation methods are used. In automated design, computer programs that implement calculation methods of varying complexity are used [4–7]. It should be noted that the choice of the method for calculating direct sound is influenced by the planning structure of the near highway territory. For example, in low-rise buildings, the calculation of direct sound can be performed based on techniques that take into account the quasi-cylindrical nature of the attenuation of sound energy [8–10].

Calculation of the reflected noise component is a more complex and time-consuming task. For this reason, most often, the reflected component in the total noise is taken into account according to simplified methods in the form of additives to direct sound levels. In computer modeling, the reflected component is also most often taken into account in the form of additives to direct sound or to background noise available in the building area. In some software products, the calculation of reflected noise uses geometric acoustics and, in particular, the ray tracking method [11]. However, as the practice of using such programs shows, with an increase in the complexity of calculations, their accuracy increases insignificantly [6]. The mirror model of sound reflection used in the calculations does not correspond to the actual nature of sound reflection from the surfaces of building facades. The complex surface of the facades leads to a chaotic, difficult to predict nature of reflection.

The reflection of sound from fences has complex spatial dependencies, determined by the shape of the surface, the structure of the material, the angle of incidence of sound. This is why in practice, in the development of calculation methods, number of different conditional models of sound reflection are used, shown in Fig. 1 [12].

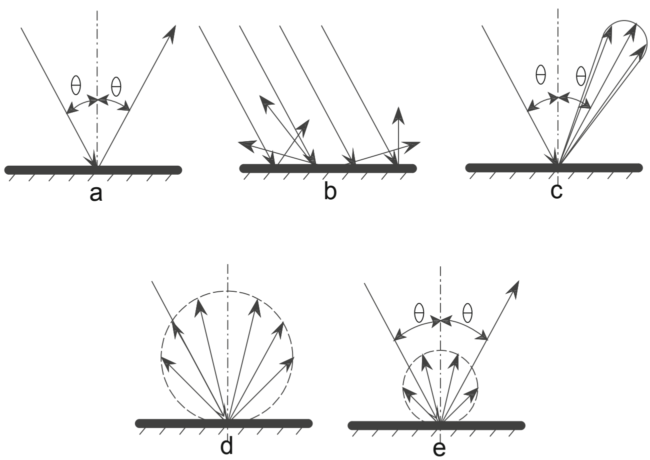

Fig. 1. Models of sound reflection from fences: a - mirror; b - randomly directed; c - directionally scattered; d - scattered according to Lambert's law; e - specularly scattered

Glazed sections of the facades with complex indicatrixes of the distribution of reflected sound energy occupy a significant area of the surfaces of the facades and consequently contribute significantly to the distribution of reflected energy. Depending on the ratio of the sizes of the scattering elements and the wave-length, all possible forms of reflection can be expected. When calculating reflected sound fields in a building, based on the practice of assessing the noise regime inside built-up areas [13–15], it is advisable to adopt a diffuse model of sound reflection corresponding to the nature of reflection according to Lambert's law. In this case, it is possible to calculate the reflected sound fields arising between the buildings using the Fredholm integral equation of the second kind [16], which Kuttruf used to calculate the sound fields in the rooms with diffuse reflection of sound from fences [17]. In particular, the Kuttruff integral equation is currently used to estimate the energy characteristics of non-constant noise fields in rooms [18] and to calculate the reflected noise that occurs in buildings, for example, between screens and the first echelon of buildings [19].

The use of the integral equation to calculate the reflected noise in the main building when it is noisy by auto- and rail- transport meets significant difficulties. In this case, the estimated area, as a rule, covers a significant territory with a large number of buildings. Consequently, while calculating it is required to create, store in computer memory and process large amounts of information. To calculate the noise in such a building, we propose to use the method of homogeneous Markov chains. In [20], it is indicated that the probabilistic model of homogeneous discrete Markov chains can be used in solving problems of building acoustics. With reference to the calculation of reflected sound in urban development, the Markov chain method can be considered as a kind of integral equation, when the surfaces of facades act as elementary surfaces, and the magnitude of the reflected sound energy is determined based on the calculation of the probability of its exchange between the facades.

2 Computational Model of Reflected Noise in Buildings Based on Markov Chains

Markov process is an any random process with discrete states, when for each moment of time the probability of any state in the future depends only on the state of the system at the current moment of time and does not depend on how the system came to this state [21]. In the energy formulation, the process of the formation of the reflected sound field in urban buildings with diffuse sound reflection from the facades is Markov, since the probability of sound energy falling from the i-th surface to the j-th depends only on how the energy is distributed at a given moment in time and completely independent of what led it to such a distribution. It should be noted that the mirror sound reflection from fences cannot be realized by the Markov process. In mirror reflection, the probability of irradiation of a specific surface depends not only on the prevailing distribution of sound energy, but also on the direction from which the incident energy arrives at the radiating surface.

Let us consider the urban area, consisting of several buildings that reflect sound energy and are involved in the formation of the reflected noise field. The initial energy distribution over the surfaces of the facades is determined based on the calculation of direct noise propagation in the construction area according to well-known patterns, taking into account the limitation of the visibility of noise sources, reduction of noise intensity with distance and the influence of the underlying soil layers. A certain contribution to the initial energy distribution will also be made by noise falling on the facades of buildings as a result of diffraction of objects shielding noise sources, for example, railways.

Initially distributed over the facades of buildings, the incident sound energy will be reflected many times from the surfaces of the facades and form a reflected sound field. From the point of view of the final distribution of the incident and reflected energy reflected from the facades, the temporal differences in the arrival of the various components of the reflected sound field are not significant. In this case, it is convenient to consider the energy state of the system as a result of the same number of acts of sound reflection. Thus, at every moment of reflection of sound rays from surfaces, the system transitions from one energy state to another. This transition, among other factors, will be determined by the model used to reflect sound from facades.

In a discrete homogeneous Markov chain, the transition of a system from a state i to j is characterized by conditional probabilities Pij, which are time independent. Thus, in order to calculate the trajectory of the states of the system in the Markov chain, it is enough to know the initial state of the system and the transition probability matrix, which has the following form

$$\{P\} = \begin{pmatrix} 0 & P_{12\ldots} & P_{1n} \\ P_{21} & 0\ldots & P_{2n} \\ P_{n1} & P_{n2\ldots} & 0 \end{pmatrix}. \tag{1}$$

In the matrix (1) $P_{ii} = 0$, since the surface cannot irradiate itself. Transition probability values P_{ij} can be calculated based on numerical integration over the surfaces of facades S_i, as the probability of the transition of sound energy from i-th to j-th surface

$$P_{ij} = \frac{W_j}{W_i}, \tag{2}$$

where W_i is power of sound energy radiated by the i-th facade

$$W_i = \int_{S_i} I dS_i. \tag{3}$$

In expression (3) J is the intensity of the radiated or reflected energy by the facade elements dS_i. The power of sound energy incident on the j-th facade is determined by integration

$$W_i = K_{ot} \int_{S_i} \int_{S_j} \frac{I \cos(\theta_i) \cos(\theta_j)}{\pi r_{ij}^2} dS_j dS_i, \tag{4}$$

where K_{om} is coefficient taking into account the influence of the underlying layer (K_{om} = 2 for asphalt or concrete pavement). The angles θ_i, θ_j and the distances r_{ij} between facade elements dS_i and dS_j are shown in Fig. 2.

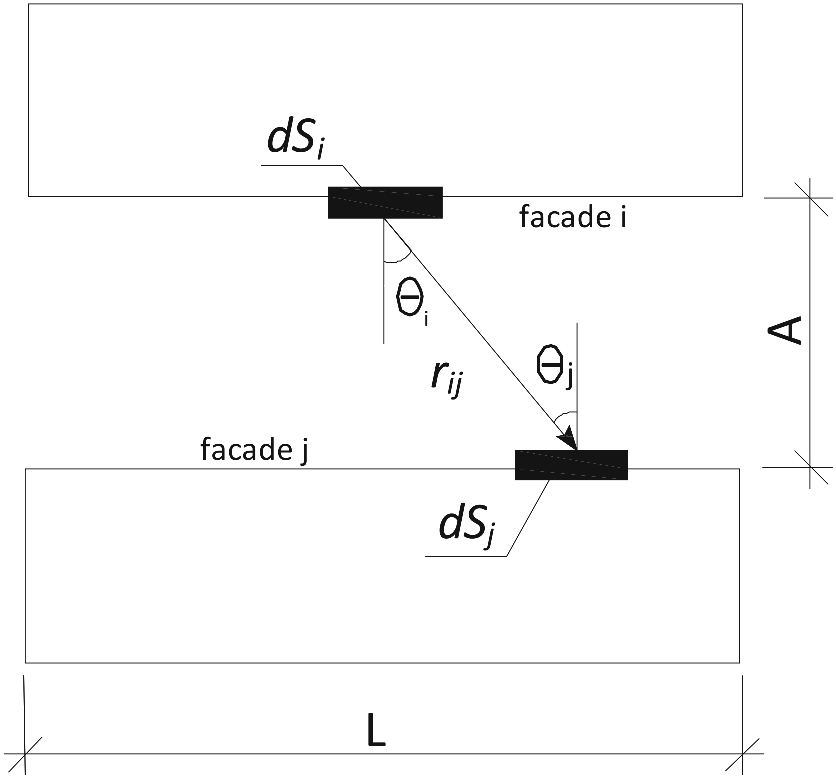

Fig. 2. Scheme for calculating probability of P_{ij}

The probability of the transition of sound energy P_{ij} depends on the distribution of the intensity of the reflected energy I, over the i-th facade, and consequently on the previous conditions for the formation of the reflected sound field. The greatest inequality of the distribution of the energy intensity I over the facades is generic for the initial energy state, which is determined by direct sound from noise sources (highways). With an increase in the number of acts of reflection, especially in the depth of the building, the uneven distribution of reflected energy over the facades decreases and can be assumed constant $I = const$. In this case, the probability of energy transfer from facade i to facade j will be determined by the expression

$$P_{ij} = \frac{K_{ot}}{S_i} \int\limits_{S_i} \int\limits_{S_j} \frac{\cos(\theta_i)\cos(\theta_j)}{\pi r_{ij}^2} dS_j dS_i. \quad (5)$$

The reliability of expression (5) determines the accuracy and applicability limits of the Markov chain method in calculating the distribution of reflected noise in urban areas.

For energy status $\bar{w} = (w_1, w_2 \ldots w_n)$ the power values of sound energy falling on the surface after several acts of reflection should be taken. The absorption of sound energy on surfaces is taken into account by multiplying the incident energy by the corresponding diffuse reflection coefficient, which can be assumed the same for all facades $\beta = 1 - \alpha$, where α – coefficient of sound absorption of surfaces.

At the initial moment, the distribution of energy power $\bar{w}_0 = (w_{01}, w_{02} \ldots w_{0n})$ is set using a vector from the results of calculating direct sound from noise sources in urban areas. After the first act of reflection, the first discrete transition from the initial energy state occurs

$$\bar{w}_1 = \bar{w}_0 \bar{P} \beta. \tag{6}$$

The corresponding vector after the *k*-acts of reflection is determined by the formula

$$\bar{w}_k = (w_{01}, w_{02} \ldots w_{0n}) = \left[\begin{pmatrix} 0 & P_{12\ldots} & P_{1n} \\ P_{21} & 0\ldots & P_{2n} \\ P_{n1} & P_{n2\ldots} & 0 \end{pmatrix} . \beta \right]^k . \tag{7}$$

Based on the known values of sound energy on each facade, you can calculate the required sound insulation of windows, as well as determine the value of the reflected sound energy at a computational point in the territory.

At computational points on the construction site, the calculation of the reflected energy density from the facades should be calculated as from flat sound sources. In article [22], an expression is given for calculating the density of sound energy from a facade, considered as a rectangular plane

$$\varepsilon_{dir} = \frac{w''(\alpha_2 - \alpha_1)(\sin \phi_2 - \sin \phi_1)}{\pi c} \tag{8}$$

where c – speed of sound in air, w'' - surface radiation power of sound energy by a noise source. The angles φ and α set the boundaries of the facade in horizontal and vertical directions. The total energy at the calculated point is determined by the formula

$$\varepsilon = \sum_{i=1}^{N} \varepsilon_i, \tag{9}$$

where N – the number of facades radiating energy to a computational point not in the building area.

3 Comparative Assessment of the Accuracy of the Calculation Method Based on Markov Chains

The Markov chain method has a number of previously indicated advantages over other methods. However, it requires verification by comparing the results of its calculations with the calculation data obtained by more accurate calculation methods.

For comparative analysis, the method based on the Kuttruf integral equation [19] was adopted as the exact method. Greater accuracy of the method is ensured by a more detailed division of the facade into individual elements *dS*, within which the intensity of radiation of reflected energy is constant, but varies throughout the facade depending on the magnitude of the sound incident on the facade.

Both methods implement a diffuse model of sound reflection from fences.

Below is an example of the results of a comparative analysis of the data obtained on the basis of the integral equation and Markov chains. The calculation is made for the space between two buildings located perpendicular to the traffic flow. The layout of buildings and roads is shown in Fig. 3.

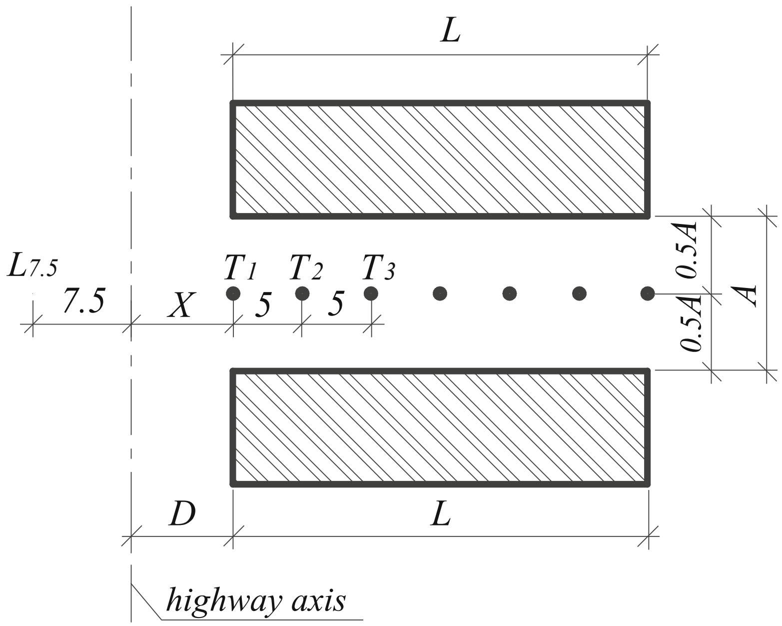

Fig. 3. Geometric computational scheme

The calculations were performed using a calculation program that implements both compared methods.

Below are the calculation results for the situation given in Fig. 3 with the following initial data: building length $L = 60$ m; building height $H = 30$ m; distance between buildings $A = 30$ m; distance from the sidewalls of buildings to the road $D = 20$ m;

average diffuse sound absorption coefficient of building facades α = 0.10; sound pressure level at a distance of 7.5 m from the axis of the road $L_{7.5}$ = 90 dB. Computational points are located in space of 5.0 m, at a height of 1.5 m from the surface of the earth.

The calculation results are shown in the graphs of Figs. 4 and 5. In Fig. 4 values of sound pressure levels of direct and reflected sound are given. In Fig. 5 the increase in sound pressure levels in the space between buildings due to the formation of reflected noise is shown.

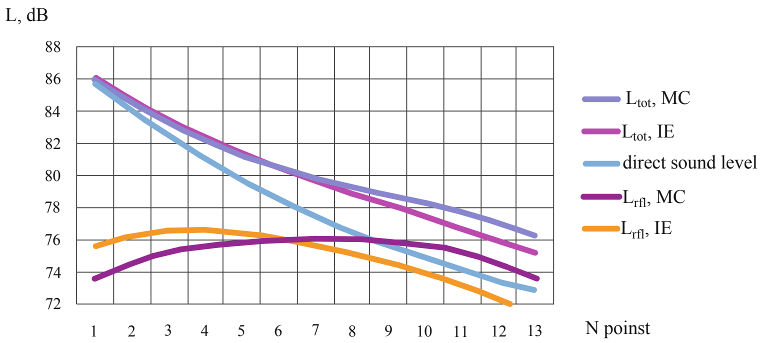

Fig. 4. Comparison of noise levels calculated by the integral equation and Markov chains: L_{tot} – direct and reflected sound level; L_{rfl} – reflected sound level

It can be seen from the graphs that the Markov chain method underestimates the levels of reflected sound in the closest to the noise source (road) and overestimates them in the furthest zone. At the same time, this increase or decrease does not exceed 1.5 dB in this planning situation. It should be noted that in the zone closest to the road, a decrease in the accuracy of the calculation of reflected noise by the Markov chain method is not significant, since direct sound energy from the road prevails in this zone.

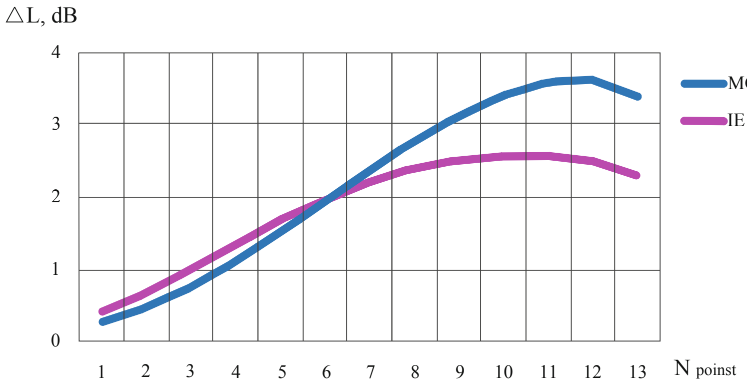

Fig. 5. Increase in total noise levels due to reflected sound calculated by the integral equation and Markov chains

From the graphs shown in Fig. 5 it is seen that the generated reflected energy significantly worsens the noise regime. Consequently, at the planning stage, it is necessary to evaluate it, taking into account the planning decision for development in the territories adjacent to the railways and highways.

4 Conclusions

In addition to direct sound, the noise mode inside the near highway building is also significantly affected by the reflected component of noise, which is formed when reflections from building facades penetrate the building by the direct sound energy of the highways. To evaluate the degree of influence of reflected noise on the noise mode of development, a reliable calculation of the energy characteristics of reflected noise is necessary.

The choice of methods for calculating reflected noise depends on the processes of formation of sound fields of direct and reflected sound for various building options. It is established that for a building of limited size, it is advisable to calculate the reflected noise by a method based on the use of the Kuttruff integral equation. A new method based on the use of the theory of homogeneous Markov chains is proposed for calculating the reflected noise generated within large territories with a free lay-out of multi-storey buildings. The method is very effective in performing calculations and at the same time provides accuracy acceptable for practical calculations.

Computer programs that allow calculating the energy characteristics of noise not only from highways, but also from other intra-quarter noise sources have been developed. The programs allow you to build noise fields on the coastal territories of development and on their basis to evaluate the acoustic efficiency of various options for noise protection measures.

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Sandwich Belt High-Angle Conveyors in Solving the Transportation Problems of Deep Open Pits

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Abstract. Along with the increase in the number of mining enterprises with open way of extraction further increase in the extraction of minerals is connected with development of new deeper ways of extraction. The complexity of mining and transportation works on the deepening of pits is constantly increasing. Thereby an important problem is the required performance of mining companies while reducing costs for delivery of the mined rock from the open pit. At the same time transportation of mined rock and its production cost are rising. Combined road-rail and road-conveyor means of transportation with traditionally designed conveyors do not solve problems for economic reasons and engineering factors.

Keywords: Conveyors · Deep open pits · Mining enterprises · Minerals · Hoisting device

1 Introduction

The share of expenses on open-cut transport in the total cost of mining currently accounts 40–60%, and the efficiency of traditional types of open-cut transport is sharply reduced. The complexity of mining and transportation works on the deepening of pits is constantly increasing. Thereby an important problem is the required performance of mining companies while reducing costs for delivery of the mined rock from the open pit.

The paper presents a design with parameters feasibility of a sandwich belt high-angle conveyor with clamping elements for the delivery of mined rock from deep pits. The main idea is to ensure the effective retention of the load from drifting downward under the action of gravity due to the interaction of the upper (clamping) belt with the lower (load-bearing) belt by developing special clamping wheeled dollies moving along the conveyor path.

The proposed design of the hoisting device significantly improves the production practices and the staff safety.

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2 Methods

The efficiency of the device was determined on the basis of the analysis of estimated efficiency, increase in productivity and operating costs, decrease in specific power/weight ratio, maintenance cost and operational reliability enhancement in the given conditions of cyclical-and-continuous method.

To lift the mined rock from deep open pits, a cyclical-and-continuous method was used. This method provides a cost reduction of 25–30% and improving labour efficiency by 2–3 times compared to cyclic methods of mining [1].

Studies have shown the relevance of solving the problem of hoisting the mined rock from deep open pits [2].

Single-bucket excavators with a straight shovel and wheeled open pit loaders are used as a cyclical element in this technology. They are currently produced in lots. Mobile crushing plants and belt conveyors are used as a production link in this technology (Fig. 1).

The considered cyclical-and-continuous method will help to solve the transport problem of deep open pits to some extent, since the cost of transporting the mined rock in this method is lower than in the continuous mining that is currently used. Thus, at an open pit depth of 200 m and an angle of inclination of the conveyor path of 40°, the transportation distance of the mineral is approximately 315 m. The high-angle conveyor uses electricity as an energy source, which eliminates the emission of harmful components of exhaust gases from the combustion of liquid fuel into the atmosphere. Dust and toxic components emissions into the air are reduced by 35–45% [3].

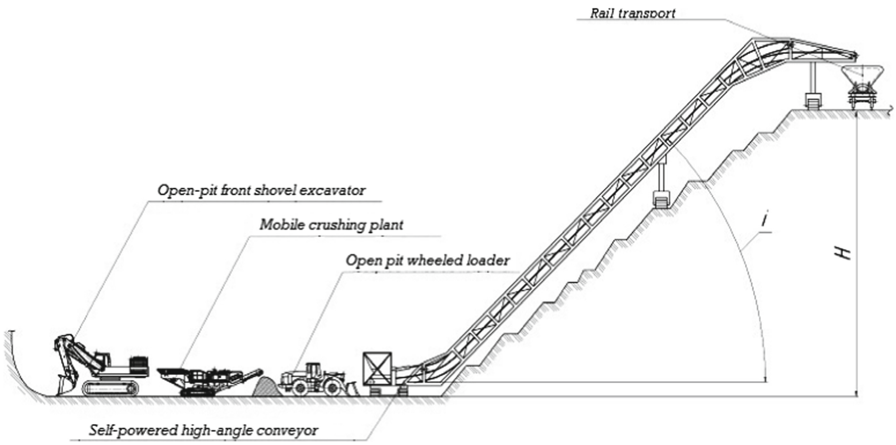

Fig. 1. Scheme of hosting the mined rock from deep open pits with cyclical-and-continuous method

It is commonly known that the cyclical-and-continuous method consists of several stages:

Stage 1 - the blasted mined rock is supplied by an open-pit front shovel excavator to the receiving bunker of the mobile crushing plant;
Stage 2 - mobile crushing plant produces crushing of mined rock to the required size and forms small dumps with crushed mined rock;
Stage 3 - wheeled open pit loader delivers crushed mined rock from the dumps to the storage hopper of self-powered high-angle conveyor;
Stage 4 - high-angle conveyor delivers crushed mined rock to the set of cars on the daylight area of the open pit for its further transportation to the Mining and Processing Plant (MPP) or to the consumer.

However, one of the drawbacks of the applied cyclical-and-continuous method schemes is the stationarity of crushing and conveyor systems, thus, their use does not correspond to the dynamics of mining operations development and the conditions of technological freight flows organization [1].

According to the published research results [4], the technology with the use of self-powered belt high-angle conveyors is the most advanced.

The purpose of this study is to propose and justify the design of belt high-angle conveyor for cyclical-and-continuous method shown in Fig. 1.

To achieve the greatest economic efficiency of conveyor transport in deep open pits, it must meet the following requirements:

– mobility - the ability to follow the loading station along the path while deepening an open pit;
– productivity - the ability to ensure the transportation of the extracted volume of mined rock to the daylight area of the open pit to the full extend;
– the shortest transportation of mined rock - to reduce the cost of transportation;
– pattern simplicity of the conveyor path - to avoid a large amount of mining and development work;
– ease of cleaning the load-carrying surface;
– ease of maintenance and repair - to avoid costly down-time of equipment in large quantities;
– safety - in case of emergency situations, such as breakage of the belt, there should be no damage to personnel, equipment and permanent structures;
– no side spillage - for best performance;
– no return of the transported material;
– environmental friendliness - no harmful emissions into open pit environment;
– hermiticity of transported material - to have a positive effect on the open pit environment.

Innovative scientific and technical research and developments are currently carried out. They are characterized by novelty and have the prospect of further development [5–10]. The greatest interest is the consideration of the requirement providing no return of the transported material from the belt of the load-bearing conveyor. In this connection, it is most reasonable to classify the high-angle conveyors according to the structural and functional characteristics of the devices that retain the load on the load-bearing element. Classification of high-angle belt conveyors according to the way of load retention is shown in Fig. 2 [11].

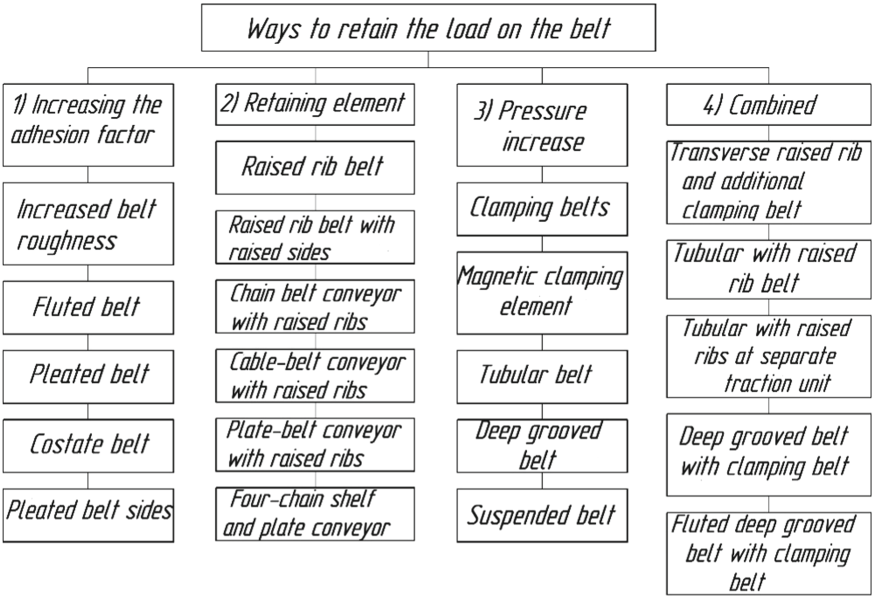

Fig. 2. Ways to retain the load on the load-bearing belt of the high-angle conveyor

From the classification it follows that the methods of load retention on the conveyor belt, such as increasing the adhesion factor coefficient of the load to the belt surface, the providing of load retaining element on the load-bearing belt, increasing the pressure of the load on the load-bearing belt - can be used individually or in a certain combination with each other [12].

3 Results

Based on the above requirements, we think that the design of the high-angle conveyor, shown in Fig. 3 meets these requirements to a greater extent and it is of a considerable interest from the viewpoint of the greatest economic efficiency of the conveyor transport application in deep open pits.

According to the proposed engineering solution, the structure shown in Fig. 3, is mobile as the conveyor frame is mounted on a self-powered caterpillar truck. To ensure the shortest distance of mined rock transportation, the conveyor path is located at a high angle (40–60°), which is achieved due to a sandwich belt conveyor mounted in the frame. Mobile sandwich belt high-angle conveyor consists of load-bearing belt, where the transported material is placed, and the clamping belt, which creates the necessary force to retain the transported material on load-bearing belt for the transportation at high angle. The sandwich belt conveyor uses smooth conveyor belts, making it easy to clean them from adhering particles using existing devices such as scrapers, cleaning rollers, etc.

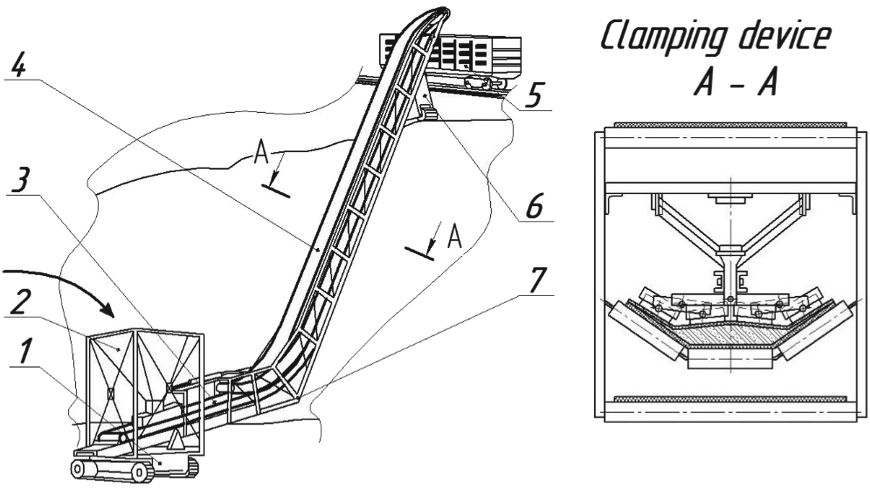

Fig. 3. The considered design of the high-angle conveyor: 1 - self-powered caterpillar truck; 2 - storage hopper; 3 - load-bearing belt; 4 - clamping belt; 5 - open wagon; 6 - dolly; 7 - conveyor frame

High-angle conveyors with clamping devices in the form of side rollers that are currently used have significant disadvantages, for example, reducing the receiving capacity of the load-bearing belt by 30–40% due to the use of its side strips about 200–250 mm wide for pressing to the load-bearing belt. These disadvantages can be eliminated by using the clamping elements that can be moved together with the transported material and press the load regardless of the height of its location in the groove of the load-bearing belt.

Our research have shown that the most appropriate sandwich belt conveyors are ones with clamping devices acting on the clamping belt, in the form of spring-loaded rollers, permanently mounted on a linear conveyor flight. They press together the sides of the load-bearing and clamping belts and the latter to the transported material. This creates the required clamping force, which prevents the return of the raising mined rock caused by gravitational forces.

The purpose of this research is to develop the design and parameters feasibility of a mobile sandwich belt high-angle conveyor with balance clamping elements for the delivery of mined rock from deep open pits.

The main idea of the work is to ensure the effective retention of the load due to the interaction of the upper (clamping) belt with the lower (load-bearing) belt by using special clamping wheeled dollies, which design is shown in Fig. 4.

Clamping devices comprise rollers equipped with ratchet mechanisms, which allow them to rotate only in one direction, and contribute to the locking of the transported material when sliding in the case of break-down. The speed of the load-bearing and the clamping belts is equalized by using a controller and sensors that measure the rate of rotation of the drive pulleys. The design of the clamping devices also contributes to the hermetic transportation of the material.

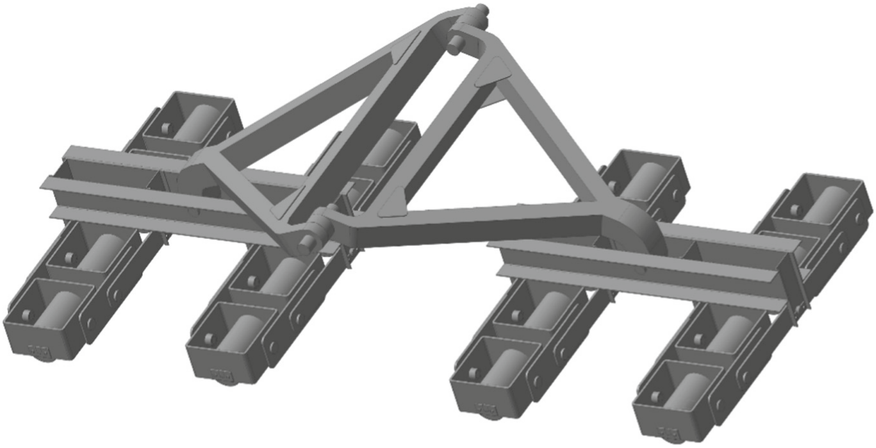

Fig. 4. The design of clamping devices – clamping wheeled dollies (the position of clamping devices in the two-belt conveyor is shown in section A – A Fig. 3)

It is possible to further increase the depth of open pit through the use of several proposed facilities located on different ledges. When the open pit reaches a greater depth than that when the proposed self-powered high-angle conveyor is able to transport the mined rock, several proposed designs located on different height ledges are used, as it is shown in Fig. 5.

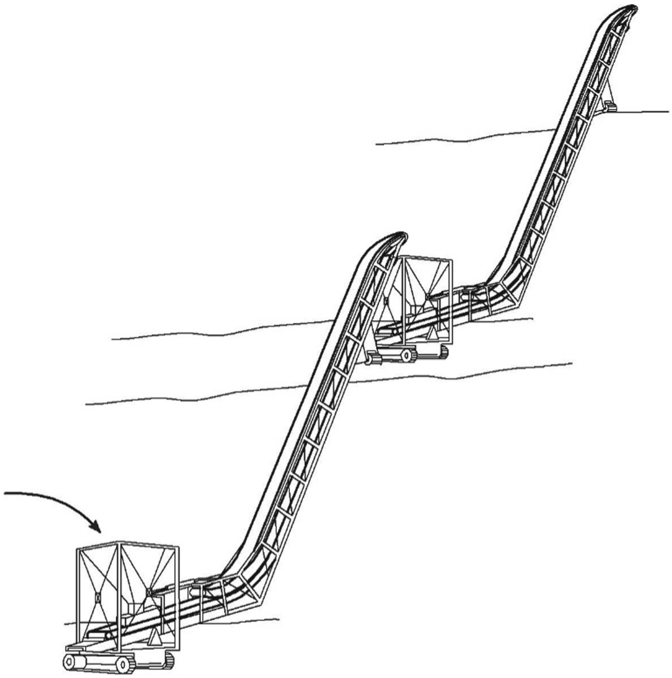

Fig. 5. Application variant of the proposed self-powered high-angle conveyor

The proposed design of a self-powered sandwich belt conveyor is installed with little to no additional mining and preparatory work on a narrow strip of the side section, which does not constrain the development of mining operations along the entire area of the open pit. When applying the proposed design does not require the laying of special trenches or going through trunks. At the same time, there are more opportunities for the arrangement of conveyor transport paths, and their configurations can combine sites with different angles of inclination.

Let us consider the special functional features of practical geometric parameters of the mobile sandwich belt high-angle conveyor.

Assume that the height of hoisting the mined rock is up to 200 m and the stationary sandwich belt conveyor is used for hoisting. The path of the stationary sandwich belt conveyor is shown in Fig. 6. We will carry out the synthesis of the path of the proposed design.

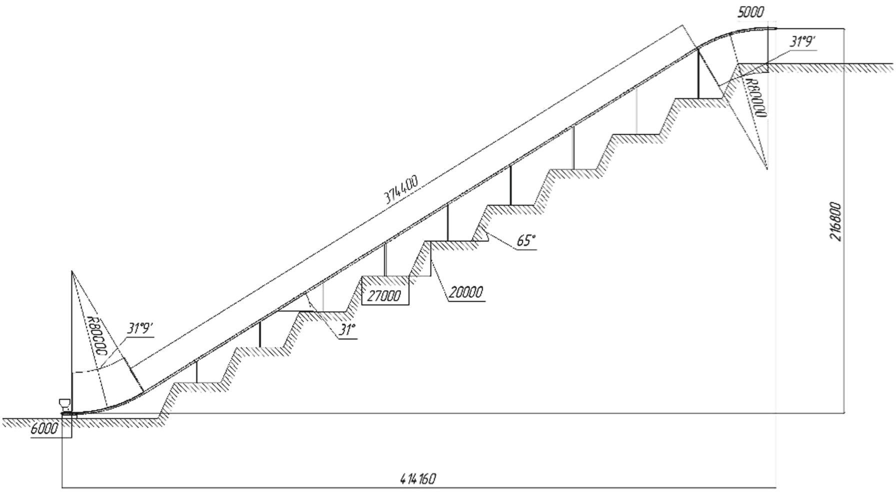

Fig. 6. Layout of the sandwich belt conveyor path in a stationary version

The layout of the sandwich belt conveyor path allows you to determine the following parameters:

- hoisting height - 216.8 m;
- length of the horizontal projection of the conveyor path - 414.16 m;
- radii of the transition sections of the path - 80 m;
- inclination of rectilinear high-angle section 31°;
- length of the rectilinear high-angle section 374.4 m;
- length of the rectilinear section of the conveyor tail - 6 m;
- length of the rectilinear section of the conveyor head - 5 m.

The parameters obtained after the synthesis of the path and a brief preliminary calculation show that only a stationary version of the conveyor is suitable for hoisting the mined rock from open pits with a depth of at least 200 m. The large length of the conveyor horizontal projection, the large size and weight of the asynchronous motor in particular, and the conveyor drive in general, do not allow you to place the driving gear device on a self-powered caterpillar truck. Driving gears of such conveyors are usually placed in separate buildings and structures specially built for this purpose. In addition, such length of the conveyor path horizontal projection requires large radii of the transition sections (up to 120 m), which requires a previously prepared working platform for placing the tail and head parts of the conveyor.

With the general tendency of increasing the specific weight of conveyors in the transport schemes of open pits, mobile conveyors with angles of inclination exceeding the angle of the natural slope of the transported material for transportation of bulk load are of increasing interest. A number of papers [13, 14] consider the cascade method of application of mobile belt conveyors in deep pits. Cascade method was considered for other modes of transport from deep open pits as well [15]. Mobile conveyors are capable of transporting mined rock at an angle of not less than 40° as a part of mobile crushing and loading complexes. An important advantage of such complexes, in comparison with stationary ones, is the absence of necessity to construct the loading points, which make up to 40% of the total costs and are “waste” when transferring [13].

A set of mobile high-angle conveyors for the transportation of mined rock from deep open pits is proposed in this paper. With a low hoisting height of one mobile conveyor, for example 30–50 m, up to 5 mobile conveyors will be required to hoist the mined rock from a depth of 200 m. The low hoisting height of one conveyor allows to reduce the dimensions of its mechanisms and the dimensions and weight of the whole structure, which will allow to place a sandwich belt conveyor on a self-powered caterpillar truck. The layout of transportation of mined rock with a set of mobile conveyors is shown in Fig. 7.

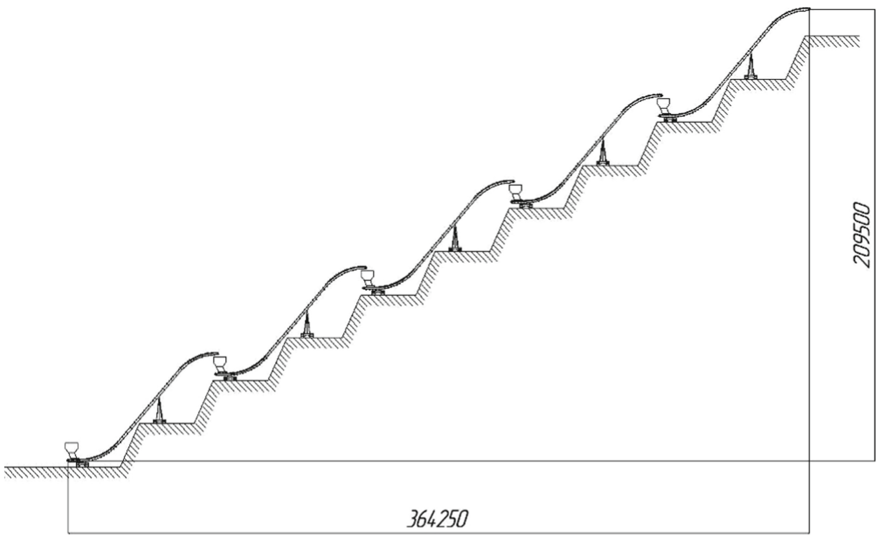

Fig. 7. Layout of mined rock transportation with a set of mobile conveyors at their cascade placement

The given layout of mined rock transportation allows to determine the following parameters:

– hoisting height of the mobile conveyors complex - 209.5 m;
– length of the horizontal projection of the mobile conveyors complex - 364.25 m.

Layout of the path of the self-powered sandwich belt high-angle conveyor, having the design as sown in Fig. 3 and being the part of the complex at a cascade arrangement is shown in Fig. 8.

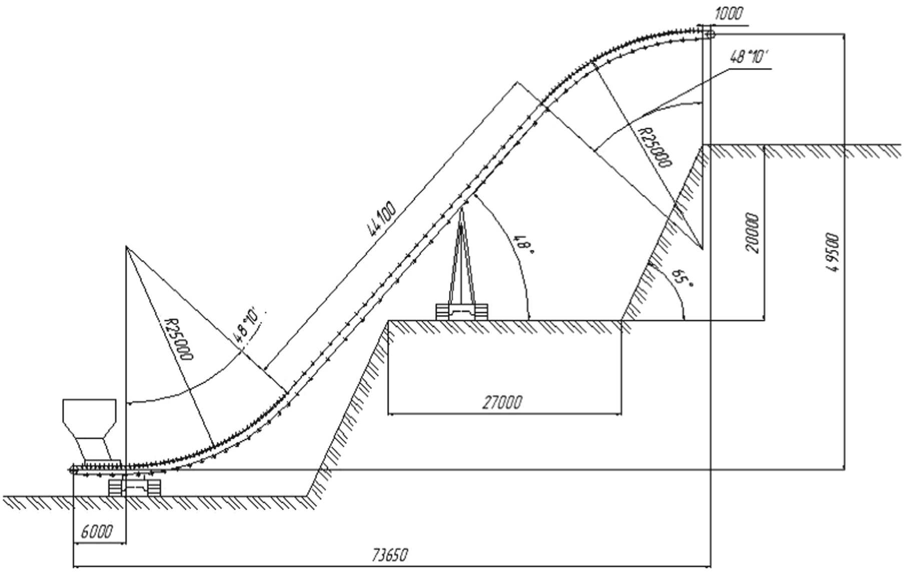

Fig. 8. Layout of the path of the self-powered high angle conveyor

Let us consider the features of determining the parameters of the path transition sections of the designed conveyor with a clamping belt. Its loading occurs on a horizontal or slightly inclined section of the path, where the traffic of mined rock is formed. The length of this section should be enough for the transported material to "calm down" on the load-bearing belt (the transported material movement stops as relating to the moving load-bearing belt due to the alignment of the transported material and the belt speeds). The transition from the loading section to the high-angle one occurs along the circular arc. The load-bearing belt on the loading section is tangent to it from one side and the high-angle section from the other side (Fig. 9).

Thus, the central angle of the transition curve is equal to the angle of conveyor inclination minus the angle of the loading section inclination $\beta - \beta_0$, and the angle at which the load begins to roll off the load-bearing belt is equal to $\beta_\delta - \beta_0$ where β_δ - the permissible angle of inclination of the belt conveyor of general purpose type.

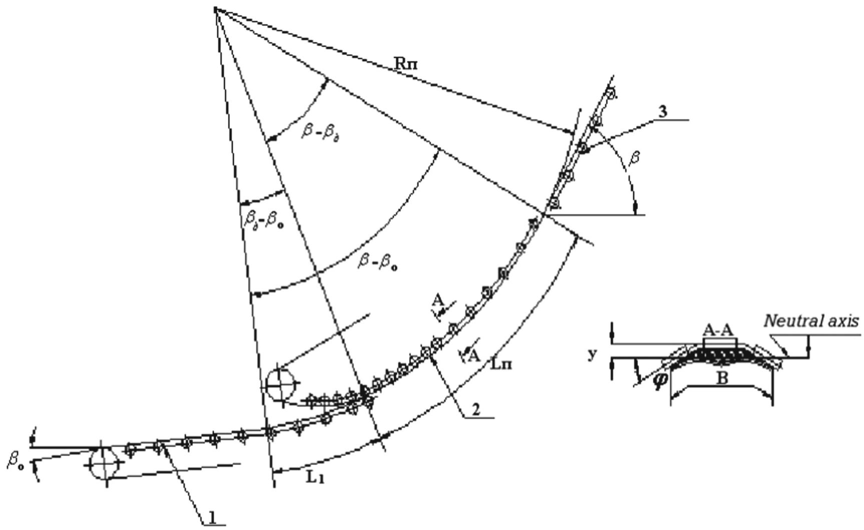

Fig. 9. Layout of the path section of the mobile high-angle conveyor at the loading unit: 1 - low-angle (loading) section; 2 - transition section; 3 - high-angle rectilinear section

Hence, the arc of the transition section with the central angle $\beta - \beta_O$ requires measures to hold the load on the load-bearing surface of the belt (Fig. 9). There are several variants of this unit, but most designs of conveyors in commercial operation have the option of pressing the load-bearing belt to the clamping belt.

While being on the arc of the transition section with a central angle ($\beta - \beta_O$), the load-bearing belt presses the load to the clamping belt with its tension until it passes to a rectilinear high-angle section with clamping elements.

Due to the complex belts configuration and the action of bending moments in two planes, part of the same belt (clamping and load-bearing) can experience both tensile and compressive forces, which adversely affects the fatigue state of the belt, since no part of the belt should not experience either excessive stress or compressive forces. The conveyor belt is not able to accept even minor compressive forces as they can cause a loss of stability of its shape, wrinkling, delamination of gaskets and, as a result, a sharp decrease in its service life. The amount of these efforts are due to the radius of the transition section and its central angle among other things.

However, the size of the radius and the angle of inclination of the conveyor determine the parameters of the transition section. Therefore when taking excessively large radii of the transition curves it is not reasonable and sometimes even impossible to guarantee the absence of excessive stress.

Let's take the following assumption. Since the depth and the width of the belt groove are significantly less than the length of the transition curve, and the supporting idlers are located close to each other, it is assumed that the neutral axis of the conveyor cross section is curved along the radius.

The tape is jointly affected by the bending moment M = EI/R (where E is the elasticity modulus of the belt, I is the moment of inertia of the belt cross section, R is the radius of the transition curve) and the tensile force (tension on the curvilinear section of the Scr), causing the resulting normal stresses. The load-bearing belt when moving with the load is under the bending action in the section of tensile forces, but the clamping belt is partially in the section of compressive forces and partially in the section of tensile forces. According to the traction diagrams the tension in the belts in the loading sections is much less than in the working section, so there is no danger of excessive stress of the load-bearing belt. In this case the only constraint for the radius feasibility of the transition curve can be the compression stresses in the clamping belt.

When starting and stopping the conveyor, as well as when the unloaded conveyor is running, the load-bearing belt on the curvilinear section is pressed with force to the clamping belt under the action of tension and it also can create compressive stresses.

To prevent excessive stresses and compressive forces in the belt, the total bending and tensile load should not exceed the maximum calculated for the accepted type of belt Smax, and should not be less than a certain minimum. To avoid the transition of the belt in the section without tension or even in the compression section, this minimum (Smin) according to published data can be taken equal to 5 N/mm of the belt width.

The arrangement of the supporting and guiding devices of the sandwich belt conveyor is shown in Fig. 10.

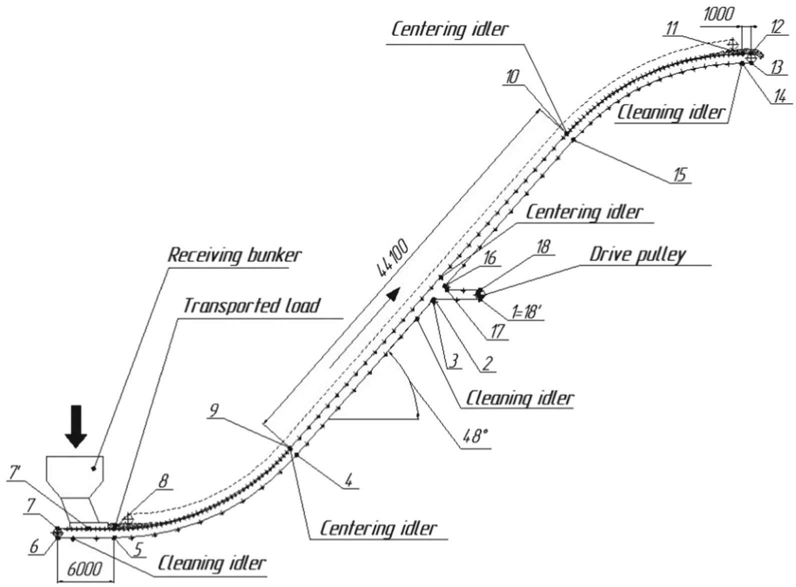

Fig. 10. The path layout of sandwich belt high-angle conveyor (the dashed lines in Fig. 10 indicate the location of the clamping conveyor).

The dashed lines in Fig. 10 indicate the location of the clamping conveyor.

Under the receiving bunker, cushion supporting idlers are installed at a pitch of 500 mm. On the transitional sections of the conveyor there are sets of supporting idlers at a pitch of 500 mm. Three-roller grooved supporting idlers are installed in rows on the loaded belt of the high angle section at a pitch of 1,500 mm. When the angle of inclination of the side supporting idlers in rows is equal to 30°, supporting idlers with an angle of inclination of 20° are installed in the transition support. One supporting idler is installed after the tail pulley in the conveyor tail and the other in front of the tail pulley in the conveyor head. Supporting idlers are installed on the idle belt in rows, at a pitch of 3,000 mm. There are three centering idlers at a pitch of 20 m on the loaded belt and two centering idlers on the idle belt as well as three ones on the idle belt of the high angle section with the same pitch. To clean the working belt surface from dry and wet particles, three disc straight idlers with metal disks are installed on the idle belt, two of them are near the tail pulleys and another one in the middle of the high angle section. To clean the inside surface of the belt, plow type double-sided rubber scrapers are installed in front of the tail pulley at a pitch of 0.8 m on an idle belt.

The path layout of the clamping conveyor and its dimensional parameters are shown in Fig. 11.

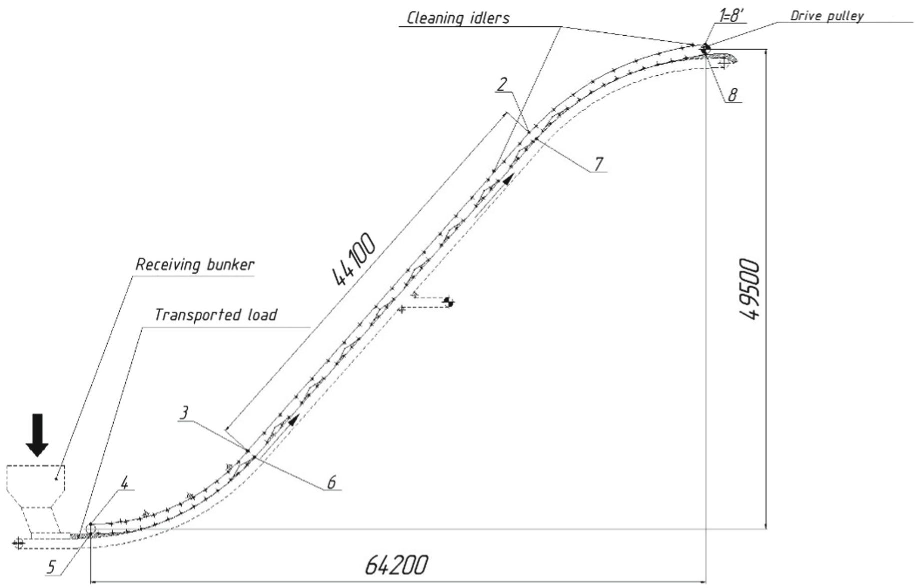

Fig. 11. The path layout of the clamping conveyor

As a traction body in the clamping conveyor, we take the same belt as in the main conveyor.

The path of the clamping conveyor consists of two transition sections (from the tail part to the inclined one and from the inclined part to the head one) and a high angle section. Ten three-roller grooved idlers at a pitch of 1,500 mm are installed in rows on transitional sections. When the angle of inclination of the side supporting idlers in rows is equal to 20°, supporting idlers with an angle of inclination of 10° are installed in the transition support. One supporting idler is installed after the tail pulley in the conveyor tail and the other in front of the drive pulley in the conveyor head. Special balancing clamping devices are installed on the clamping belt of the high angle section at a pitch of 6,000 mm with a length of clamping devices 3,600 mm. Clamping devices create the necessary pressure to prevent the return of the transported mined rock. Supporting idlers are installed in rows under the idle belt of the clamping conveyor at a pitch of 3,000 mm. To clean the working belt surface from dry and wet particles, three disc straight idlers with metal disks are installed on an idle belt near the tail pulleys.

Clamping devices (Fig. 12), comprising balance wheeled dolly, are fastened to the supporting metal structure of the sandwich belt conveyor with the help of a lever system.

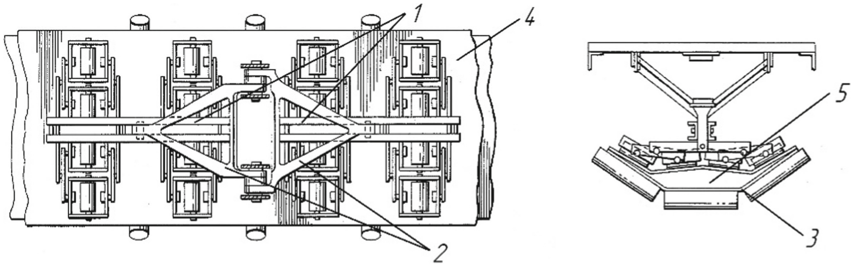

Fig. 12. The proposed clamping devices: 1 - balance wheeled dollies; 2 - lever system; 3 - load-bearing belt; 4 - clamping belt; 5 - transported mined rock

During transportation, the mined rock, having a parabolic shape in the upper part, is hermetically located between the clamping and load-bearing belts at some distance from the edges of the belt. Tightness is achieved through the use of balance clamping wheeled dollies. Their design provides uniform pressure on the load due to its weight, which helps to avoid dusting and the formation of side spillage when hoisting the mined rock. If oversized pieces accidentally get into the mainstream flow of transported mined rock, the balance clamping wheeled dollies raised by a lever system to a certain height, which allows the oversized piece to pass without loss of uniform pressure from the clamping devices and without the appearance of a high specific pressure on the clamping and load-bearing belts. The design of the rollers is quite simple and reliable since it does not require additional pressing force with springs, pneumatic cylinders, etc.

The studies of the efficiency of mining operations development presented in this paper confirmed the objective tendencies, which have already led to qualitative changes in the operation of mining enterprises.

The most revolutionary way for hoisting the material on the daylight area from deep open pits is the use of high angle belt conveyors, which makes it possible to stop using the park of overweight mining trucks. This will reduce the cost of raw materials extraction in the deep open pits by reducing the cost of transporting the extracted material.

4 Discussion

The use of high angle conveyors allows to leave the initial part of the process cyclic and to use continuous method in the following stage of transportation, replacing open-pit dump trucks with conveyor transport, while achieving a cyclical-and-continuous method.

If the using of the conveyor transport is carried out in much deepened open pits, then sandwich belt high-angle conveyor can be multi-flight (cascade) - consistently increased as the open pit deepens.

The paper describes the results of the research that was carried out and the main characteristics of the proposed design are recommended. Thereafter, the development of high-performance clamping devices of sandwich belt high-angle conveyors and mechanisms for the movement of such conveyors as part of a cyclical-and-continuous method is of interest.

As a research result of possible changes of the considered characteristics of sandwich belt high-angle conveyors the factors allowing, among others, to control the characteristics of cyclical-and-continuous method to reduce the cost of transporting mined rock from deep open pits are revealed.

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Service-Life Evaluation of Reinforced Concrete Sleepers Under Various Working Conditions

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Abstract. In the present study, we briefly describe the history of the emergence and development of ferroconcrete sleeper structures on railroad of Russia and foreign countries. Interstate standards of Russia, and Eurasian Economic Union and European Community states are analyzed. It is noted that the standards have many things in common, and they can be used in the commercial activity of Russian and foreign companies on observation of national ecological standards. With the aim of improving the field operation effectiveness, the Rossiiskie Zheleznye Dorogi Joint Stock Company (RZhD JSC) poses a task on bringing the service life of the continuous railway structure using ferroconcrete sleepers to 1.5 bln gross ton hauled. In this connection, there arises a necessity in evaluating the manufacturing quality and service life of railway sleepers being produced at the plants in Russia and other countries. For solving this problem, we have developed a procedure for evaluating the manufacturing quality of ferroconcrete sleepers at the Spetszhelezobeton Plant, BetElTrans JSC, taken as an example as well as the service life of such sleepers in operation at the Trans-Siberian Railway. As a result of the study, we have found that the railway sleepers manufactured by the Italian Olmi technology exhibited the highest values of their quality indicators. A statistical treatment of sleeper-faults data performed using a regression analysis has allowed us to reveal the dependence of sleeper gamma-procentile lifetime on the rolling-stock axle load, on the curve radius, and on the fraction of curves in the analyzed railroad section. Results of the study can find use both at the RZhD JSC and at foreign railroad companies.

Keywords: Continuous welded rail tracks with ferroconcrete sleepers · Technical requirements · Manufacturing quality of railroad sleepers · Gamma-percentile life of ferroconcrete sleepers

1 Introduction

The performance of track superstructure under present-day operating conditions is being improved along two lines: (i) development and introduction of advanced railroad components (rails, clamps, reinforced concrete sleepers); (ii) application of measures aimed at the maximum use of the working capacity of already available structures.

Issues concerning the quality and service durability of railway sleepers have always occupied a significant place in the most important national and foreign developments.

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The management of RZhD JSC poses the problem on bringing the service life of the continuous-railway structure with ferroconcrete sleepers and resilient rail fastening to 1500 mln gross ton hauled.

In this connection, let us estimate the no-failure service life of ferroconcrete sleepers under various working conditions, including those met in foreign countries.

As registered in AREA Proceedings, ferroconcrete sleepers at a main-line railway were first laid in the USA in 1896 by the Reading Company. At that time, the design of the sleepers was imperfect. Ferroconcrete sleepers gained wider application in the USA and Canada during World War II due to the shortage of wood.

In Europe, ferroconcrete sleepers were introduced at the railroads of Austria and Italy at the beginning of the XX century. Then, the process has continued at the railroads of other European countries.

The mass use of reinforced concrete sleepers at the USSR railroad net dates back to 1959, when the manufacturing of standard S-56 railway sleepers was initiated at newly built specialized plants. From that time on, a steady growth of the use of reinforced concrete sleepers has been continued.

Till the year of 1959, numerous performance tests of reinforced concrete sleepers of various types and designs have been carried out at national railways. Those tests had shown that it was string concrete ties that were the best sleepers satisfying the operating requirements in terms of the main characteristics of sleepers to the largest degree. By the results of the tests, the standard design of S-56 reinforced concrete sleepers was approved; the basic design features of those sleepers are now retained in modern standard railway sleepers.

Further development of the ferroconcrete-sleeper design was continued on the basis of research activities that were carried out on the basis of the large testing area of laying and many-year operation of reinforced concrete sleepers. By the results obtained, some structural improvements were introduced into the design of standard reinforced concrete sleepers.

For establishing particular quantitative dependences of the outage of reinforced concrete sleepers on various factors, special inspection activities on railroad sections with various operating features have been under way over a period of years. For instance, as a result of an analysis of many-year inspection activities over the damage and outage content of reinforced concrete sleepers having been conducted by Railroad Inspection Station No. 7 of the Railroad Directorate General of the Ministry of Railways, empirical dependences of the mean outage (L, sleeper/km) of ferroconcrete sleepers on the hauled tonnage (T, mln gross ton) were obtained in 1973. For S-56-2 railway sleepers, this dependence has the form.

$$B = 0.16\left(\frac{T}{100}\right)^{2.5} \quad (1)$$

In 1987, in the USSR railroads the reinforced concrete railway sleepers were operated over a track length of more than 55 thousand kilometers (112.7 mln sleepers).

According to statistical data, over a period of 16 years the total outage of standard string concrete ties has reached a value of 3.2%. According to the newly adopted classification of ferroconcrete-sleeper defects, about 60% of this value was due to operation-induced defects whereas the rest 40%, due to technological defects.

The operating defects involve tree-nail faults – wear and shrinkage of wood, screw fracture (about 20% of the total amount of all faults), longitudinal cracks and splits of the concrete in the tree-nail zone and in other regions (more than 10%); longitudinal cracks in the concrete at the butt ends of sleepers and in their middle part propagating along the steel direction (about 15%); transverse cracks in the middle part of sleepers (about 11%), and others.

Defects due to technological factors include the following flaws: transverse cracks in the rail part of sleepers propagating due to insufficient concrete pre-stressing; factory concrete spolling proceeding along cracks originating during the sleeper production process; concrete mixture preparation induced defects; insufficiently long freeze-thaw durability of concrete, violation of sleeper fabrication process, in particular, insufficiently large thickness of the protective concrete bed, etc.

Ferroconcrete sleepers are widely used in the majority of foreign countries. The designs of such sleepers are rather numerous and versatile. Below, we will only restrict ourselves to a general description of the designs.

Like in Russia, most frequently used railroad sleepers are pre-stressed rectangular sleepers. Apart from such sleepers, lesser (yet large) amounts of non-prestressed ferroconcrete double-block sleepers are being used abroad. Such railroad sleepers are used in France, Spain, Sweden and, also, in some African and South-American countries.

Typical of most railroad sleepers is a simplest shape without any projections to protrude beyond the main pre-stressed rectangle with smooth transitions from one section to another. Normally, the sleeper height in the rail part is larger than that in the middle part. In many designs, the sleeper width increases toward the sleeper ends.

An exception from this rule is railroad sleepers with the so-called "ears" and "ties" provided to enhance the resistance of structure to the lateral slip and enlarge the bearing area [1].

Abroad, it is believed to be more rational to use longer and heavier ferroconcrete sleepers in lines with high train speeds. Typical in this respect is the example of Germany railroads. Till 1955, the first ferroconcrete sleepers in Germany had 2.3-m length, their mass reaching 230 kg. In recent years, 2.6-m long B70 sleepers with a mass up to 280 kg were used. Today, there are reports mentioning the fabrication and testing of 2.8-m long B75 sleepers with 400-kg mass. Similar tendencies are observed in some other countries.

The purposes, the basic principles and the procedure for interstate standardization in Russia are defined by Russian Standard. The standard on ferroconcrete sleeper in force in Russia is an international one used by other countries in accordance with their respective codes according to International classification (ISO 3166) 004-97: AZ (Azerbaijan), AM (Armenia), KG (Kirghizia), RU (Russia), TJ (Tajikistan).

Within their commercial activities, the European countries Max Bögl, Vossloh, Alstom, Olmi and others are capable of producing ferroconcrete sleepers based on the EN 13230–1:2016 standard as applied to the national conditions in accord with the EN ISO 14001 ecological management system with codes of their countries: I.S. (Ireland), DIN (Germany), NF (France), NS (Norway), UNI (Italy), NBN (Belgium), SN (Switzerland), SS (Sweden), ONORM (Austria), UNE (Spain), NEN (Netherlands).

The Russian Standard and EN 13230–1:2016 standards have many things in common in terms of the requirement to sleeper structure, concrete and concrete reinforcement quality, and fabrication technology. A fundamental difference here is the Russia and European rail gauges for which the sleepers are intended.

In producing manufactured articles, their additional tests and, also, concrete tests aimed at the insurance of their long service life under recurring loads and atmospheric actions are carried out.

Abroad, two new types of coupling members have found widespread use in ferroconcrete sleepers [2]:

1. polymer dowels. Such dowels are widely used at railroads in Japan and Germany. Plastic dowels are often designed as replaceable components. On the outer surface of such dowels, special threading is provided to allow the dowels to be screwed into and screwed out of the sleeper.
2. metal staples or other special components rigidly clamped with one end in the concrete and coming, with its other end, to the sleeper rail seat surface. The most known example of such coupling members is the Pandrol rail fastening that has gained wide acceptance at railroads in Great Britain and some other countries.

At railroads, DB AG sleepers fabricated from pre-stressed ferroconcrete were recognized as most economical ones. The predicted service life of such sleepers (not less than 40 years) was confirmed by the using practice. The lifetime costs of such sleepers are between the values for wooden and steel sleepers. Due to their properties and high-quality fabrication technology, the ferroconcrete sleepers in the DB AG railroad net proved to be highly reliable structural components. Today, at sleeper maintenance the damaging mechanisms and crack propagation laws are being investigated both experimentally and within the framework of field observations. Simultaneously, crack detection and identification processes are being automated. In publications [3–8], results of theoretical and laboratory studies of the impact of reinforcement tension and freeze-thaw processes on crack formation and propagation and on sleepers longevity were reported.

For improving the longevity and ecological compatibility of pre-stressed ferroconcrete sleepers, designs with partial replacement of Portland concrete with alkali-activated and granulated blast-furnace slag were analyzed [6, 7].

All domestic railroad sleepers in Russia are pre-stressed rectangular sleepers with straight wire reinforcement without anchoring (string-concrete sleepers). Such sleepers are intended for application with R65 rails in straight and curved lines of not-less-than-350-m curve radius. In accord with Russian Standard depending on the rail fastening, ferroconcrete sleepers are classed to three types and several subtypes with some design features. In terms of production quality, the railroad sleepers belong either to the first- or second-quality class. Second-quality sleepers are allowed for use only in low-density class-V lines.

As performed measurements have shown, the track stiffness at ferroconcrete sleepers two-three times exceeds that at wooden sleepers. The latter property of ferroconcrete sleepers adversely affects the track stability and the operation of track elements.

Because of the higher track stiffness at ferroconcrete sleepers, any dynamic non-uniformity on the rail head surface or on the rolling-stock wheal develops in a dangerous trouble. The latter is manifested most brightly at rail joints, which therefore collapse more rapidly while the rail ends suffer non-uniform, intense wear. Data taken from a number of railroads show that, with ferroconcrete sleepers, individual rail outages in terms of joint-zone damages occur two-three times more frequently than those at wooden sleepers do.

For preventing the latter, as a rule, the ferroconcrete sleepers are laid in Russia's railroad only in continuous welded tracks.

The common principle of all systems suppressing the dynamic action of the rolling stock on railroad components is the use of various elastic pads. Such systems act as obstacles for frequencies exceeding the natural oscillation frequency by a factor of $\sqrt{2}$ [8].

Rail fastenings with enhanced-rigidity polymer pads improve the interactions between the wheel pair and the track structure, thus reducing the noise and vibration level [6, 7].

One of the efficient vibrodamping means is roadbed base plates, being reliable products made of high-quality rubbers 20 to 27 mm thick [8].

To satisfy the present-day and future engineering and economic requirements placed by RZhD JSC to the track-structure components, including ferroconcrete sleepers, Russian manufacturers have implemented a number of measures aimed at modernization of the manufacturing process of ferroconcrete products.

The main consumer and the only big customer of ferroconcrete sleepers and bars is the RZhD JSC, which forms the Russian market at the level of 10 mln sleepers/year. The fraction due to the third parties is 3–4%; those parties are some industrial and mining enterprises.

Under the present-day economical conditions, an acknowledged leader at the Russian market of ferroconcrete bars and sleepers is the BetElTrans (Betonnye Elementy Transporta) JSC.

The major activities of BetElTrans JSC include the production and selling of ferroconcrete sleepers of the following types:

- Sh1 – for separate KB terminal-bolted fastenings;
- Sh3 – for ZhBR-65 and ZhBR-65P (lining) fastenings;
- Sh3-D – for ZhBR-65Sh and ZhBR-65ShP screw-dowel fastenings;
- ShS-ARS – for ARS–4 anchor-type fastenings;
- Sh5-DF – for Vossloh rail fastenings;
- ShP-350 – for Pandrol rail fastenings.

BetElTrans JSC provides more than 90% of the Russian market of ferroconcrete sleepers. Other 10% are due to RZhD-Stroi and TransYuzhStroi JSC, and some Byelorussian, Kazakhstan and Ukrainian plants.

Starting from 2013 on, the production of ferroconcrete sleepers equipped with intermediate rail fastenings was initiated at all BetElTrans plants. The latter fact promotes the preservation and strengthening of the current position of BetElTrans at the market.

The guaranteed service life of ferroconcrete sleepers as defined by the Inter-State Standard is five years or 300 mln gross ton hauled. For prolonging the guaranteed service life of ferroconcrete sleepers to 10 year or the assigned life to 1.5 bln gross ton, BetElTrans has to solve the following problems:

1. to increase the freeze-thaw durability of F200-sleeper concrete (200 freeze-thaw cycles) to that of F300 sleepers and more;
2. to increase the compressive strength of concrete from Class B40 to Class B50 and B60 (and for sleepers reinforced with 9.6-mm diameter rod reinforcement, from Class B50 to Class B60); the concrete composition is to be further improved using advanced chemical additives.

One of the main leaders in ferroconcrete production is the Gornovsk Plant, being a BetElTrans department (Gornyi, Novosibirskaya Oblast). For instance, in 2015, of 9.3 mln ferroconcrete sleepers manufactured by BetElTrans, 1.8 mln ferroconcrete sleepers (or 18%) were manufactured at the Gornovsk Plant, and this fraction will keep growing.

Under the present-day and prognosticated requirements to the quality, volume and range of products, the position of "BetElTrans" JSC at the Russian market and, in the long term, at the markets of Customs-Union countries look rather stable and capable of ensuring further growth.

Along with the production lines already available at BetElTrans plants, a new semi-automatic conveyer-type production line first developed by the Olmi company (Italia) and intended for production of ferroconcrete sleepers was introduced in 2010.

The Siemens management system allows cutting of the labor force down to 15–16 persons/shift and minimization of reject frequency rate. The Olmi production line was designed to produce railroad sleepers with a fundamentally new reinforcement scheme (four rods of 9.6-mm diameter, strength class A1400ZK) – Sh-3D 4 × 10; in addition, such production lines are introduced as intended for the production of railroad sleepers with both ARS and ZhBR-65ShD rail fastenings.

The design power of an Olmi production line is 500 thousand sleepers/year at double-shift work, and the design power of the Spetszhelezobeton Plant (Gornyi), a department of BetElTrans, is up to 520 thousand sleepers/year.

2 Materials and Methods

The reliability of technical objects is ensured at the manufacturing stage and is being maintained at the stage of operation. Here, the state of the object at which the value of at least one parameter reflecting the capability of the object to execute certain functions does not satisfy specification requirements is called unworkable.

The reliability assessment of ferroconcrete sleepers at the manufacturing stage is implemented via the control of the performance quality of each process step for compliance with engineering specifications.

The sleepers are accepted for use according to the results of:

– acceptance tests;
– periodic tests;
– product approval tests.

The reliability of reinforced concrete sleepers at the operating stage is assessed using truncated-sampling fault data.

For evaluating the reliability of non-repairable objects such as railroad sleepers, probabilistic characteristics of a random quantity such as the service life t of an object from its bringing to operation to a first fault, are used. Under the service life, we understand the amount of the work having been done by the sleepers; this amount of work is measured in mln gross tons hauled.

In reliability tests of railway sleepers, the normal distribution law is most frequently used since the sleeper faults normally occur due to many factors equally affecting the sleeper serviceability. The distribution parameters for the normal law is the mean prefailure life, defined as the mathematical expectation of quantity t, Mt = Tm, and the variance of this quantity D_t. Using the statistical data on the faults, the mean prefailure life can be calculated by the formula

$$T_m = \sum\nolimits_{i=1}^{k} \frac{t_i n_i}{N_0}, \tag{2}$$

where k is the number of the service-hour intervals, t_i is the middle point of the i-th service-hour interval, n_i is the number of the railroad sleepers having failed in the i-th interval, and N_0 is the total number of test sleepers.

The statistical estimate of the variance of t is

$$D_t = \frac{1}{N_0} \sum\nolimits_{i=1}^{k} t_i^2 n_i - T_m^2. \tag{3}$$

As the measure of dispersion, the root-mean-square deviation

$$\sigma_t = \sqrt{D_t} \tag{4}$$

is also used.

The calculations are carried out using the integral (normalized and centered) normal distribution function

$$F_0(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} e^{-\frac{x^2}{2}dx}. \tag{5}$$

The variable component of the function is

$$x = (t_i - T_m)/\sigma_t. \tag{6}$$

Railroad sleepers cannot be exploited to a complete failure of all sleeper components; that is why for determining the faults distribution parameters truncated samplings are used.

In the case of a truncated sampling, when, as a result of objects tests, r increasing lifelength values ($r < N_0$) for faulted objects $t_1, t_2, \ldots, t_r$ were obtained, while after a lapse of time $t_0 \geq t_r$ $N_{0\text{-}r}$ objects remained nonfaulted. The values of T_m and σ_t can be estimated by the method of quantiles as follows.

The quantile of order P is such a value U_P of a random quantity x for which we have

$$F_0(x) = F_0(U_P) = P(0 < P < 1). \quad (7)$$

The values of the function $F_0(U_P) = P$ and the related values U_P can be found in special normal-distribution tables,

$$U_P = \frac{t_i - T_m}{\sigma_t} \quad (8)$$

and

$$t_i = T_m + U_P \sigma_t. \quad (9)$$

The subscript P stands for "probability"; in the quantile tables, the probability is specified within the interval $0.5 \leq P \leq 1$. If $P \leq 0.5$, then one can determine the quantity $1 - P$, so that

$$U_{1-P} = -U_P \quad (10)$$

and

$$t_{1-P} = T_m - U_P \sigma_t. \quad (11)$$

We assume that the outage probability of test objects during the time t_{i} is

$$F(t_i) = \frac{r(t_i)}{N_0}. \quad (12)$$

For this probability (rate of occurrences), we determine the quantiles U_P by the table and compose r equations:

$$\begin{cases} T_m + U_{P1}\sigma_t = t_1; \\ T_m + U_{P2}\sigma_t = t_2; \\ \ldots \\ T_m + Ut_{r\,Pr} \end{cases} \quad (13)$$

We solve the obtained equation system by the least-squares method. To this end, we multiply the left-hand sides of each equation of (13) respectively by $U_{P1}, U_{P2}, \ldots,$ U_{Pr} and, then, sum all the r equations together. This procedure yields the first, so-called normal, equation

$$T_m \sum_{i=1}^{r} U_{Pi} + \sigma_t \sum_{i=1}^{r} U_{Pi}^2 = \sum_{i=1}^{r} U_{Pi} t_i. \tag{14}$$

Summation of all equations in system (13) yields a second normal equation

$$T_m r + \sigma_t \sum_{i=1}^{r} U_{Pi} = \sum_{i=1}^{r} t_i. \tag{15}$$

We solve Eqs. (14) and (15) for the unknown T_m and σ_t; this procedure yields estimates for those quantities.

The confidence bounds (95%) for the found values of T_m and σ_t can be estimated by the formulas

$$\left.\begin{array}{r} T_m(max/min) = T_m \pm 2\sigma(T_m), \\ \sigma_t(max/min) = \sigma_t \pm 2\sigma(\sigma_t). \end{array}\right\} \tag{16}$$

In dependences (16), the values of $\sigma(T_m)$ and $\sigma(\sigma_t)$ are to be calculated as

$$\sigma^2(T_m) = \frac{\sigma_t^2}{N_0} f_2(k); \tag{17}$$

$$\sigma^2(\sigma_t) = \frac{\sigma_t^2}{N_0} f_3(k), \tag{18}$$

where k is the trimming ratio,

$$k = \frac{T_m - t_r}{\sigma_t}, \tag{19}$$

$f_2(k)$ and $f_3(k)$ are auxiliary functions, and N_0 is the total number of the sleepers having been inspected in the given railroad section.

2.1 Determination of the Gamma-Procentile Lifetime of Ferroconcrete Sleepers

Here, one has to solve a problem inverse to the above algorithm. Namely, given the value of fault probability, it is required to determine the corresponding service life.

Suppose that the function $F(t) = F(t_P)$ is known. To this function, a normalized function $F_0(x) = F_0(U_P)$ corresponds; here, we have $t = t_P$ and $x = U_P$.

Corresponding to the gamma-procentile lifetime of sleepers $\gamma = 97.0\%$ is the no-failure operation probability

$$P(T_\gamma) = \gamma/100 = 0.970. \tag{20}$$

To each value of $\gamma/100$, a certain quantile value U_P equal to the root of the function $F_0(U_P)$ corresponds.

As applied to the case of interest, the quantile U_P corresponds to the service life during which a given fault probability $F(t_\gamma) = 0.075$ will occur. The values of $F_0(U_P)$ and the related values U_P can be found in special tables:

$$U_P = \frac{T_\gamma - T_m}{\sigma_t} \tag{21}$$

and

$$T_\gamma = T_m - U_P \sigma_t. \tag{22}$$

In the case of interest, we have $U_P = 1.881$.

2.2 Prediction of Sleeper Faults

For ensuring safe railway operation, one has to be able to predict sleeper faults at all sleeper lifetime stages.

Consider the fault prediction technique using the normal law of sleeper longevity.

In prognostication, one has to solve the following problem: given some estimates of T_m and σ_t, calculate the point prediction of the sleeper fault probability $F(t_i)$ for service life t_i.

The sequence of calculation steps is as follows. Using the formula

$$U_{Pi} = \frac{t_i - T_m}{\sigma_t}. \tag{23}$$

we determine the normal-distribution quantile corresponding to the probability $F(t_i)$. Knowing U_{Pi}, we determine the probability $F(t_i)$ with the use of the tabulated function $F_0(x)$.

The total outage of railroad sleepers per one kilometer of continuous welded track can be calculated by the formula

$$n(t_i) = 1880F(t_i), \tag{24}$$

where 1880 is the average number of the sleepers laid in one-kilometer section of continuous welded track.

The prediction accuracy and reliability both depend on the ratio between the forecast basis (or retrospective period) and the forecast depth (or forestalling period)

$$\tau = \frac{t_y}{t_p}, \tag{25}$$

where t_y is the forestalling period and t_p is the length of the retrospective period.

The relative forecast error is

$$E = \frac{n_p - n_a}{n_a} 100\%, \tag{26}$$

where n_p and n_a are the predicted and actual sleeper-fault rates.

Normally, the higher is τ, the less reliable are the forecast results.

3 Results and Discussion

The final control of products at the Spetszhelezobeton Plant (Gornyi) has revealed nonconformance to engineering specifications (Table 1).

Table 1. Inspection data for finished sleepers

Year		2014		2015	
Sleeper type		ShZ-D	Sh3-D 4 × 10	Sh3-D	Sh3-D 4 × 10
Fraction defective in terms of defect types, %	Washer plate (dowel) deepening	0.0019	0.0031	0.0023	0.008
	Dowel/washer plate/blockout displacement	0.0034	–	0.002	0.0009
	Other geometry violations	0.0017	0.0002	0.0007	–
	Crushed stop edges, butt ends and other surfaces	0.0194	0.0019	0.0165	0.0016
	Concrete striations, swollen openings	0.0007	0.0033	0.0001	0.0005
	Honeycombs	–	–	0.0003	–
	Concrete mixture defects (various inclusions, concrete disintegration)	–	–	0.0012	–
	Lowered fracture strength	0.0007	–	–	–
	Cracks (in cross-sections, in the sole, at butt ends, on the sleeper surface, etc.)	0.0058	–	0.0058	–
	Broken strings, string slippage (rod rupture)	0.0172	0.0559	0.0103	0.0139
	Incidental defects	0.0006	0.0004	0.0007	–
Net fraction defective		0.0513	0.0648	0.0398	0.0249

Irrespective of the type of production line, almost for all main types of sleepers the total fraction of the products lacking conformity requirements varies within 0.02–0.06%. In 2015, the best quality indices were exhibited by Sh3-D 4 × 10 sleepers being fabricated by the well-rooted Olmi technology, 0.025-% fraction defective. For Sh1 and Sh3 sleepers, the fractions defective were respectively 0.046 and 0.043%.

The growth of products quality at the Olmi production line is due to implemented measures aimed at elimination of nonconformities [6]:

– crushed stop edges – improved inspection at mould cleaning and lubrication posts, at concrete pre-stressing post; mould repair; purchasing of new moulds;
– string slippage and insufficient string tension – improved inspection at string-packet tension posts; increase in input control, collaboration with reinforcement suppliers;
– violation of dowel-opening geometry – improved inspection at assembling/disassembling posts;
– violation of geometric sizes – mould repair; improved inspection at molding posts.

Unlike the Sh3-D sleepers fabricated in the Mogilev line, the Sh3-D 4 × 10 sleepers fabricated at the Olmi production line contain a lower (by a factor of 10.3) amount of defects at the stop edges of the sleepers. However, there are drawbacks in terms of insufficient string tension, string slippage, and washer-plate (dowel) deepening. In this connection, fault diagnostics is being regularly performed and measures aimed at elimination of products quality nonconformities are being introduced.

Data illustrating the variation of the fraction due to first-grade sleepers with the account of the large-scale production of Sh3 and Sh3-D 4 × 10 sleepers (since 2010) are shown in Fig. 1.

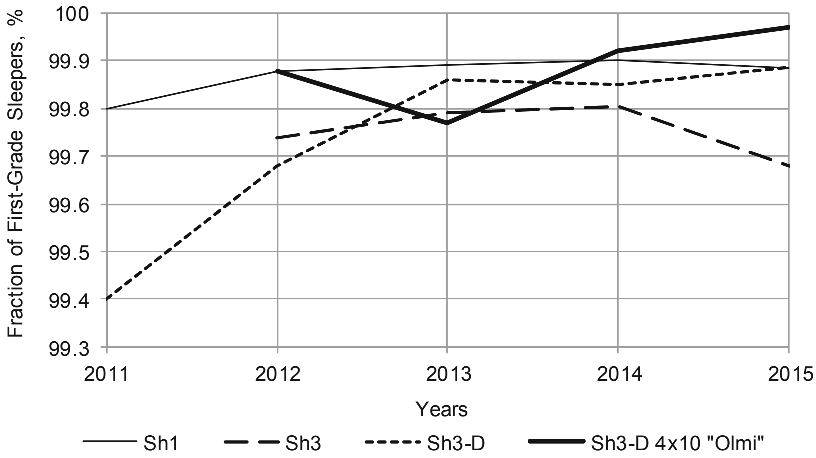

Fig. 1. Quality indices of produced sleepers

A distinct tendency toward the growth of the production output of first-quality railroad sleepers at the Olmi production line observed since 2011 due to applied measures and process developments, by 0.20% up to 99.97% in 2015.

3.1 Investigation of Operating Faults and Longevity of Ferroconcrete Sleepers

Following the introduction of a new mass rolling stock, including that with an increased axle load, the conformity of the rolling stock to longevity as well as to strength indices of superstructure elements must be estimated.

That is why primary attention was focused on the estimation of railroad safety in terms of faults of superstructure elements, including reinforced concrete sleepers in two-track railroad lines of the West-Siberian Infrastructure Management: O. – N., N. – K. (Trans-Siberian Railway).

Engineering parameters of the test sections are summarized in Table 2.

Table 2. Characteristics of test track sections

Operational direction	Technical parameters of track sections			
	Average axle load, kN	Length-weighted curve radius, m	Fraction due to the curves in the track section	Gamma-procentile lifetime of sleepers (γ = 97%), mln gross ton
O. – N., track 1	180	721	0.06	1821
O. – N., track 2	123	748	0.17	2333
N. – K., track 1	205	509	0.09	1629

The analysis of sleeper faults was performed using the Book of Laid Sleepers, 2009 to 2016 inclusive. The tonnage hauled over the local railroad sections was 100 to 1300 mln gross ton.

Data on the sleeper faults having occurred over a particular test section form a variational series of random numbers that can be considered as a function of hauled tonnage ti (Tables 3, 4 and 5). The actual fault frequency r(ti) is defined as the ratio between the total amount of accumulated faults and the length of the local section expressed in km.

The values of the normal-distribution parameters T_m and σ_t are to be determined from gained data by the method of quantiles combined with the least-squares method.

Using dependence (23) and the values of T_m found for each track section and the value of σ_t for U_P = 1.881, we have obtained the values of T_γ given in Table 2 and shown in Fig. 2.

An analysis of the data in Fig. 2 shows that, on the reduction and growth of the mean axle load with respect to the value P_m = 180 kN being typical of the Trans-Siberian Railway, the gamma-percentile lifetime of T_γ = 1821 mln gross tons will increase and decrease, respectively. On reduction of the length-weighted radius and on increasing the fraction due to curves in the track section, the value of the gamma-procentile lifetime of rails also decreases.

Table 3. Estimation and prediction of rail faults at the O. – N. line, track 1

Average axle load, kN	Fraction due to curves	Service time t_i, mln gross ton hauled	Amount of sleeper faults $n(t_i)$, events	Actual fault rate $r(t_i)$, faults/km	Predicted fault rate $r'(t_i)$, faults/km	Relative error E, %
180	0.06	200	0	0	0.0	0
		400	2	2	1.8	8.4
		600	3	3	3.2	7.6
		800	5	5	5.5	10.4
		1000	10	10	9.2	8.2
		1200	15	15	15.0	0.03
		1400	23	23	23.6	2.6
		1600	0	0	0.0	0
T_{cp} = 4017 mln gross ton; σ_t = 1167 mln gross ton; T (97.0%) = 1821 mln gross ton					E_m	6.2

Table 4. Estimation and prediction of rail faults at the O. – N. line, track 2

Average axle load, kN	Fraction due to curves	Service time t_i, mln gross ton hauled	Amount of sleeper faults $n(t_i)$, events	Actual fault rate $r(t_i)$, faults/km	Predicted fault rate $r'(t_i)$, faults/km	Relative error E, %
121	0.17	200	1	1	1.1	11.6
		400	2	2	1.7	13.8
		600	3	3	2.6	12.0
		800	4	4	4.0	0.5
		1000	5	5	5.9	18.4
		1200	8	8	8.6	8.0
		1400	13	13	12.5	3.9
		1600	18	18	17.7	1.7
T_{cp} = 5277 mln gross tons; σ_t = 1565 mln gross tons; T (97.0%) = 2333 mln gross tons					E_{cp}	8.7

A statistical analysis of T_γ data using a regression analysis has yielded the following dependence for T_γ:

$$T_\gamma = 1900\left(\left(\frac{P_{st}}{P_m}\right)^{\alpha} - \varepsilon\left(\frac{R_m}{R_{st}}\right)^{\beta}\right), \qquad (27)$$

In formula (27), P_m is the mean axle load for the rolling stock in the railway section of interest; P_{st} is the standard load at which the parameters involved in (27) were determined (P_{st} = 180 kN); R_{st} is the standard radius at which the parameters involved in (27) were determined; traditionally, a value R_{st} = 1000 m is adopted here since the

Table 5. Estimation and prediction of rail faults at the N. – K. line, track 2

Average axle load, kN	Fraction due to curves	Service time t_i, mln gross ton hauled	Amount of sleeper faults $n(t_i)$, events	Actual fault rate $r(t_i)$, faults/km	Predicted fault rate $r'(t_i)$, faults/km	Relative error E, %
215	0.09	200	0	0	0.0	0
		400	2	2	2.2	10.1
		600	4	4	4.1	1.5
		800	8	8	7.2	9.5
		1000	14	14	12.5	10.8
		1200	21	21	20.9	0.7
		1400	30	30	33.7	12.5
		1600	–	0	0.0	0
T_m = 3619 mln gross tons; σ_t = 1058 mln gross tons; T (97.0%) = 1629 mln gross tons					E_{cp}	7.5

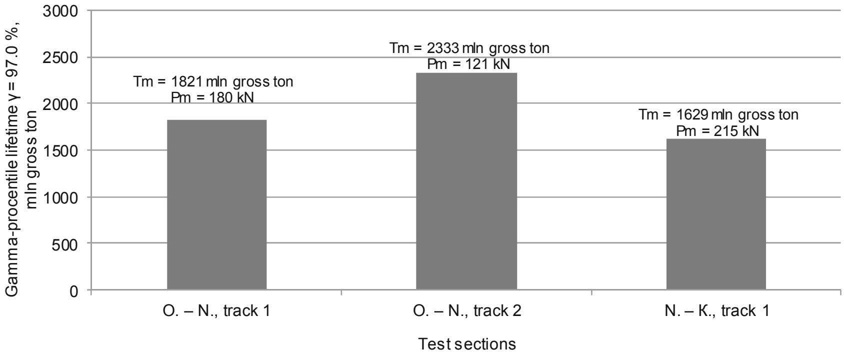

Fig. 2. Gamma-procentile lifetime (γ = 97.0%) of ferroconcrete sleepers in the test sections

rate of rail faults at such curves differs little from that at tangents; R_m is the length-weighted radius of the curves in the railway section of interest; ε is the portion due to curves per 1-km length of the railway section; and $\alpha = 0.8$ and $\beta = 1.1$ are regression parameters.

In the latter case, formula (27) will assume the form

$$T_\gamma = 1900\left(\left(\frac{180}{P_m}\right)^{0,8} - \varepsilon\left(\frac{R_m}{1000}\right)^{1,1}\right). \tag{28}$$

With known parameters of the normal distribution of rail faults according to the actual data, we can predict the outage rate of rails and calculate the relative prediction error (see Tables 2, 3 and 4). The total rail outage per one kilometer for service life t_i was calculated by formula (24).

According to this formula, the total amount of sleeper faults at $F(T_\gamma) = 0.03$ reaches 56 sleepers, this value not being in contradiction to Specifications. With further growth of tonnage, the sleeper outage sharply increases (see Tables 3, 4 and 5), leading to additional track maintenance expenditures.

Calculations by formula (28) show that the gamma-procentile lifetime ($\gamma = 97\%$) may vary in the interval $T_\gamma = 1500\ldots2500$ mln gross ton depending on operating conditions.

4 Conclusions

1. In compliance with the task posed, in the present article we have introduced a procedure for evaluating the reliability of reinforced concrete sleepers at their manufacturing and operating stages. At the manufacturing stage, the sleeper reliability is to be evaluated for compliance of every technological operation to specification requirements. The product tests performed at the Spetszhelezobeton Plant (Gornyi) for railroad sleepers of all types have revealed a 0.02–0.06% nonconformance to specifications irrespective of particular production technology. The best quality index is demonstrated by Sh3-D railroad sleepers produced by the Olmi technology (percentage of defective sleepers 0.025%).
2. As a longevity characteristic of ferroconcrete sleepers at the operating stage, the gamma-procentile lifetime T_γ from modernization (overall repair) to the serviceability limiting state with $\gamma = 97\%$ was adopted. The value of γ was adopted as a result of inspections of a 55000-km track during a period of 16 years. Over this period, the outage of sleepers due to defects has amounted to 3.2%. The assessment of sleeper reliability was performed using truncated fault sampling.
3. As a result of an analysis of sleeper-fault data taken from three sections of the Trans-Siberian Railway with different working conditions, the service life $T\gamma =$ 1900 mln gross ton, the rolling-stock axle load $P_{st} = 180$ kN, and the standard curve radius $R_{st} = 1000$ m were adopted as standard parameters. As the mean axle load decreases with respect to its standard value, the service life T_γ grows in magnitude, whereas on decreasing the weighted mean curve radius, it decreases.
4. A statistical treatment of the data using a regression analysis has allowed us to derive a formula for evaluating the gamma-procentile lifetime of sleepers versus the values of axle loads, the curve radii, and the fraction of curves in the railroad section of interest.

According to the derived formula, the gamma-procentile lifetime ($\gamma = 97\%$) may vary, depending on the particular operating conditions, within the interval of $T_\gamma = 1500\ldots2500$ mln gross ton. Under such conditions, hauling of tonnages in excess of 1500 mln gross tons is only possible over track sections where the mean axle loads do not exceed 120 kN, and the fraction due to curves does not exceed 20% of the whole track-section length.

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Porosity and Strength of Limestone Treated with Stone-Strengthening Composition

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Abstract. Since ancient times, limestone has been known as an inexpensive and reliable building material. However, there are problems associated with the restoration of historical buildings made of this natural stone. In this paper, the object of study is Crimean nummulitic limestone of natural origin and nummulitic limestone treated with stone-strengthening composition Oxal NK100. The purpose of this scientific work is practical confirmation of the improvement of the physical and mechanical parameters of nummulitic limestone, such as a decrease in porosity and an increase in strength, after its treatment with Oxal NK100. A review of literature on the problem of durability and the study of the physical and mechanical properties of limestone is presented. The porosity and strength of both types of limestone were determined experimentally, and the obtained data were analyzed. It was revealed that the composition Oxal NK100 increases the strength characteristics of the stone and slightly affects its porosity. Conclusions about the effectiveness of the use of stone-strengthening composition are made.

Keywords: Limestone · Lasting quality · Porosity · Strength · Constructional materials

1 Introduction

Limestone is one of the cheapest and most popular building materials of natural origin. It is a common sedimentary rock and has many properties, such as wear resistance, durability, ease of processing, and aesthetics.

Depending on the conditions of formation, limestone is divided into several types. One of them is nummulitic limestone. Nummulitic limestones got their name due to the presence of nummulite shells in their composition, which have a form of a coin. The deposits of these limestones are located in the Crimea and are developed mainly for wall materials [1].

It is noteworthy that the Crimean Peninsula can be called the “Museum” of ancient limestone buildings. In Sevastopol, there are the ruins of Tauric Chersonesos made of

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this variety of limestone. Also, limestone structures in cave cities between Sevastopol and Bakhchisaray have been preserved. Large halls, passages and galleries are carved from a single limestone massif. Underground cities, such as Bakla, Eski-Kermen, Inkerman, were created in limestone rocks [2–4].

Preserving the cultural heritage and preventing the negative impact of external factors in future limestone buildings is an important practical task. Some authors have devoted their work to the study of the mechanical properties of limestone. So, in their paper, Frolova Yu.V. and Arakcheeva Y.A. consider the dependence of the strength of limestone samples from the Domodedovo quarry under uniaxial compression on their absolute and relative sizes, shapes and friction at the contacts between their ends and loading plates. In the scientific work of Borodin I.N. and Abramyan A.K., a number of three-dimensional effects are demonstrated that arise during the numerical simulation of the dynamic loading of limestone samples in Hopkinson-Kolsky bars. Various fracture modes of porous limestone samples and their corresponding deformation curves were studied [5, 6].

The studies of the mechanical properties of limestone during processing of core samples by accelerated electrons are described in the works of Kondratiev S.A., Rostovtsev V.I., Kulagin O.R., and Sivolapa B.B. The ultimate strength under uniaxial loading, the static and dynamic elastic moduli, and the Poisson's ratios depending on the dose absorbed by the samples were determined [7].

The authors of Russian and foreign scientific papers are concerned about the durability of building materials. Such aspects as the safety of structural materials in time, the life of the material after the treatment with various compositions, and also after a long or short-term effect of various external factors to the material (radiation, heat, long-term static loading, etc.) are considered [8, 9], [10, 11].

Despite the widespread use of limestone in the construction industry, only a small part of the scientific work is devoted to the study and improvement of its physical and mechanical characteristics by various impregnations. There are many materials with various properties, compositions and methods of application. For example, such as latex impregnation, silicone-based impregnation, materials in the composition with various chemicals that have different effects from the application. Nowadays, it remains relevant to find new methods and materials to improve the properties of the stone and increase its durability.

In this paper, the object of study is Crimean nummulitic limestone of natural origin and nummulitic limestone treated with stone-strengthening composition. The material used, called NK100, is a strengthening gel developed by MC-Bauchemie, which is used to fix natural stone, plaster, and brick. This composition is based on silicic acid. It does not contain solvents or hydrophobic additives. Its composition allows its use on mineral and absorbent materials. The composition is used for the reconstruction of historical objects. The site requiring strengthening is impregnated with NK100 stone-strengthening composition using a sprayer.

The choice of the object of study is caused by several reasons:

1. Most Crimean historical buildings are made of limestone and sandstone.

2. Nowadays, there is an acute question of introducing new materials for the restoration of historical architectural objects that require improved operational properties that affect the durability of the building.

The paper presents the results of laboratory tests with the aim of determining the porosity and strength of the rock before the treatment with the stone-strengthening composition and after the treatment, a comparative analysis of the obtained data is performed. The results obtained make it possible to determine the appropriateness of using Oxal NK100 composition in construction.

The purpose of this scientific work is practical confirmation of the improvement of physical and mechanical parameters of nummulitic limestone, such as a decrease in porosity and an increase in strength, after its treatment with an Oxal NK100 stone-strengthening composition. To achieve this goal, the following tasks were set:

- Experimentally determine the average and true density of untreated limestone and limestone NK100 with further calculation of the rock's porosity;
- Conduct a comparative test of two types of limestone samples (limestone without additives and limestone NK100) with obtaining strength characteristics;
- Perform a comparative analysis of the results obtained;
- Draw conclusions on the effectiveness of the Oxal NK100 gel in relation to test samples.

2 Materials and Methods

2.1 Test Preparation

The tests were carried out using nummulitic limestone samples with the size: a = b = c = 50 mm (error ± 2 mm). Samples were color-coded and numbered according to the test. In order to obtain operational technical characteristics, the following tests were carried out:

- porosity;
- strength.

All tests were carried out in accordance with Russian State Standard GOST 30629-2011 "Facing rock materials and products. Test methods".

2.2 Determination of the Average Density

Two types of samples dried to constant weight were weighed and measured. Their volume was also determined (Fig. 1).

The average density ρ_o, g/cm^3 is calculated by the formula:

$$\rho_0 = \frac{m}{V} \quad (1)$$

Fig. 1. Powdered samples in an oven

where

m – sample weight, g;

V – sample volume, cm^3.

The average density of the rock is calculated as the arithmetic mean of the results of determining the average density of five samples.

2.3 Determination of True Density by the Accelerated Method

For testing, samples on which the average density was determined were used. Each marked sample was powdered to a grain size of 5 mm, then the obtained sample was quartered to 150 g. After that, the sample was again powdered to a grain size of less than 1.25 mm and dried to constant weight (Figs. 2 and 3).

The Le Chatelier's device was filled with water to the lower zero mark, the water level was determined by the lower meniscus. Each sub-sample was poured out through the funnel of the device in small uniform portions until the liquid level in the device, determined by the lower meniscus, rose to the filling mark of 20 ml. The remainder of the sub-sample not included in the device was weighed to within 0.01 g.

The true density ρ, g/cm^3, is calculated by the formula:

$$\rho = \frac{m - m_1}{V} \tag{2}$$

where

m – weight of the dried sub-sample, g;

m_1 – mass of the sub-sample remainder, g;

V – volume of water displaced by powder, which is equal to 20 cm^3.

2.4 Determination of the Porosity

The porosity of the rock was determined on the basis of predefined values of the true and average densities of the rock.

The porosity Vpor,%, was calculated by the formula:

$$V\text{por} = \left(1 - \frac{\rho_0}{\rho}\right) \cdot 100 \quad (3)$$

where

ρ_o – average porosity, g/cm^3;

ρ – true porosity, g/cm^3.

2.5 Experimental Determination of Ultimate Compression Strength in the Dry and Water-Saturated States

Before determining the strength, the samples were dried to constant weight and measured. To determine the ultimate compression strength of the samples in a water-saturated state, the samples were placed in a vessel with water at a temperature of (20 ± 5) °C so that the water level in the vessel was not less than 20 mm above the top of the samples. The samples were kept in water for 48 h.

The samples were subjected to compression tests on a hydraulic press. The ultimate compression strength in the dry state Rcom, MPa (kgf/cm^2) was calculated with an accuracy of 1 MPa by the formula:

$$R_{\text{com}} = \frac{P}{F} \quad (4)$$

where

P – breaking load, N (kgf);

F – cross-sectional area of the sample, cm^2.

The ultimate compression strength was calculated as the arithmetic mean of the test results of five samples.

The decrease in compression strength of the rock in the water-saturated state ΔR,% was calculated by the formula:

$$\Delta R = \frac{R_{\text{com}} - R^1_{\text{com}}}{R_{\text{com}}} \cdot 100 \quad (5)$$

where

R_{com} – average strength of samples dried to constant weight, MPa;

R^1_{com} – average strength of water-saturated samples, MPa.

The ultimate strength R_{com} was determined automatically when entering these parameters before testing on the press.

3 Results and Discussion

3.1 Results of Limestone Porosity Determination

The results of measurements of the weight of the samples and their volume are presented in Tables 1, 2 and 3.

Table 1. Weight of samples with constant weight, g

Name	Sample no.				
	1	2	3	4	5
Limestone	297.225	255.283	275.024	281.659	315.795
Limestone NK100	271.950	287.951	271.038	252.44	260.46

Fig. 2. Quartering

Fig. 3. Powdering of the sample

Table 2. Volume of raw limestone samples

Name	Sample no.				
	1	2	3	4	5
A, cm	5.25	5.11	5.10	5.20	5.12
B, cm	5.20	5.05	5.10	5.18	5.19
C, cm	5.05	5.12	5.10	5.20	5.20
V, cm^3	137.865	132.124	132.651	140.067	138.179

Table 3. Volume of limestone NK100 samples

Name	Sample no.				
	1	2	3	4	5
A, cm	5.03	5.23	5.10	5.15	5.11
B, cm	5.20	5.03	5.10	5.07	5.10
C, cm	5.15	5.23	5.20	5.01	5.20
V, cm^3	134.703	137.585	135,252	130,814	135.517

The average density of each sample of limestone:

$$\rho_{01} = \frac{m}{V} = \frac{297.225}{137.865} = 2.156\,\text{g/cm}^3 \tag{6}$$

$$\rho_{02} = \frac{m}{V} = \frac{255.283}{132.124} = 1.923\,\text{g/cm}^3 \tag{7}$$

$$\rho_{03} = \frac{m}{V} = \frac{275.024}{132.651} = 2.073\text{g/cm}^3 \tag{8}$$

$$\rho_{04} = \frac{m}{V} = \frac{281.659}{140.067} = 2.011\,\text{g/cm}^3 \tag{9}$$

$$\rho_{03} = \frac{m}{V} = \frac{251.795}{138.179} = 1.822\,\text{g/cm}^3 \tag{10}$$

$$\rho_0 = \frac{\rho_{01} + \rho_{02} + \rho_{03} + \rho_{04} + \rho_{05}}{5} = \frac{2.156 + 1.932 + 2.073 + 2.011 + 1.822}{5} = 1.999\,\text{g/cm}^3 \tag{11}$$

The average density of each sample of limestone NK100:

$$\rho_{01} = \frac{m}{V} = \frac{271.95}{134.703} = 2.019\,\text{g/cm}^3 \tag{12}$$

$$\rho_{02} = \frac{m}{V} = \frac{287.951}{137.585} = 2.093\,\text{g/cm}^3 \tag{13}$$

$$\rho_{03} = \frac{m}{V} = \frac{271.038}{135.252} = 2.004\,\text{g/cm}^3 \tag{14}$$

$$\rho_{04} = \frac{m}{V} = \frac{252.44}{130.814} = 1.930\text{g/cm}^3 \tag{15}$$

$$\rho_{03} = \frac{m}{V} = \frac{260.46}{135.517} = 1.922\,\text{g/cm}^3 \tag{16}$$

$$\rho_0 = \frac{\rho_{01} + \rho_{02} + \rho_{03} + \rho_{04} + \rho_{05}}{5} = \frac{2.019 + 2.093 + 2.004 + 1.930 + 1.922}{5} = 1.994\,\text{g/cm}^3 \tag{17}$$

The true density of limestone:

$$\rho_1 = \frac{m - m_1}{V} = \frac{100 - 46.381}{20} = 2.681\,\text{g/cm}^3 \tag{18}$$

$$\rho_2 = \frac{m - m_1}{V} = \frac{100 - 45.05}{20} = 2.748\,\text{g/cm}^3 \tag{19}$$

$$\rho_3 = \frac{m - m_1}{V} = \frac{100 - 44.521}{20} = 2.774\,\text{g/cm}^3 \tag{20}$$

$$\rho_4 = \frac{m - m_1}{V} = \frac{100 - 44.031}{20} = 2.798\,\text{g/cm}^3 \tag{21}$$

$$\rho_5 = \frac{m - m_1}{V} = \frac{100 - 46.645}{20} = 2.668\,\text{g/cm}^3 \tag{22}$$

$$\rho = \frac{\rho_1 + \rho_2 + \rho_3 + \rho_4 + \rho_5}{5} = \frac{2.681 + 2.748 + 2.774 + 2.798 + 2.668}{5} = 2.734\,\text{g/cm}^3 \tag{23}$$

The true density of limestone NK100:

$$\rho_1 = \frac{m - m_1}{V} = \frac{100 - 45.622}{20} = 2.717\,\text{g/cm}^3 \tag{24}$$

$$\rho_2 = \frac{m - m_1}{V} = \frac{100 - 47.289}{20} = 2.635\,\text{g/cm}^3 \tag{25}$$

$$\rho_3 = \frac{m - m_1}{V} = \frac{100 - 48.441}{20} = 2.561\,\text{g/cm}^3 \tag{26}$$

$$\rho_4 = \frac{m - m_1}{V} = \frac{100 - 47.993}{20} = 2.600\,\text{g/cm}^3 \tag{27}$$

$$\rho_5 = \frac{m - m_1}{V} = \frac{100 - 47.432}{20} = 2.628\,\mathrm{g/cm^3} \tag{28}$$

$$\rho = \frac{\rho_1 + \rho_2 + \rho_3 + \rho_4 + \rho_5}{5} = \frac{2.717 + 2.635 + 2.561 + 2.600 + 2.628}{5} = 2.628\,\mathrm{g/cm^3} \tag{29}$$

The porosity of limestone samples:

$$V_{por} = \left(1 - \frac{\rho_0}{\rho}\right) \cdot 100 = \left(1 - \frac{1.999}{2.734}\right) \cdot 100 = 26.89\% \tag{30}$$

The porosity of limestone NK100 samples:

$$V_{por} = \left(1 - \frac{\rho_0}{\rho}\right) \cdot 100 = \left(1 - \frac{1.994}{2.628}\right) \cdot 100 = 24.125\% \tag{31}$$

3.2 Results of Limestone Strength Determination

Table 4. Ultimate strength R_{com} in a dry state, MPa

Name	Sample no.					R_{com}, MPa
	1	2	3	4	5	
Limestone	26.56	23.26	12.52	23.68	23.36	21.87
Limestone NK100	29.43	26.29	21.05	31.95	34.44	28.63

Table 5. Ultimate strength R_{com} in a water-saturated state, MPa

Name	Sample no.					R_{com}, MPa
	1	2	3	4	5	
Limestone	4.1	6.4	8.6	8.6	8.7	7.28
Limestone NK100	22.5	29.5	9.5	14.4	20.2	19.22

The ultimate strength of two states of limestone impregnated with the composition NK100 can be represented as a histogram (Fig. 4). The histogram below shows the arithmetic mean ultimate strength of two states of both types of samples (Fig. 5). The decrease in compression strength of rock in a water-saturated state (Tables 4 and 5):

$$\Delta R_{limestone} = \frac{R_{com} - R^1_{com}}{R_{com}} \cdot 100 = \frac{21.87 - 7.28}{21.87} \cdot 100 = 66.71\%$$

$$\Delta R_{\text{limestone}NK100} = \frac{R_{\text{com}} - R_{\text{com}}^{1}}{R_{\text{com}}} \cdot 100 = \frac{28.63 - 19.22}{28.63} \cdot 100 = 32.87\%$$

3.3 Analysis of the Results

It can be seen from the calculations that the porosity of the treated samples decreases by about 2.5%. Thus, it should be assumed that the stone-strengthening gel has almost no effect on the thermal conductivity of the stone and its soundproofing properties. High porosity allows limestone to adhere well to stucco (plaster) and masonry mortars. However, the significant porosity of the stone usually indicates low strength indicators, especially in cases where moisture fills the pores. The histogram in Fig. 4 shows that the stone-strengthening composition Oxal NK100 does not equalize the strength indicators of limestone in dry and water-saturated states. Nevertheless, Fig. 5 clearly shows that the limestone impregnated with the stone-strengthening material Oxal NK100 shows a result in which the decrease in strength in the dry and water-saturated states is less than that of limestone in a similar state without impregnation. The decrease in compression strength of a stone in a water-saturated state in impregnated limestone is 2 times less than the same indicator in untreated stone. The test results allow drawing conclusions about the effectiveness of the Oxal NK100 gel, which is applicable to natural limestones and sandstones. These results confirm the need for further research of the composition on real objects to clarify, observe and evidence the effect of stone- strengthening material NK100.

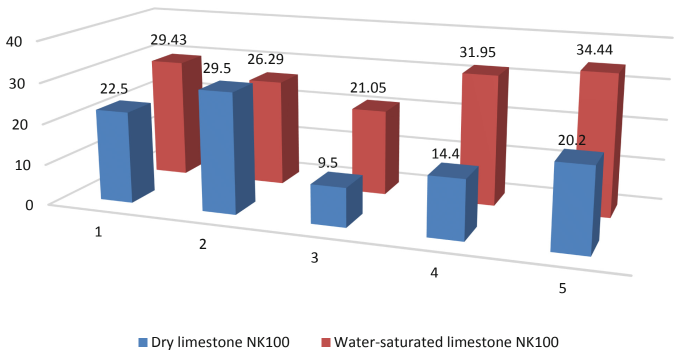

Fig. 4. The ultimate strength of two states of limestone impregnated with NK100

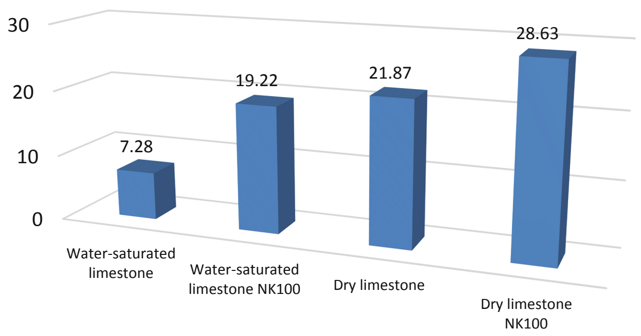

Fig. 5. The arithmetic mean ultimate strength of two states of both types of samples

4 Conclusion

As a result of the analysis of the obtained data, the following conclusions can be drawn:

1. Based on theoretical studies, there is a problem of strengthening buildings and structures made of limestone and sandstone, and also a small number of restoration methods of historical buildings made of natural stone.
2. The strength characteristics of the treated material have improved performance compared to untreated stone, since the compression strength of limestone with Oxal NK100 material is higher than that of stone without treatment.
3. The porosity of a stone treated with Oxal NK100 decreases slightly compared to a stone without stone- strengthening material.

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Artificial Intelligence for Managing Small Hydro Power Plants in Southern Regions of Siberia

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Abstract. The possibility of integrating the automatic and remote control systems for the planned small hydro power plants (SHPP) in the Republic of Khakassia is considered in this paper. The use of MATLAB SIMULINK software for dynamic modeling of hydro power plant components is considered. A simulation model of a hydro power plant has been developed in MATLAB/Simulink environment. The Matlab/Simulink hydro power model is also being transformed into RT-LAB (Real-TimeLaboratory) for real-time modeling (OPAL-RT).

Keywords: Hydropower · Modeling · MatLab · Automation · Control

1 Introduction

In the whole world, including Russia, the attention to small generation has increased. Over the past decade, problems related to the energy crisis, such as the oil crisis, as well as climate change, power demand and restrictions on sales markets have increased around the world. These difficulties are constantly on increase, which indicates the need for technological alternatives to solve them.

Small hydropower is both efficient and reliable form of renewable energy source at the same time. The Republic of Khakassia has a high hydropower potential. This region counts 324 rivers. The topography of the Yenisei valley in some places creates favorable conditions for the construction of dams and capacious reservoirs that can regulate the runoff.

In accordance with the socio-economic development forecast of the Republic of Khakassia by 2030 [1], there will be a shortage of electricity due to the planned construction of mining and processing enterprises. There is no alternative to small hydropower for power supply of new enterprises and foothill areas.

It seems fair to say that a promising direction is the construction of low-capacity hydro power plants, which do not require large capital expenditures during

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construction, have short payback periods and can provide the consumer with inexpensive electricity. The problem of providing cheap electricity remains highly relevant and is especially significant for remote areas.

At present, it is necessary to apply inexpensive and effective automation and remote control solutions when solving problems related to the reconstruction and construction of small hydro power plants (SHPP), so the power plants could be operated without the constant presence of service personnel.

With a view to the shortage of power generation, the question of finding additional generating capacity arises. In order to solve the problem of power shortages in the Republic of Khakassia by 2030, it is advisable to build low-capacity hydro power plants. Such hydro power plants will be able to completely power a small mine or a settlement and work both in the general load demand and in isolation from the power grid. Thus, power grid construction could be possibly abandoned or its volume can be significantly reduced. Studies related to the problem were analyzed in a previously published paper [2].

The dynamic model of the three following main components of a hydro power plant is presented: a synchronous generator, a hydraulic turbine and a hydroturbine regulator. The equations describing the dynamic model of a synchronous machine with regard to the Laplace transform are created by connecting the corresponding functional blocks. In order to simulate transients in a synchronous machine, new submodels have been added to create various control functions. The analytical model of the hydraulic system includes a turbine and control system.

The speed control system adjusts the generator speed based on input signals, such as system frequency deviation, and also on interchangeability with respect to the reference settings. This is necessary for the generator to always work at a nominal speed. The use of MATLAB SIMULINK software for dynamic simulation of hydro power plant components is considered in the paper. The main advantage of SIMULINK over other software is that the simulation model is systematically created using basic function blocks instead of compiling the program code. The dynamic behavior or differential equations of a synchronous machine, as well as hydro turbines, are taken into account in order to simulate the dynamics of a hydro power plant.

2 Research

The efficiency of the hydrogenerator is affected by the dynamic characteristics of the turbine hydraulic regulators when exposed to external disturbance and after its removal. Accurate modeling of the turbine hydraulic regulator is important for characterizing and diagnosing the system response in an emergency case [3]. The simulation of a hydraulic system consists of controlled proportional-integral-derivatives and proportional-integral regulators. This model investigates transients on disturbances through simulation in Matlab/Simulink [4]. The complete block diagram of a turbine hydraulic control system is presented at Fig. 1.

The speed control system adjusts the generator speed in accordance with the input signals of the current frequency deviation and power relative to the reference settings. This is to ensure that the generator operates at rated speed [5].

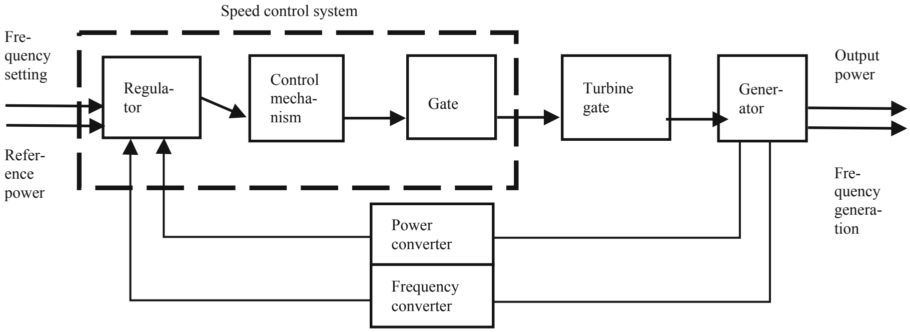

Fig. 1. Functional block diagram of a hydropower plant

Due to the load change throughout the day, the frequency of the current in the power system varies. A turbine regulator is used to maintain a constant turbine speed. The turbine regulator adjusts the water feed into the turbine, which, in turn, rotates the generator to produce electricity [3].

Let us consider an analytical model of a hydraulic control system that includes a turbine and a control system. Hydro-turbine systems are strongly affected by water inertia [4]. The servo-motor controls the auxiliary valve in order to regulate the gate opening, The servo-motor is activated by signals generated by the turbine regulator. Expression (1) is obtained according to the assumption of a minor hydraulic shock and incompressible fluid flow through the conduit [3]. It defines the flow characteristics per turbine unit in terms of the time constant of water and pressure:

$$\frac{dq}{dt} = (h_s - h - h_l)\frac{gA}{L} \tag{1}$$

where q – turbine flow, m^3/s;
h_s – static water head, m;
h – entry head of the turbine, m;
h_l – friction losses, m;
L – the length of the water head, m;
A – the cross-sectional area of the conduit, m^2;
g – gravitational acceleration, m/s^2.
The function of flow and turbine torque is described by the following expressions:

$$Q = Q(H, x, y); \tag{2}$$

$$M_t = M_t(H, x, y), \tag{3}$$

where Q is the flow velocity, m/s;
M_t – turbine torque, $N \cdot m$;
H – pressure turbine, m;
y – gate opening, m;
x – turbine velocity, m/s.

When the turbine characteristics change in a small range at a stable operating point, the functions of torque and flow velocity will be written as follows in the linearized form:

$$q = e_{qy} \cdot y + e_{qx} \cdot x + e_{qh} \cdot h \tag{4}$$

$$M_t = e_y \cdot y + e_x \cdot x + e_h \cdot h \tag{5}$$

where $e_y = \frac{\partial m_t}{\partial y}$ – partial derivative of the torque from the gate opening;
$e_x = \frac{\partial m_t}{\partial x}$ – partial derivative of the torque from the turbine velocity;
$e_h = \frac{\partial m_t}{\partial h}$ – partial derivative of torque from the turbine head;
$e_{qy} = \frac{\partial q}{\partial y}$ – partial derivative of the flow from the gate opening;
$e_{qx} = \frac{\partial q}{\partial x}$ – partial derivative of the flow from the turbine velocity;
$e_{qh} = \frac{\partial q}{\partial h}$ – partial derivative of the flow from the turbine head.

The proportional-integral-differentiating (PID) controller is used in this model. The velocity error is given to the controller input, and the PID controller attempts to reduce the difference between the actual and the nominal velocity by adjusting the controller constants. The name of the PID controller comes from three functions involved in the correction computing, and, accordingly, it is sometimes called by three control terms: P denotes proportional, I denotes integrator, and D denotes derived controls. These values can be interpreted in terms of time, P depends on the current error, I depends on the accumulation of past errors, and D is a forecast of future errors based on the current rate of change [5]. The output of the PID controller is recorded as an error signal (6):

$$\theta(t) = k_p e(t) + k_i \int e(t)dt + k_d \frac{de(t)}{dt} \tag{6}$$

The following can be obtained considering the Laplace transform:

$$\theta(s) = k_p E(s) + k_i \frac{E(s)}{s} + k_d s E(s) \tag{7}$$

The transfer function of the PID controller:

$$C(s) = \frac{\theta(s)}{E(s)} = k_p + \frac{k_i}{s} + k_d s \tag{8}$$

where $\theta(s)$ is the output of the PID controller, a signal of the controller position.

The model of the controller is shown at Fig. 2.

In the turbine model, the servo-motor controller is used in order to control the gate according to the controller signal. The controller eliminates the velocity signal error by sending a signal to the servo-motor to control the gate [6].

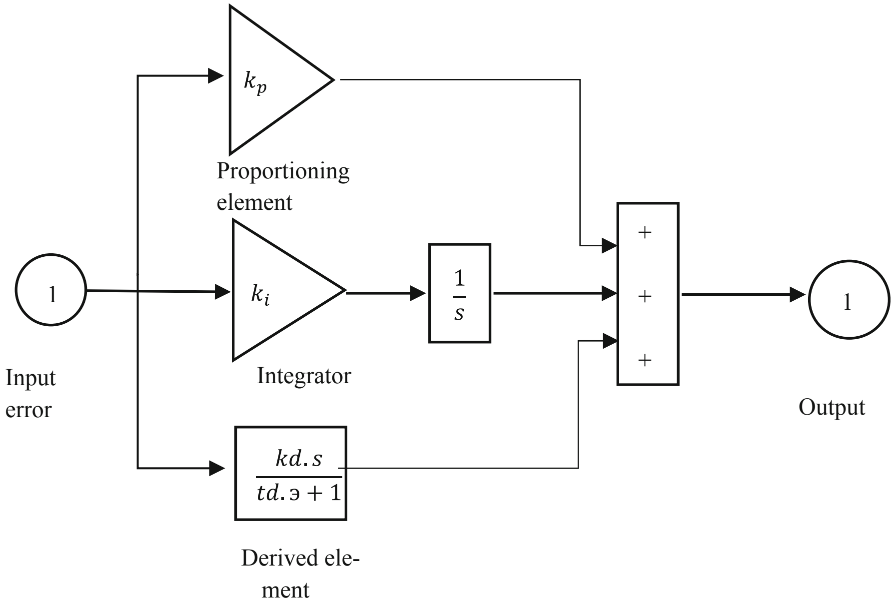

Fig. 2. Controller model

Engine torque is a function of velocity and error signal:

$$T_m = f(\theta, e) \tag{9}$$

The expression for servo torque (9) is transformed into a Taylor series (10):

$$T_m = t_a(0) + \frac{dt_a}{de}(e(t) - e(0)) + \cdots + \frac{dt_a}{d\theta}(\theta(t) - \theta(0)) + \ldots \tag{10}$$

Let us consider the first two members of the Taylor series:

$$T_m = k_e(t) - f\theta(t), \tag{11}$$

Where $k_e = \frac{dT_m}{de}$ and $f = -\frac{dT_m}{d\theta}$
Servo torque will be as follows:

$$T_m = J\theta + B\theta, \tag{12}$$

where J and B are the friction coefficient and the moment of inertia, respectively.
Taking into account expressions (11) and (12), it can be obtained:

$$k_e(t) - f\theta(t) = J\theta + B\theta \tag{13}$$

Using the Laplace transform the following can be exposed:

$$\frac{\theta(s)}{E(s)} = \frac{K}{Js^2 + (B+f)s} = \frac{K}{s(Js + B + f)} = \frac{K_a}{s(t_a s + 1)} \tag{14}$$

Where $K_a = \frac{K}{B+f}$ and $t_a = \frac{J}{B+f}$ – gain ration and time constant, respectively (Fig. 3).

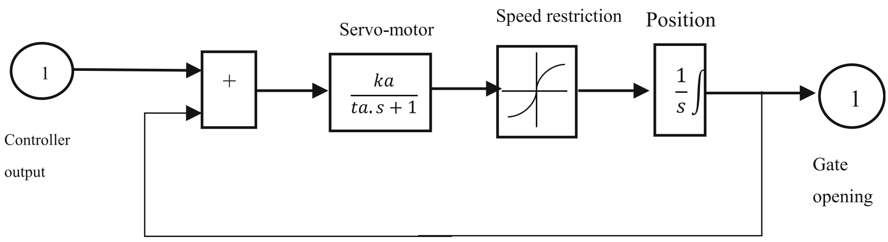

Fig. 3. Hydraulic system model

It is assumed that the system is working steadily. The flow rate and the developed mechanical power on the shaft are described by expressions (15) and (16):

$$Q = G\sqrt{H}, \tag{15}$$

where Q is the flow rate, m^3/s;

G – the opening angle of the gate, glad;

H – water head, m.

Power Pm, kW:

$$P_m = A_t H(Q - Q_{nl}) \tag{16}$$

where A_t is turbine gain;

Q_{nl} – consumption at idle, m^3/s.

After transforming the expression (15) it can be exposed:

$$U = K_u G\sqrt{H}, \tag{17}$$

where U is the water velocity in the conduit, m/s;

K_u – proportionality coefficient.

Consumption will be as follows:

$$Q = AU, \tag{18}$$

Acceleration of fluid in the gate is described by the following expression:

$$\frac{dU}{dt} = -\frac{a_g}{L}(H - H_0) \tag{19}$$

where a_g is the acceleration of gravity, m/s^2;

L – the length of the conduit, m.

Expression (17) considering (20) is as follows:

$$\overline{H} = \left(\frac{\overline{U}}{\overline{G}}\right)^2 \tag{20}$$

$$\frac{\overline{U}}{\overline{H - H_0}} = -\frac{1}{T_{w^3}} \tag{21}$$

where $\frac{LQ_r}{a_g A H_r}$is the start time of water at nominal load, s;

Qr and Hr – nominal water flow, m^3;

Hr – head, m.

Output mechanical power, kW:

$$P_m = P - P_l, \tag{22}$$

where P_l – fixed power losses in the turbine due to friction, kW.

$$P_l = U_{NL} H, \tag{23}$$

where U_{NL} – the speed of the turbine without load, m/s.

The complete flow chart of the hydro turbine model is presented at Fig. 4. The transfer function described by expression (21) relates the flow rate Q and the head H. Here (H-H0) is an input signal and the flow rate is the output signal of the transfer function. H0 is a static head, which is taken as a reference value. The signal (H-H0) is obtained after using the summation block. In accordance with the expression (21), 1/Tw is multiplied by the signal (H-H0) and integrated to obtain the flow rate Q. In order to find the actual flow rate of the water, the no-load flow is subtracted from Q using the summation block. Using the signal Q and 1/G and the auxiliary unit, a new signal Q/G is created, the square root of which gives the actual value of the head H in accordance with the expression (15). In order to get the Pm value, the expression (16) is used, which establishes a relationship between the turbine power, the actual water flow and the head [6].

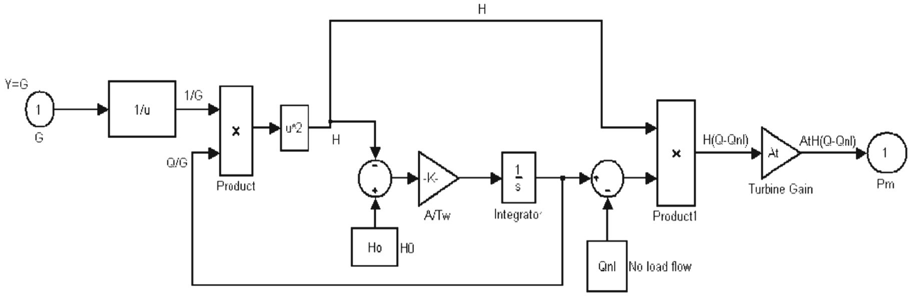

Fig. 4. Hydraulic turbine model

The turbine controller controls the change in the generator rotation speed. The PID controller, servo-system and hydraulic turbine are the main components of a hydraulic turbine controller. It is assumed that the turbine rotates at a constant frequency. A flow chart of the turbine controller is shown at Fig. 5. The first element of the controller is the PID controller [7]. Speed error and power deviation is given as the input to the controller, which generates a position signal at the input of the hydroelectric servo-motor (Fig. 5).

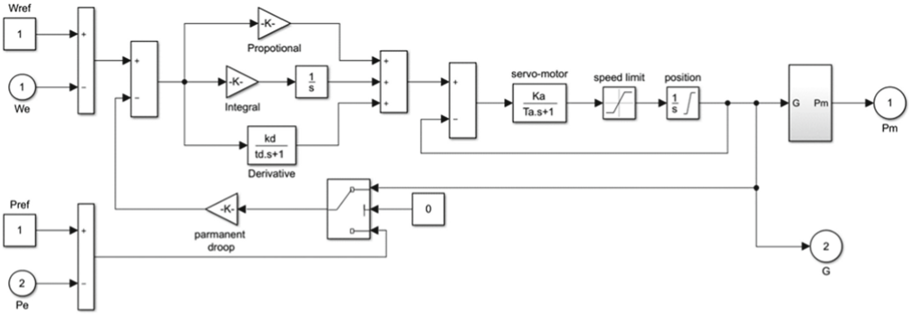

Fig. 5. Hydroturbine controller model

The mathematical model of the synchronous machine is described by the Park equations [8]. Equations (24–27) are used to describe the electrodynamic model of a synchronous generator [9]:

$$T''^{d_0\frac{dE''q}{dt}} = E'q - E''q + \left(X'_d - X''_d\right)I_d; \quad (24)$$

$$T''^{q_0\frac{dE''d}{dt}} = E'd - E''d + \left(X'_q - X''_q\right)I_q; \quad (25)$$

$$T'^{d_0\frac{dE'q}{dt}} = E'f - E'q + \left(X_d - X'_d\right)I_d; \quad (26)$$

$$T'^{q_0\frac{dE'd}{dt}} = -E'd - E''q + \left(X_q - X'_q\right)I_d; \quad (27)$$

Based on these generalized equations, the synchronous machine is modeled in the MATLAB/Simulink software suite. This model is presented as a single unit (Fig. 6). The model considers the dynamics of the stator windings, the main field of the machine and the damper winding [10].

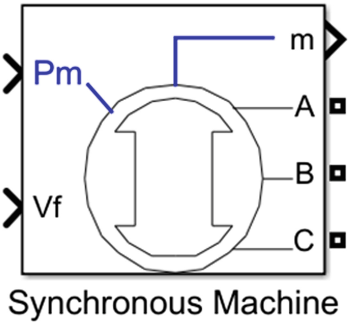

Fig. 6. Flow chart of the synchronous machine

Separate sub-models, such as a hydro-turbine controller, a synchronous generator and an excitation system form a complete flow chart of a small hydro power plant (Fig. 7), which is used for modeling and analysis under various operating conditions [11].

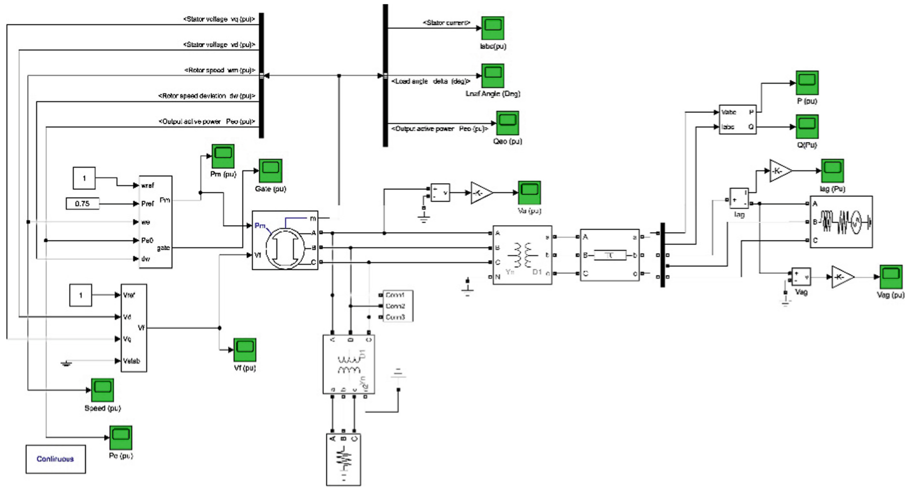

Fig. 7. Model of the hydro power plant

The synchronous vertical generator with a nominal power of 20 MW and a generator voltage of 13.8 kV was adopted in order to simulate the hydroelectric power station. The PID controller with the following parameters was adopted: proportional gain kp = 1.0, integral gain ki = 0.2 and the derivative coefficient kd = 0.1.

This study uses a DC excitation system. The exciter model is a DC field switch with constant voltage controllers. It can be self-excited or separately excited. For a self-excited system, $K_A = 300$ is selected so that the voltage value of the V_R regulator is initially zero. The standard built-in model of the excitation system in the Matlab/Simulink library is used to model a hydro power plant.

The generator works with a load of 20 MW, which is the total load on the installation. Disturbing effect is created by reducing the load by 2 MW.

3 Results and Discussion

Initially, the generator voltage, rotor speed and mains voltage are 1.0 p.u., while the generator current and mains current are 0.65 p.u. and 0.35 p.u., respectively. The load current is 0.1 p.u., the electric power is 0.75 p.u., the excitation voltage at 1.10 p.u., the generator load angle at 27°, the mechanical power 0.755 p.u. and gate opening 0.726 p.u.

The generator load angle is the divergence angle of the e.m.f. of generator and the voltage at the generator terminals during asynchronous operation.

When the load decreases, the electrical power decreases from the initial value of 0.75 p.u. to 0.7 p.u., and reaches the initial value after 7.0 s (Fig. 8).

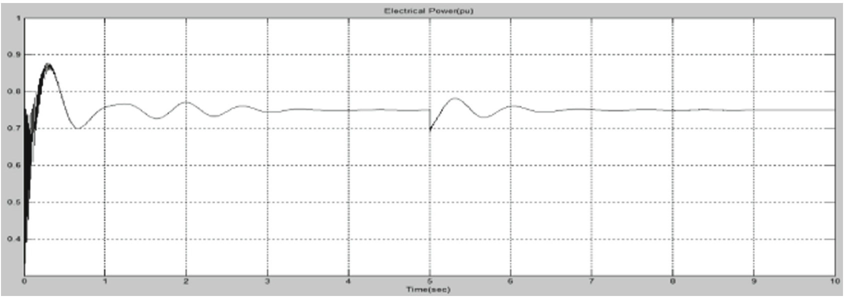

Fig. 8. Characteristics of the hydro power plant electric power (power in relative units vertically and time in seconds horizontally)

The characteristic of the rotation frequency of the synchronous hydrogenerator is shown at Fig. 9.

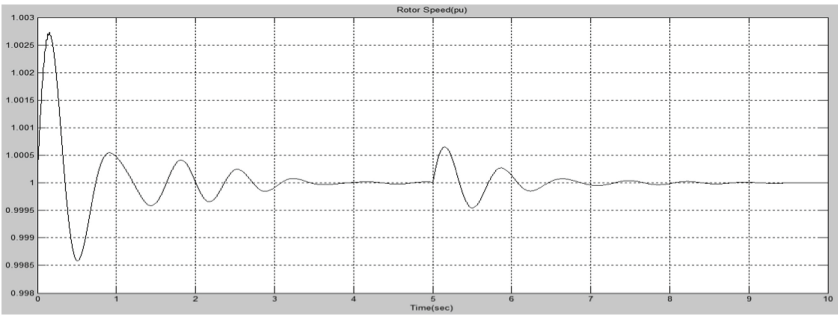

Fig. 9. Velocity characteristics of a synchronous generator (speed in relative units vertically, time in seconds horizontally)

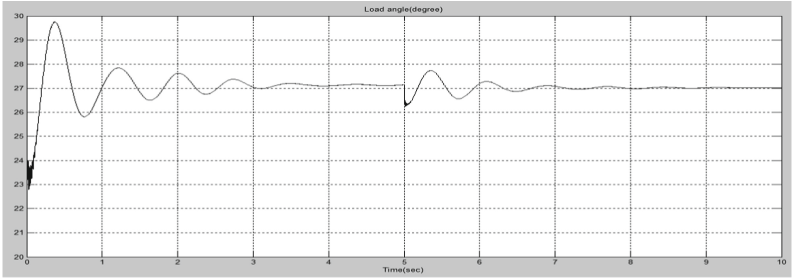

Fig. 10. Generator load angle (angle in degrees vertically, time in seconds horizontally)

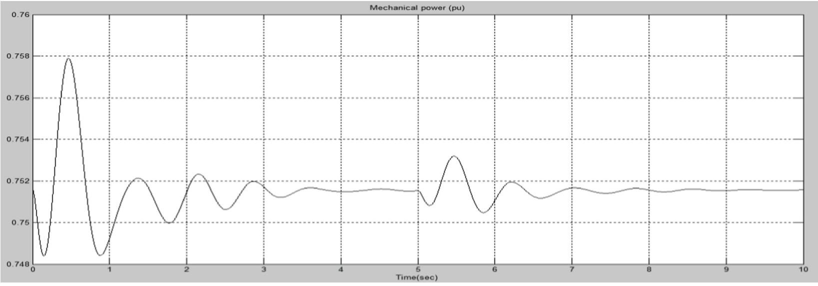

Fig. 11. The characteristic of the mechanical power of a hydro power plant (power in relative units vertically, time in seconds horizontally)

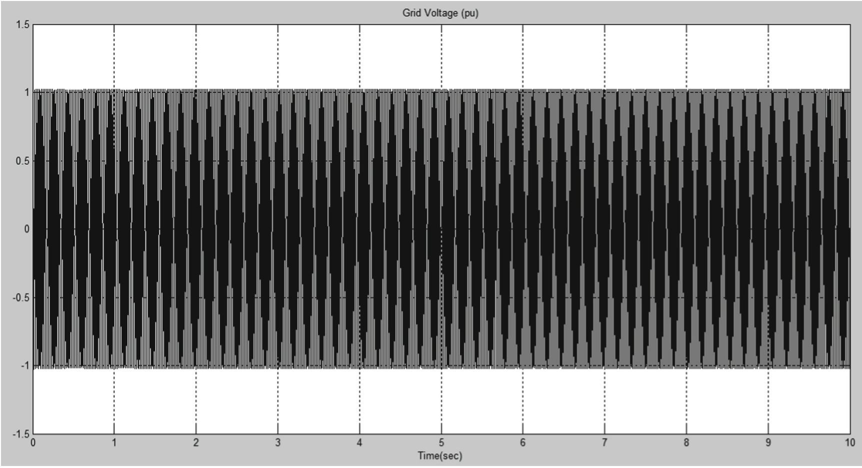

Fig. 12. Mains current characteristics (current in relative units vertically, time in seconds horizontally)

The load angle of the generator also decreases from 27° to 26° while reducing the load (Fig. 10).

Mechanical power decreases with decreasing load and reaches its initial stable state after 8.0 s (Fig. 11).

Due to the decrease in load, the mains current increases up to 0.35 p.u. (Figure 12).

4 Conclusion

The intellectual basis required for managing the small hydro power plant should include a corresponding set of algorithms and programs implemented in control devices. With the participation of the MHPP such devices are used in the electricity market to control the regime with a limited water inflow, which allows achieving maximum power generation and generating income.

Mathematical modeling (MATLAB/SIMULINK software suite was used in this case) allows selecting the most appropriate algorithm for controlling the operation of the SHPP with limited water resources.

Small hydro power plants can be operated in automatic mode without the constant presence of staff. Operating costs are reduced, the efficiency of the SHPP operation increases.

Creating a network of fully automated small hydro power plants controlled by a single center will effectively solve the problems of autonomous power supply of industrial and agricultural enterprises and remote facilities.

With the right choice of the SHPP control system, the units are optimally loaded with varying loads of consumers, which ultimately has a positive effect on the technical and economic performance of the power system.

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Justifying and Opting Lightweight Railway Superstructure

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Abstract. The article proposes a method of substantiation and opting railway superstructure with various design solutions. Based on the methodology for assessing the cost effectiveness, a method was developed for determining the coefficient of change in the cost of maintaining the superstructure, taking into account changes in stresses in its elements depending on the design decisions made. Technical solutions for the installation of a lightweight track structure were substantiated, and various solutions were proposed. For the proposed design options, the coefficients of change in the intensity of the railway track disorder and the coefficients of change in the cost of its ongoing maintenance in the average network operating conditions were determined. Based on the calculations, the option of a lightweight superstructure for laying on the Experimental Ring was chosen for further operational testing.

Keywords: Railway superstructure · Lightweight track structure · Railway transport

1 Introduction

At present, there are segments of railway network that, by their design (slopes, radii, etc.) or operating conditions (speed, load capacity, axial load), need strengthen typical design of the track [1–4] and shorten time between overhauls. At the same time, there are sections where the resource of standard designed structure is redundant, and the costs of installing the track on such sections can be reduced through the use of a less expensive lightweight railway track structure that has a lower resource. Preliminary estimates have shown that the effect of applying the design of the track, optimally matching the conditions of its operation, can reach 10–15% of the sum of all JSC Russian Railways costs spent on maintenance of the track, while most of the effect is achieved when introducing the lightweight construction of the track and reducing the costs associated with resource redundancy compared to typical decisions [5, 6]. The results of these economic assessments were used to substantiate the need to develop such a construction of the track and its further experimental implementation in the practice of operating Russian railways.

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2 Calculations of Stress-Strain State of Lightweight Railway Track Structures and Assessment of Track Disorder Intensity Changes

The main criteria for justifying and selecting the track design is ensuring the traffic safety during its operation, as well as an estimated cost of maintaining the track. As a criterion for assessing the compliance of the track design with the safety requirements is the stresses in the track elements not be exceeded of the specified threshold values. Maintenance costs are estimated on the basis of determining the coefficient of change in the cost of its maintenance (k_τ) compared to a typical track design.

For determining the coefficient of change in the cost of maintenance (k_τ), based on the methodology for assessing the cost effectiveness [7], there was a method developed, taking into account changes in stresses in track elements depending on the design decisions made:

$$k_\tau = k_{\tau_j} \cdot \varepsilon_j, \qquad (1)$$

wherein k_{τ_j} – coefficient of track disorder intensity changes, as for j-th track element;

ε_j – the share of maintenance costs in the part related to the j-th element of the track.

In turn, the values of the coefficient of track disorder intensity changes are determined by the following expression [8]:

$$k_{\tau_j} = \left(\frac{\left(\sigma_j^{norm}\right)}{\left[\sigma_j^{norm}\right]}\right)^{\chi}, \qquad (2)$$

wherein $\left(\sigma_j^{norm}\right)$ – normalized value of stress in the j-th track element for the considered track structure, kg/cm^2;

$\left[\sigma_j^{norm}\right]$ – normalized values of stress in the j-th track element for the basic design track, kg/cm^2;

χ – power exponent ($\chi = 2$).

The calculation of stress values in the elements of the track superstructure is carried out in accordance with the Methodology for assessing the impact of rolling stock on the track according to the conditions for ensuring its reliability, which also indicates the criteria for their evaluation, ensuring traffic safety [9].

The maximum stresses in the elements of the track superstructure were determined by the formulas:

– at edge of rail foot

$$\sigma_{\mathrm{p}} = f\sigma_o, \mathrm{kg/cm}^2 \qquad (3)$$

wherein $f-$ coefficient of transition from axial stresses in the rail foot to the edge ones, taking into account the effect of horizontal loads on the rail and the eccentricity of the application of vertical load;

σ_o- maximum stresses in rail foot from bending under the action of torque M.

$$\sigma_o = \frac{M}{W} = \frac{P^I_{eqv}}{4kW}, \mathrm{kg/cm^2}, \tag{4}$$

wherein $P^I_{eqv}-$ maximum equivalent load for stress calculations in rails from bending and torsion, kg;

$k-$ coefficient of relative stiffness of rail base and rail, cm^{-1};

$W-$ moment of resistance of rail relative to its base, cm^3;

- in sleeper on crumple in lining

$$\sigma_{\mathrm{III}} = \frac{Q}{\omega} = \frac{kl_s}{2\omega} P^{II}_{eqv}, kg/cm^2, \tag{5}$$

wherein l_s- distance between axes of sleepers, cm;

$P^{II}_{eqv}-$ maximum equivalent load for calculation of stresses and forces in elements of rail base, kg;

$\omega-$ rail lining area, cm^2;

- in ballast under sleeper

$$\sigma_{bal} = \frac{Q}{\Omega_a} = \frac{kl_{\mathrm{III}}}{2\Omega_a} P^{II}_{eqv}, kg/cm^2, \tag{6}$$

wherein Ω_a- area of half-sleeper with bending correction, cm^2.

The calculation formula for determining the normal stresses in the ballast (including at the main site of the roadbed) at a depth h from the base of the sleeper on the calculated vertical is

$$\sigma_{mprb} = \sigma_{h_1} + \sigma_{h_2} + \sigma_{h_3}, kg/cm^2, \tag{7}$$

wherein σ_{h_1}, $\sigma_{h_3}-$ stresses from the effects of the 1st and 3rd sleepers, respectively, lying on either side of calculated sleepers, $\mathrm{kg/cm^2}$;

$\sigma_{h_2}-$ stresses from the impact of the 2nd sleepers (calculated) in cross section of the track under the calculated wheel, $\mathrm{kg/cm^2}$.

In order to estimate the stress state of the rail-sleeper grid, taking into account the train flow, the normalized stresses were determined:

$$\sigma_j^{norm} = \sum \sigma_j^i \gamma_i, \tag{8}$$

wherein σ_j^i- stress in j-th element of the track for the considered design track, $\mathrm{kg/cm^2}$;

γ_i- share of i-th rolling stock in train flow, %.

To carry out calculations to substantiate the possibility of using lightweight track construction, the following directions were chosen to form such a construction - reducing the linear mass of the rail, increasing the inter-hatch distance by reducing the number of sleepers by 1 km of track, reducing the thickness of the ballast layer. The initial design characteristics of the standard and the lightweight structures of the track (option No. 1–4) are presented in Table 1.

Table 1. Calculated characteristics of track

Option №	Characteristics of track structure		*U*, kg/cm^2	*k*, cm^{-1}	L_s, cm	*ω*, cm^2	*W*, cm^3	Ω_a, cm^2
Typical structure	Rail type	R65	710.2	0.0124	55	255	417	3092
	Bond type	GBR-65S						
	Sleeper type	Reinforced concrete						
	Sleeper density	1840						
	Kind of ballast	Crushed stone						
	Ballast thickness	40 cm						
	Rail length	Continuous track						
1	Rail type	R50	210.98	0.00795	70	255	417	3092
	Bond type	GBR-65S						
	Sleeper type	Reinforced concrete						
	Sleeper density	1440						
	Kind of ballast	Crushed stone						
	Ballast thickness	25 cm						
	Rail length	Continuous track						
2	Rail type	R65	306.38	0.01003	67	255	417	3092
	Bond type	GBR-65S						
	Sleeper type	Reinforced concrete						
	Sleeper density	1600						
	Kind of ballast	Crushed stone						
	Ballast thickness	25 cm						
	Rail length	Link track						

(*continued*)

Table 1. (*continued*)

Option №	Characteristics of track structure		U, kg/cm^2	k, cm^{-1}	L_s, cm	ω, cm^2	W, cm^3	Ω_a, cm^2
3	Rail type	R65	639.65	0.01205	55	255	417	3092
	Bond type	GBR-65S						
	Sleeper type	Reinforced concrete						
	Sleeper density	1840						
	Kind of ballast	Crushed stone						
	Ballast thickness	15 cm						
	Rail length	Continuous track						
4	Rail type	R65	371.57	0.01052	63	255	417	3092
	Bond type	GBR-65S						
	Sleeper type	Reinforced concrete						
	Sleeper density	1600						
	Kind of ballast	Crushed stone						
	Ballast thickness	15 cm						
	Rail length	Link track						

The main design characteristics of the impact on the path [10, 11] for the above mobile units are given in Table 2.

Table 2. Design characteristics of rolling stock

Type of rolling stock, speed	P_{din}^{max}, kg	P_{av} kg	l_i cm	f		γ_i
				Straight	Curve	
Passenger car, 120 km/h	11111	9746	185	1.09	1.3	0.92
Freight car (23.5 t/axle), 80 km/h	17958.5	12066	185	1.18	1.65	0.01
Freight car (25 t/axle), 80 km/h	17460	12540	185	1.18	1.4	0.01
Passenger locomotive, 120 km/h	14325	11950	230	1.2	2.19	0.05
Freight locomotive, 80 km/h	15890	13390	300	1.25	1.82	0.01

Calculations of the stress-strain state of lightweight structures were performed for the average network operating conditions according to the line plan, the load density and the composition of the wagon and train flow. Table 3 presents the values of the normalized stresses acting in the elements of the track superstructure and the roadbed for the standard design and various options of the lightweight design. The results of calculations of the coefficients k_{τ_j} depending on the element under consideration and the values of the coefficient k_τ for each option of the lightweight construction are presented in Table 4.

Table 3. Normalized stresses in elements of standard design and options of lightweight track superstructure

Stress values, MPa	Typical structure	Option #1	Option #2	Option #3	Option #4	Admissible stress values $[\sigma]^a$, MPa
Stresses in rails - σ_r	67.2	149.1	78.7	68.6	75.8	240
Stresses in sleepers - σ_s	2.10	2.34	2.23	2.06	2.16	–
Stresses in ballast layer - σ_{bal}	0.127	0.124	0.135	0.124	0.131	0.325
Stresses on main platform of roadbed - σ_{mprb}	0.048	0.053	0.058	0.081	0.082	0.08

[a]–allowable stress for cars [9, 12]

Table 4. Values of coefficients of track disorder intensity change and coefficient of ongoing maintenance cost change, depending on element under consideration

Indicators	Option #1	Option #2	Option #3	Option #4
$k^{r}_{\tau_j}$	4.941	1.375	1.041	1.274
$k^{fas+s}_{\tau_j}$	1.241	1.132	0.960	1.058
$k^{bal}_{\tau_j}$	0.961	1.132	0.960	1.058
$k^{mprb}_{\tau_j}$	1.239	1.478	1.901	2.059
k_τ	1.691	1.172	0.981	1.100

When analyzing the results of the calculations, it was found that the values of the coefficient k_{τ_j} in almost all options exceed the values in the typical superstructure, which indicates the intensity of element disorder of other options will exceed the element disorder intensity values of the typical track design.

The worst indicators correspond to the design of the track option number 1. This version of the design has a maximum rate of change in the intensity of rails disorder k_{τ_j} = 4.9. Option number 2 satisfies the requirement to not exceed the permissible stresses, but with a decrease in the sleeper density to 1600, the accumulation of disturbances in track elements increases by 15–50% depending on the element: in rails k_{τ_j} = 1.38, in sleepers k_{τ_j} = 1.13, in ballast k_{τ_j} = 1.13, in ballast k_{τ_j} = 1.48.

When the thickness of the ballast layer is changed to 15 cm, which is typical for option No. 3, the stresses on the main surface of the roadbed exceed the allowable stresses and the coefficient k_{τ_j} increases from 1 to 1.9.

The simultaneous decrease in thickness of the ballast and the sleeper density (option number 4) has a negative impact on the track, because the intensity of the roadbed base disorder accumulation is 2 times higher compared to the typical design. On elements of HST designs: rails k_{τ_j} = 1.27, sleepers k_{τ_j} = 1.06, in ballast k_{τ_j} = 1.06, in ballast k_{τ_j} = 2.06.

Taking into account the analysis of all the results, the following conclusion can be made:

1. the Use of the track design option №1 is not advisable under the conditions of traffic safety (stresses in the rails are more than 2 times higher than the other options) and economic efficiency (the intensity of the accumulation of disorders for individual elements increases by almost 5 times compared to the typical, and for all elements in the aggregate – 1.7 times), which excludes option №1.
2. Reducing the thickness of the ballast in the typical design from 40 cm to 15 cm increases the coefficient of accumulation of disorders on the main site of the roadbed by 1.9–2.06 times (options №3 and №4, k_{τ_j} = 1.9–2.06, although the intensity of accumulation of disorders of the entire structure in option №3 is 0.981, and in option №4 – 1.100, which is significantly less than k_τ option №1), while the reduced stresses of the main site σ_{mprb} exceed the permissible [σ], which excludes options №3 and №4. The reduction of the sleeper density from 1840 to 1600 and the reduction of the ballast layer thickness from 40 cm to 25 cm leads to an increase in the intensity of the rails output by 38% (k_{τ_j}) = 1.38, option No. 2), bonds and ballast by 13% (k_{τ_j}) = 1.13, option No. 2) and the intensity of the accumulation of disorders on the main platform of the roadbed by 1.48 times (k_{τ_j}) = 1.48, option No. 2). The total cost change factor for option 2 is 1.172.

3 Recommendations for Selection and Further Testing of Lightweight Track Design

Thus, the following construction was adopted as a lightweight for laying on the Experimental Ring of JSC VNIIZhT - a link track, R65 rails, GBR-65S fastening, ferroconcrete sleepers with a density of 1600 pcs/km, 25 cm thick crushed stone ballast, which corresponds to No. 2 of Table 1.

This version of the lightweight track superstructure provides all the safety requirements for the criteria of not exceeding the permissible stresses and has the least impact on the main platform of the roadbed compared to the typical design.

For the final decision-making on applicating this design on the railway network of JSC "Russian Railways" it is necessary:

– carry out operational tests on the Experimental ring of JSC "VNIIZHT", during which experimentally determine the stresses values in the track structural elements for the typical and lightweight options;
– perform comparative observations of the failure of the track structural elements and fault occurrences in the track geometry for both structures;
– implement feasibility study of the chosen lightweight track design with the definition of rational areas of its application.

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Switching Shunters on a Slab Base

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Abstract. The article considers the possibility of using the switching shunters on the slab base. The slabs were calculated on the vertical load from the impact of rolling stock. The initial data for the calculation of reinforced concrete slabs was formed using the rules for calculating the track for strength. In the present study, as a base was taken the model based on the assumption that the slab of the ballastless track, including the switch, is an orthotropic plate supported on the damping base by the bottom surface and fixed along the edges of the contour with different boundary conditions. Trial operation showed that the joints are the weak point of the switching shunters on the slab base. Even though the stresses in the concrete of the slabs did not exceed the permissible values during the operation, defects appeared in the slabs. The most typical defects of all slabs are: chips of concrete at the longitudinal and butt edges with reinforcement exposition and with growth of cracks deep into the concrete. Analysis of labor costs for the current maintenance of the switching shunters on reinforced concrete slabs shows a significant reduction in the labor intensity of straightening work. High costs for other types of works is caused by the change of metal parts on the switching shunters.

Keywords: Switching shunters · Rolling stock · Ballastless track

1 Introduction

As the main type of the superstructures of the track on the ways of OJSC "RZHD", at present and in the future, it is planned to use the track on a reinforced concrete sub-rail base. Reinforced concrete structures at the base of the track are planned to be used both for the way on the ballast and in ballastless structures.

At present, on the Russian railways, reinforced concrete bars are used as the base of all new types of switch products. Measures to strengthen the rail base of the switches are mainly reduced to optimize the distribution diagram, improving the manufacturing technology of reinforced concrete bars and ensuring the possibility of applying modern methods for attaching metal parts of the switch to the bars [1].

The operating experience of reinforced concrete sub-rail foundations in the form of bars showed that using them at the base of turnouts allows you to create reliable structures, but for lines with high speeds and lines with high axial load, it is advisable to consider the possibility of using the other types of reinforced concrete base for switches [2].

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Work on the development of various types of reinforced concrete sub-rail base has been conducted in our country since the middle of the last century. The following types of bases were considered, such as longitudinal rails, joined in frames, separate slabs and solid reinforced concrete base (monolithic slab).

One of the directions in the application of reinforced concrete base under the switches is the creation of switches with slab base. The use of such switches makes it possible to reduce the unequal elasticity of the way within the switches and increase the stability of its position in the plan and profile, as well as reduce the time and money spent on the current operation of the switches. The positive effect of the use of this type of base should be attributed to the fact that it protects the ballast layer from clogging and increases its service life and the duration of the periods between cleanings, thus making it possible to increase the life of the base as a whole [3, 4].

The first switch on reinforced concrete slab was laid on the South-Western road in 1961. In the following years, the switches were laid on the roads of the central region [5].

The results of the operation of such switches are generally positive, but some limitations were identified, some of which were eliminated when developing new projects.

2 Research Methods

Considering the experience gained, several projects of switches on reinforced concrete slabs of the type P50 of the marks 1/11 and 1/18 and P65 of the mark 1/11 were developed (Fig. 1). In addition, the projects of P65 crossovers mark 1/11 were developed for different distances between the axes of the tracks [6].

Fig. 1. General view of the switch on the slab base

The base slabs of these switches had a constant cross-section with a size along the way, allowing to place three rail supports, i.e., 1.625 m. Across the way, the dimensions of the slabs are from 2.8 to 5.2 m, depending on their position under the switch. The thickness of the slabs for P50 transfers mark 1/11 is assumed to be 0.16 m, for P65 and P50 types, and for mark 1/18 it is 0.18 m. The weight of the slabs, depending on their size, ranges from 2,000 to 3,750 kg.

25 slabs are laid under one switch with the P50 rails, 27 slabs for the P65 rails mark 1/11 and 46 slabs for the mark 1/18 (Figs. 2 and 3).

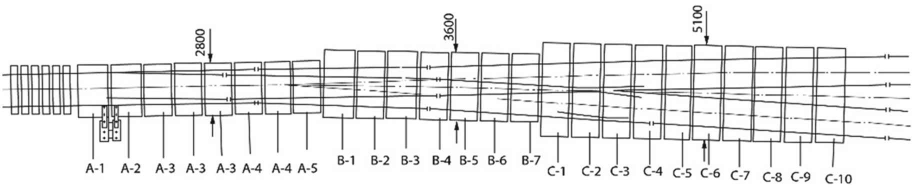


Fig. 2. The layout of the slabs in the switch of 1/11 mark with rails of the type P50

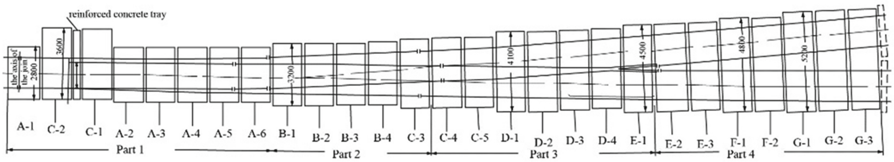


Fig. 3. The layout of the slabs in the switch of 1/11 mark with rails of the type P65

The slabs were calculated for the vertical load from the impact of rolling stock. The initial data for the calculation of reinforced concrete slabs were formed using the rules for calculating the way for strength.

When calculating the slabs, the following method was used.

First, the effect of the calculated moving load was determined. Then a static calculation of the slab was carried out with the definition of bending moments. After that, the fittings were selected, and the overall strength and crack resistance of the slab were checked.

The impact of a moving load on a slab was considered as quasi-static. When developing projects of switches on the slabs, the locomotive with a load of 24 T/axle and carriages with a load of 22 T/axle were taken as design. The calculated value of the elastic modulus U of the track was assumed to be equal to 5,000 kg/cm^2.

In determining the bending moments in the slab, the latter was considered lying on a solid elastic foundation. The bedding ratio of the base was taken equal to 10 kg/cm^3.

The base slabs of the switch have the form of rectangles, and the load on them is transmitted in the form of strips parallel to the sides of the slab. This made it possible to consider that the bending of slabs on an elastic base occurs along a cylindrical surface and their work under load can be considered as the work of beams lying on an elastic base [7].

The static calculation of the slabs was carried out by the section method. The design scheme of the plates is shown in Fig. 4.

The sum of the reactions of the supports located within one slab is marked by ΣQ. The value of X varies depending on the length of the slabs and can take values from 0.6 to 3.0 m.

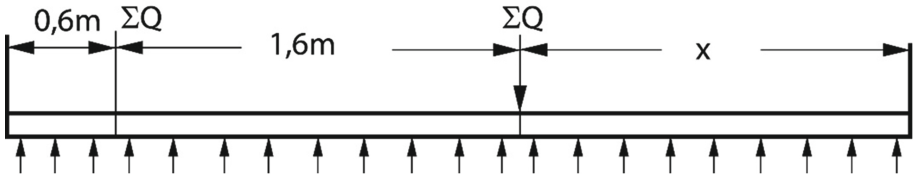


Fig. 4. The design scheme of the slab switch

Let's consider a ballastless railway in the form of a system of flat segments of reinforced concrete (Fig. 5), interconnected in several directions. Segments can be connected from two sides, if slab elements divide the base of the path in width, as well as from three or four sides, if the possibility of replacing individual slabs as part of an integral transport infrastructure object is constructively provided. Various options for the relative position of the slabs associated with single-track or double-track execution of the road, as well as with many other design factors [1–6]. In the present study, the model assumes that the base slab of the ballastless track, including the switch, is an orthotropic plate supported by the bottom surface on the damping base and fixed along the edges of the contour with different boundary conditions.

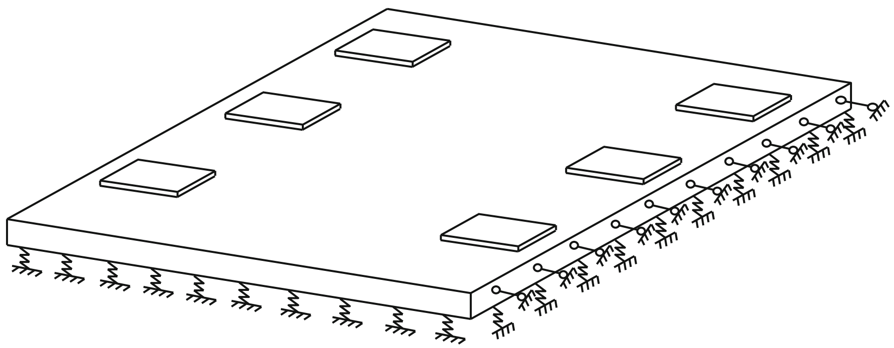


Fig. 5. The model of the rectangular element of the base slab switch

The dynamic behavior of an elastic orthotropic plate of the Uflyand-Mindlin type, which has cylindrical anisotropy, in the polar coordinate system is described by equations that take into account the inertia of cross sections rotation and the deformation of the transverse shear:

$$D_{r\theta}\frac{1}{r}\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial^2 w}{\partial\theta^2}\right)-\frac{1}{r}\left\{-D_r\frac{\partial}{\partial r}\left(r\frac{\partial\varphi}{\partial r}\right)+D_k\frac{1}{r}\left(\frac{\partial^3 w}{\partial\theta^2\partial r}-\frac{\partial^2\varphi}{\partial\theta^2}\right)+D_\theta\frac{1}{r}\varphi\right.$$
$$\left.+\ (D_\theta\sigma_r+D_k)\left(\frac{\partial^2}{\partial r\partial\theta}\left(\frac{\partial w}{r\partial\theta}\right)-\frac{\partial^2\psi}{\partial r\partial\theta}\right)+D_\theta\frac{1}{r}\frac{\partial\psi}{\partial\theta}-\frac{D_k}{r}\left(\frac{1}{r}\frac{\partial^2 w}{\partial\theta^2}-\frac{\partial\psi}{\partial\theta}\right)\right\} \quad (1)$$
$$+\ KhG_{rz}\left(\frac{\partial w}{\partial r}-\varphi\right)=-\rho\frac{h^3}{12}\frac{\partial^2\varphi}{\partial t^2},$$

$$KG_{rz}\left(\frac{\partial^2 w}{\partial r^2}-\frac{\partial\varphi}{\partial r}\right)+KG_{rz}\frac{1}{r}\left(\frac{\partial w}{\partial r}-\varphi\right)+KG_{\theta z}\frac{1}{r}\left(\frac{\partial^2 w}{r\partial\theta^2}-\frac{\partial\psi}{\partial\theta}\right)=\rho\frac{\partial^2 w}{\partial t^2}, \quad (2)$$

$$C_r\left(\frac{\partial^2 u}{\partial r^2}+\frac{1}{r}\frac{\partial u}{\partial r}\right)+C_k\frac{1}{r^2}\frac{\partial^2 u}{\partial\theta^2}-C_\theta\frac{u}{r^2}+(C_\theta\sigma_r+C_k)\frac{1}{r}\frac{\partial^2 v}{\partial r\partial\theta}$$
$$-\ (C_\theta+C_k)\frac{1}{r^2}\frac{\partial v}{\partial\theta}=\rho h\frac{\partial^2 u}{\partial t^2}, \quad (3)$$

$$C_\theta\frac{1}{r^2}\frac{\partial^2 v}{\partial\theta^2}+C_k\left(\frac{\partial^2 v}{\partial r^2}+\frac{1}{r}\frac{\partial v}{\partial r}-\frac{v}{r^2}\right)+(C_r\sigma_\theta+C_k)\frac{1}{r}\frac{\partial^2 u}{\partial r\partial\theta}$$
$$+\ (C_\theta+C_k)\frac{1}{r^2}\frac{\partial u}{\partial\theta}=\rho h\frac{\partial^2 v}{\partial t^2}, \quad (4)$$

$$D_{r\theta}\frac{1}{r}\frac{\partial^3 w}{\partial r^2\partial\theta}-\frac{1}{r}\left\{-D_\theta\frac{1}{r}\frac{\partial^2\psi}{\partial\theta^2}+D_k\left[r\frac{\partial^2}{\partial r^2}\left(\frac{1}{r}\frac{\partial w}{\partial\theta}-\psi\right)+\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial w}{\partial\theta}-\psi\right)\right.\right.$$
$$\left.-\frac{1}{r}\left(\frac{1}{r}\frac{\partial w}{\partial\theta}-\psi\right)\right]+(D_r\sigma_\theta+D_k)\left(\frac{\partial^3 w}{\partial r^2\partial\theta}-\frac{\partial^2\varphi}{\partial r\partial\theta}\right) \quad (5)$$
$$\left.-D_\theta\frac{1}{r}\frac{\partial\varphi}{\partial\theta}+D_k\frac{1}{r}\left(\frac{\partial^2 w}{\partial\theta\partial r}-\frac{\partial\varphi}{\partial\theta}\right)\right\}+KhG_{\theta z}\left(\frac{1}{r}\frac{\partial w}{\partial\theta}-\psi\right)=-\rho\frac{h^3}{12}\frac{\partial^2\psi}{\partial t^2},$$

where $D_r=\frac{h^3}{12}B_r$, $D_\theta=\frac{h^3}{12}B_\theta$, $D_k=\frac{h^3}{12}B_k$, $C_r=hB_r$, $C_\theta=hB_\theta$, $C_k=hB_k$, $D_{r\theta}=D_r\sigma_\theta+2D_k$, $B_r=\frac{E_r}{1-\sigma_r\sigma_\theta}$, $B_\theta=\frac{E_\theta}{1-\sigma_r\sigma_\theta}$, $B_k=G_{r\theta}$, $E_r\sigma_r=E_\theta\sigma_\theta$, $K=\frac{5}{6}$,

D_r, D_θ and C_r, C_θ - are the bending stiffness and tensile compression, for directions r, θ accordingly; D_k – torsion rigidity; C_k – shear rigidity; E_r, E_θ and σ_r, σ_θ - elastic modulus and Poisson's coefficient for directions r, θ; G_{rz}, $G_{\theta z}$ – shear module in the plates rz and θz accordingly; $w(r,\theta)$ – normal displacement of the median plane, $u(r,\theta)$ and $v(r,\theta)$ – tangential displacement of the median plane along the coordinates r, θ accordingly; $\varphi(r,\theta)$ and $\psi(r,\theta)$ – arbitrary unknown functions of coordinates r,θ.

When taking into account the existence of wave phenomena in the form of elastic waves, expanding with velocities that do not change during the whole process of deformation of the target, non-classical hyperbolic equations should be used that take into account the shear deformations of cross sections and inertial variables [9]. For this purpose, Eqs. (1)–(5) can be used, but to construct a solution in the far-field zone from the place where wave fronts appear, these equations must be rewritten in a slightly different form, using substitutions

$$\tau = \frac{t\sqrt{c_1}}{h},\ c_1 = \frac{E_r}{(1-\sigma_r\sigma_\theta)\rho},\ w = \frac{w}{h},\ u = \frac{u}{h},\ v = \frac{v}{h},\ r = \frac{r}{h}$$

after substituting these expressions into Eqs. (1)–(5) we obtain:

$$\begin{gathered}
\frac{\partial^2\varphi}{\partial r^2} + \frac{1}{r}\frac{\partial\varphi}{\partial r} + \frac{1}{r^2}\frac{\partial^2\varphi}{\partial\theta^2} - \frac{1}{r^2}\frac{c_2}{c_1}\varphi + \frac{c_2\sigma_r + c_3}{c_1 r}\frac{\partial^2\psi}{\partial r\partial\theta} - \frac{c_2 + c_3}{c_1 r^2}\frac{\partial\varphi}{\partial\theta} \\
+ \frac{12c_4}{c_1}\left(\frac{\partial w}{\partial r} - \varphi\right) = -\frac{\partial^2\varphi}{\partial\tau^2},
\end{gathered}$$

$$\frac{c_4}{c_1}\left(\frac{\partial^2 w}{\partial r^2} - \frac{\partial\varphi}{\partial r}\right) + \frac{c_4}{c_1}\left(\frac{\partial w}{r\partial r} - \frac{\varphi}{r}\right) + \frac{c_4}{c_1}\left(\frac{\partial^2 w}{r^2\partial\theta^2} - \frac{\partial\psi}{r\partial\theta}\right) = \frac{\partial^2 w}{\partial\tau^2} + q_1, \tag{6}$$

$$\left(\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r}\right) + \frac{c_3}{c_1 r^2}\frac{\partial^2 u}{\partial\theta^2} - \frac{c_2}{c_1}\frac{u}{r^2} + \frac{c_2\sigma_r + c_3}{c_1 r}\frac{\partial^2 v}{\partial r\partial\theta} - \frac{c_2 + c_3}{c_1 r^2}\frac{\partial v}{\partial\theta} = \frac{\partial^2 u}{\partial\tau^2},$$

$$\frac{c_2}{c_1 r^2}\frac{\partial^2 v}{\partial\theta^2} + \frac{c_3}{c_1}\left(\frac{\partial^2 v}{\partial r^2} + \frac{1}{r}\frac{\partial v}{\partial r} - \frac{v}{r^2}\right) + \frac{\sigma_\theta + c_3}{c_1 r}\frac{\partial^2 u}{\partial r\partial\theta} + \frac{c_2 + c_3}{c_1 r^2}\frac{\partial u}{\partial\theta} = \frac{\partial^2 v}{\partial\tau^2},$$

$$\frac{c_3}{c_1}\left(\frac{\partial^2\psi}{\partial r^2} + \frac{1}{r}\frac{\partial\psi}{\partial r} - \frac{\psi}{r^2}\right) + \frac{c_2}{c_1 r^2}\frac{\partial^2\psi}{\partial\theta^2} + \frac{\sigma_\theta + c_3}{c_1 r}\frac{\partial^2\varphi}{\partial r\partial\theta} + \frac{c_2 + c_3}{c_1 r^2}\frac{\partial\varphi}{\partial\theta} + \frac{12c_5}{c_1}\left(\frac{1}{r}\frac{\partial w}{\partial\theta} - \psi\right) = -\frac{\partial^2\psi}{\partial\tau^2},$$

$c_2 = \frac{E_\theta}{(1-\sigma_r\sigma_\theta)\rho}$, $c_3 = \frac{G_{r\theta}}{\rho}$, $c_4 = \frac{KG_{rz}}{\rho}$, $c_5 = \frac{KG_{\theta z}}{\rho}$. $q_1 = \frac{qh}{\rho c_1}$, ρ - the density of the target material, q is the external load (in this case from the wheelset), R1 is the radius of the contact area through which the load is transmitted from the carriage.

The values of c1, c2, c3, c4, c5 used in Eq. (6) determine the squares of the velocities of the wave surfaces (their number is determined by the rheological properties of the material of the flat target), the indices of the value of c are responsible for the type of the wave surface: 1, 2 determine the quasi-longitudinal wave surfaces, on the fronts of which tensile-compression stresses prevail, these waves expand along the coordinate axes r and θ, index 3 determines the quasi-transverse wave surface, on the front of which the shift in the plane rθ prevails, indices 4, 5 dissolve the quasi-transverse wave surface at the front of which shear forces prevail in the directions normal to the planes rz, θz. According to the expressions for the velocities of the wave surfaces, given in the descriptive part to formulas (6), their values directly depend on the mechanical properties of the target material in the corresponding directions. Thus, the set of velocities of the wave surfaces uniquely determines the elastic properties of the flat element.

The solution of Eq. (6) is proposed to search in the space of images, for this you need to use the Laplace transform, moving from the quantities φ, ψ, w, u, v, q_1 and M to their representation in the Laplace space - $\bar{\varphi}$, $\bar{\psi}$, $\bar{w}$, $\bar{u}$, $\bar{v}$, $\bar{q}_1$ and $\bar{M}$

$$
\begin{aligned}
&\bar{\varphi}_{,rr} + \frac{1}{r}\bar{\varphi}_{,r} + \frac{1}{r^2}\bar{\varphi}_{,\theta\theta} - \frac{1}{r^2}\frac{c_2}{c_1}\bar{\varphi} + \frac{c_2\sigma_r + c_3}{c_1 r}\bar{\psi}_{,r\theta} - \frac{c_2 + c_3}{c_1 r^2}\bar{\varphi}_{,\theta} \\
&+ \frac{12c_4}{c_1}\left(\bar{w}_{,r} - \bar{\varphi}\right) = -\bar{\varphi}p^2 + \bar{M}, \\
&\frac{c_4}{c_1}\left(\bar{w}_{,rr} - \bar{\varphi}_{,r} + \frac{1}{r}\bar{w}_{,r} - \frac{\bar{\varphi}}{r} + \frac{1}{r^2}\bar{w}_{,\theta\theta} - \frac{1}{r}\bar{\psi}_{,\theta}\right) = \bar{w}p^2 + \bar{q}_1 \sin\alpha_1, \\
&\bar{u}_{,rr} + \frac{1}{r}\bar{u}_{,r} + \frac{c_3}{c_1 r^2}\bar{u}_{,\theta\theta} - \frac{c_2}{c_1}\frac{\bar{u}}{r^2} + \frac{c_2\sigma_r + c_3}{c_1 r}\bar{v}_{,r\theta} - \frac{c_2 + c_3}{c_1 r^2}\bar{v}_{,\theta} \\
&= \bar{u}p^2 + \bar{q}_1 \cos\alpha_1 \cos\alpha_2, \\
&\frac{c_2}{c_1 r^2}\bar{v}_{,\theta\theta} + \frac{c_3}{c_1}\left(\bar{v}_{,rr} + \frac{1}{r}\bar{v}_{,r} - \frac{\bar{v}}{r^2}\right) + \frac{\sigma_\theta + c_3}{c_1 r}\bar{u}_{,r\theta} + \frac{c_2 + c_3}{c_1 r^2}\bar{u}_{,\theta} \\
&= \bar{v}p^2 + \bar{q}_1 \cos\alpha_1 \sin\alpha_2, \\
&\frac{c_3}{c_1}\left(\bar{\psi}_{,rr} + \frac{1}{r}\bar{\psi}_{,r} - \frac{\bar{\psi}}{r^2}\right) + \frac{c_2}{c_1 r^2}\bar{\psi}_{,\theta\theta} + \frac{\sigma_\theta + c_3}{c_1 r}\bar{\varphi}_{,r\theta} + \frac{c_2 + c_3}{c_1 r^2}\bar{\varphi}_{,\theta} \\
&+ \frac{12c_5}{c_1}\left(\frac{1}{r}\bar{w}_{,\theta} - \bar{\psi}\right) = -\bar{\psi}p^2,
\end{aligned} \tag{7}
$$

where p – the image space parameter, lower-case values r and θ, determine the partial derivative of the recorded parameter.

The first Eq. (7) can be rewritten in a manner which can provide possibility to present $\bar{w}$ value as an equation, then we substitute the formula obtained to the second and the third proportion (7), as a result of using this procedure we obtain a system of equations with respect to images of angular displacements $\bar{\varphi}$ and $\bar{\psi}$

$$
\begin{aligned}
&\bar{\varphi}_{,rr\theta}\left(1 - \frac{(c_1\sigma_\theta + c_3)c_4}{c_1 c_5}\right) + \frac{1}{r}\bar{\varphi}_{,r\theta}\left(1 - \frac{(c_2 + c_3)c_4}{c_1 c_5}\right) + \frac{1}{r^2}\bar{\varphi}_{,\theta\theta\theta} \\
&+ \bar{\varphi}_{,\theta}\left(p^2 + \frac{(c_2 + c_3)c_4}{c_1 c_5 r^2} - \frac{c_2}{c_1 r^2} - \frac{12c_4}{c_1}\right) + \frac{1}{r}\bar{\psi}_{,r\theta\theta}\left(\frac{c_2\sigma_r + c_3}{c_1} - \frac{c_2 c_4}{c_1 c_5}\right) \\
&- \frac{1}{r^2}\frac{c_2 + c_3}{c_1}\bar{\varphi}_{,\theta\theta} + \left(\frac{12c_4 r}{c_1} - \frac{p^2 r c_4}{c_5} + \frac{c_3 c_4}{c_1 c_5 r}\right)\left(\bar{\psi}_{,r} + \frac{\bar{\psi}}{r}\right) \\
&- \frac{c_3 c_4 r}{c_1 c_5}\left(\frac{2}{r}\bar{\psi}_{,rr} + \bar{\psi}_{,rrr}\right) + \frac{c_2 c_4}{c_1 c_5 r^2}\bar{\psi}_{,\theta\theta} = \bar{M}_{,\theta}\ ,
\end{aligned} \tag{8}
$$

$$\left(p^2\frac{c_1\sigma_\theta+c_3}{12c_5}-\frac{c_4}{c_1}+\frac{(c_2+c_3)c_4}{12c_1c_5r^2}\right)\left(\bar{\varphi}_{,r\theta}+\frac{\bar{\varphi}_{,\theta}}{r}\right)$$
$$+\bar{\psi}_{,\theta\theta}\left[\frac{c_4}{c_1}\left(\frac{c_3-c_2}{12c_5r^3}-\frac{p^2c_1}{12c_5r}\right)+\frac{p^2c_2}{12c_5r}\right]+\bar{\psi}_{,rr}\left[\frac{c_4}{c_1}\left(r-\frac{c_3}{12c_5r}-\frac{p^2c_1r}{12c_5}\right)+\frac{p^2c_3r}{12c_5}\right]$$
$$+\bar{\psi}_{,r}\left[\frac{c_4}{c_1}\left(3-\frac{c_3}{12c_5r^2}-\frac{3p^2c_1}{12c_5}\right)+\frac{p^2c_3}{12c_5}\right]-\frac{(c_2+c_3)c_4}{12c_1c_5r}\left(\bar{\psi}_{,\theta\theta rr}+\frac{\bar{\varphi}_{,\theta\theta\theta}}{r^2}\right)$$
$$+\bar{\psi}\left(r+\frac{c_3}{12c_5r}-\frac{p^2c_1r}{12c_5}\right)\left(\frac{c_4}{c_1}\frac{1}{r^2}-p^2\right)-\frac{c_2c_4}{12c_1c_5r}\bar{\psi}_{,\theta\theta\theta\theta}-\frac{c_3c_4}{3c_1c_5}\left(\frac{r}{4}\bar{\psi}_{,rrrr}+\bar{\psi}_{,rrr}\right)$$
$$-\frac{(c_1\sigma_\theta+c_2+2c_3)c_4}{12c_1c_5r}\bar{\varphi}_{,rr\theta}-\frac{(c_1\sigma_\theta+c_3)c_4}{12c_1c_5r}\left(\frac{\bar{\varphi}_{,r\theta\theta\theta}}{r}+r\bar{\varphi}_{,rrr\theta}\right)=\bar{q}_{1,\theta}\sin\alpha_1,$$

All types of linear and angular displacements present in (8), as well as the external load q (t, r, θ), appearing due to the dynamic impact of the striker through the contact force P (t) are proposed to be written as power series with spherical functions main elements of which are Legendre polynomials [10]

$$\bar{x}=\sum_{n=0}^{\infty}\sum_{m=0}^{\infty}x_{2n+m}P_{2n+1}\left(\cos\frac{\pi r}{2R}\right)\cos(m\theta) \tag{9}$$

$$\bar{q}_1=\frac{P(p)}{\pi R_c^2}\sum_{n=0}^{\infty}\sum_{m=0}^{\infty}(4n+3)P_{2n+1}\left(\cos\frac{\pi r_1}{2R}\right)P_{2n+1}\left(\cos\frac{\pi r}{2R}\right)\cos(m\theta) \tag{10}$$

in these ratio, R is the characteristic size of the slab segment that models the basis of the switch; r1 is the coordinate of the dynamic impact point of the striker on the target; x - the value that can take the values of the main displacements ϕ, ψ, w, u, v; These values are represented in the image space, which is indicated by the bar above, P (p) - represents the dependence of the interaction force from the image space parameter.

To determine the coefficients of series (9), (10), we use their representation in the form of Laurent series near the target point under study [9, 10]

$$x_{2n+m}=x^0_{2n+m}\varepsilon^0+x^1_{2n+m}\varepsilon^1+x^2_{2n+m}\varepsilon^2+x^3_{2n+m}\varepsilon^3 \tag{11}$$

where $\varepsilon=p^{-2}$.

By substituting the series (9), (10) considering ratio (11) into the system (8) and equating the coefficients with the same degrees, we obtain systems of linear algebraic equations, from which we find the coefficients of relations (11). The obtained correlation for coefficients is calculated for specific point of the slab and place the load is applied from the wheel pair, i.e. r and θ take on certain values.

After the inversed Laplace transform, displacements can be recorded as a function of time, two coordinates and interaction force on the slab base

$$x(\varphi,\theta,\tau) = \frac{(1-\sigma_\theta\sigma_r)h}{\pi R_c^2 E_r}\int_0^\tau \sum_{n=0}^{\infty}\sum_{m=0}^{\infty}(4n+3)P(\tau_1)P_{2n+1}$$
$$\times\left(\cos\left(\frac{\pi r_1}{2R}\right)\right)P_{2n+1}\left(\cos\left(\frac{\pi r}{2R}\right)\right)\cos(m\theta)$$
$$\times\left[x_{2n+m}^0 Dirac(\tau-\tau_1) + x_{2n+m}^1(\tau-\tau_1) + \frac{x_{2n+m}^2(\tau-\tau_1)^3}{6} + \frac{x_{2n+m}^3(\tau-\tau_1)^5}{120}\right]d\tau_1, \quad (12)$$

where Dirac (τ-τ_1) – delta function, from the original time interval.

This equation associates the displacement with the force of the dynamic effect on the base. To uniquely determine displacements, and through them, stresses at different points of the slab, it is necessary to use the equations relating the contact force and displacements of the slab base points of the switch, and the boundary conditions.

The contact force in the area of the impact of the wheelset and the rail-sleeper grid is associated with the movement of the slab at the point of interaction by a known functional equation describing the movement of the wheel after contact with the superstructures of the railway [10]

$$y(t) = V_0 t - \frac{1}{m}\int_0^t P(t_1)(t-t_1)dt_1 \quad (13)$$

where $y(t) = \alpha(t) + w(t)$ - full movement of the wheel in the direction of impact, m is the mass affecting on the wheelset, t is the time counted from the moment the wheel touches the superstructures of the railway, t1 is the variable integration value.

The dependence $\alpha(t)$ and P (t) is determined by solving the contact task.

Metal parts of switches on slab bases were used are the typical ones used in mass production projects.

Reinforced concrete slabs were made on factories producing concrete sleepers. Manufacturing technology was adopted the same as for conventional concrete sub-rails. The plates were molded on vibrating tables in forms designed for the perception of the prestressing of the reinforcement. Thermo-moisture treatment of concrete was carried out in steam chambers [8].

The slabs were made of concrete, mark 500 and were reinforced in the longitudinal direction with prestressed reinforcement, and in the transverse one - with non-stressed.

In the first projects of switches of the type P50 mark 1/11, screws were provided as fasteners for metal parts, for which wooden dowels were installed in reinforced concrete slabs. In connection with the unsatisfactory work of the screws in the projects, starting from 1963, setting the adhesives in the slabs according to the KB type of fasteners was provided.

For lifting the slabs during alignment in the profile and the level, as well as for carrying them when mounting the switch at the element assembly base, niches were made in the ends of the slabs, inside which there were slinging loops and angles for jacks.

The design of the metal parts of the switch was left unchanged except for the placement of holes for screws and bolts in metal linings. Metal pads were attached to the reinforced concrete slabs with two fasteners.

In order to reduce slab sizes in the left and right hand switches, the slabs were laid out perpendicular to the bisector of the arrow angle [9].

Switches on the slabs were placed on the ballast, which was previously cleaned and compacted. For a more precise planning of the surface of the ballast layer and to be able to straighten the position of individual slabs over the base layer of ballast, 5 cm of fine crushed stone of a 7–25 mm fraction is poured without compaction.

In the period from 1961 to 1965, 90 switches were installed on the slabs, 16 of them were of the P65 type.

Dynamic strength tests of switches were performed by VNIIZhT. The monitoring of the operational work of the switchers was carried out by specialists from VNIIZhT, DIIT, BelIIZhT and track survey stations.

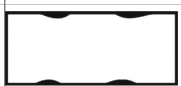
In the process of operational observations, measurements were made of the rail track geometry in the joints of the frame rails, at a distance of 1000 mm from the tip, at the tips of the guiding tongues, along the axis of the 7th lining with a rail chair, in the middle of the transfer curve in front crosspiece joint, 40 mm in cross section, a rear joint, the distance of 1477 mm crosspiece (switches had a projected track 1524 mm) and 1435 mm for the direct railway and on a side railway, respectively.

Even though the stresses in the concrete of the slabs did not exceed the permissible values during the operation, defects appeared in the slabs.

The most typical defects of all slabs are: chips of concrete at the longitudinal and butt edges with reinforcement exposition and with growth of cracks deep into the concrete. There is a certain number of slabs with through cracks through the entire slab, formed both during installation and during operation.

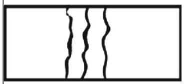
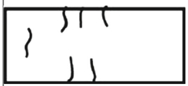
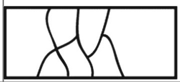
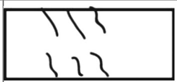
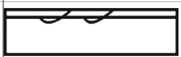
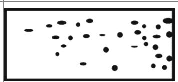
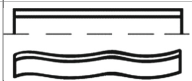
The list of defects in the slabs that occurred in operation is given in Table 1.

Table 1. Defects of reinforced concrete slabs of switches on a slab base (according to the results of trial operation)

Defects			Types of defects	Description of defects	Main causes of defects	
Group		Fig.	In slabs		Railway operation	Manufacturing
1	2	3	4	5	6	7
I	Chips	11		Chipped concrete at the transverse edges	Strikes in the assembly, installation. No gap between blocks	Curved edges
		12		Chipped concrete on longitudinal edges	Violation of the technology of alignment of the way by jacks	Loading, unloading and tilting plates without special devices

(*continued*)

Table 1. (*continued*)

Defects			Types of defects	Description of defects	Main causes of defects	
Group		Fig.	In slabs		Railway operation	Manufacturing
1	2	3	4	5	6	7
II	Cracks	21		Through transverse cracks	Poor plate support on the base. Violation of technology of railways alignment by filling	Inadequate prestressing of reinforcement. Removal of slabs and prefabricated frames from the stand with great effort
		22		Uncut transverse cracks		
		23		Through oblique cracks		
		24		Uncut oblique cracks		
		25		Through longitudinal cracks		Unsatisfactory work of the vibratory or core drivers
		26		Uncut longitudinal cracks		
		27		Longitudinal cracks on the side and in bridges		
		28		Side cracks coming to the surface		
III	Prefabricated	31		Concrete looseness	–	Violation of technology and equipment unsuitability
		32		The violation of the geometric dimensions. Flatness deviation	–	
		33		Lack of attachments	–	
IV	Other	41		Broken rods and other defects		Installation of the low quality tie rods

3 Results of the Research

Manufacturing of an experimental batch of slabs, their laying on the way and the results of operation showed that the straightness of the upper surface of the slabs, as well as the height and placement of embedded parts for fastenings should be carefully observed. The deviation of the upper surface of the slabs from the plane of more than +1 mm violates the nature of the rails bearing, impairs the interaction of the way and rolling stock, necessitates the selection of gaskets in fasteners in height. In some cases, the deviation of the slab size in height dramatically increases the amount of work on aligning the position of the slabs in the profile and level.

The results of dynamic strength tests showed that the stresses in the elements of switches, the elastic deformation of the rail track and the stresses in the concrete of the slabs do not exceed the allowable values.

From the comparative element-wise characteristics of the state of the switches for 4 years of observations, from 1970 to 1973, it follows that the deviations above the tolerances in the track gauge on the railroad point app. 1.7 mm for the widening and 0.1 mm for the narrowing, and on the cross, respectively, 0.9 mm and less than 0.1 mm. In the direct direction of the connecting ways of switches, the average deviations of the track gauge beyond the tolerances were 2.9 mm widening and 0.1 mm narrowing, on the conversion curve (lateral direction) 1.1 mm widening and 11.3 mm narrowing. Analysis of these data shows that during the switching operation changes in the gauge occurred in the direction of its increase.

In general, trial operation showed that the weak point of switches on a slab base are joints. In order to ensure a stable position of the railway switches on the slabs, creation of more advanced intermediate fasteners was recommended.

The analysis of labor costs for the current maintenance of switches on reinforced concrete slabs from 1970 to 1973 shows that, on switches, the average labor costs for correcting the level are 13.8% of the total costs, for correcting the width of the rail track - 36.6% and for other types of works - 71.0%. This confirms once again that the switches on the slabs give a significant reduction in the labor intensity of the straightening work. The high costs of other types of works are caused by the change of metal parts on the switches [10].

4 Discussion of the Results

After analyzing the experience of using switches on a block base, we can draw the following conclusions:

– switches on a block base, tested for 10 years, turned out to be promising designs, which is confirmed by the data of their technical and economic efficiency, given in the works performed on this topic;
– It is advisable to use the switches on a block base with a load density of more than 20 million tons gross per year;
– the block basis for railway switches can be again demanded for again constructed railway switches intended for heavy and high-speed movement;
– in the design of switches on the slab base, it is advisable to use new design solutions for attaching the metal parts of the switch to the base;
– the introduction of new modern manufacturing technology of reinforced concrete bars, in turn, can provide a higher quality and accuracy of reinforced concrete slabs for switches;
– it is advisable to renew the use of switches on the slab base using modern element base.

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Research of the Stress-Strain State of the Building Foundation Artificial Basis on the Weak Soils of Sakhalin Island

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Abstract. The objective of the work is to develop a rational construction of an artificially prepared base of the foundation, using modern technologies and advanced geosynthetic materials that provide the operational reliability of the structure under special conditions of the construction site. The task of the research study is to develop geotechnical structures, based on the results of numerical modeling of using the properties of modern geosynthetic materials which provides the operational reliability of the joint operation of a weak base with the foundations of a building on Sakhalin Island in accordance with the requirements of regulatory documents operating in the Russian Federation.

Keywords: Weak soil · Base · Foundation · Biaxial geogrid · Numerical simulation · Stress-strain state

1 Introduction

The study examined the possibility of using, the redistributing ability of a geocomposite pillow from inert materials of the required structure with layers of a geosynthetic integrated geogrid as an artificial base. At the same time, the construction of the artificial base should provide minimal uniform precipitation under the conditions of the calculated seismicity of the area of the construction site up to 9 points within the requirements of SR 22.13330.2016 Foundations of buildings and Structures. Updated version of Building Regulations (BR) 2.02.01-83 * of section 6.13 Design features of the foundations of structures erected in seismic areas [1]. This section indicates that on sites piled with category III soils for seismic properties, it is necessary to provide measures for construction properties of the foundation soils improvement before the construction begins.

It is impossible to use water-saturated soils capable of dynamic dilution as the bases of earthquake-resistant structures without carrying out preliminary special measures to improve the construction properties of soils. One of the serious geotechnical problems encountered during construction in the Far Eastern region is weak foundations.

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Territories suitable for human settlement and urban development are often located near large rivers. The geological structure of such areas is represented by alluvial deposits: sand, clay, silts. Thus, there is a need for construction on, such kind of, soft soils, but the engineering solution to this problem is very difficult. The most optimal and widely used option is construction on a pile foundation. But it is not always possible to support piles on primary soils, which causes great difficulties in choosing a reliable solution for the geotechnical structure. The recommended power of excavation and replacement of soft foundation soil should be rational in terms of uniformity and technological feasibility.

2 Engineering and Geological Conditions of the Research Site

To distinguish engineering-geological elements, soil distribution boundaries, quantify the characteristics of physical and mechanical properties, assess the spatial variability of the composition and properties of soils at two points, we performed static sounding of soils to a depth of 19.7–21.0 m. Static sounding was carried out to the maximum possible depth depending on the condition, soil composition and technical feasibility of the installation. Points of static sounding were located in close proximity to the point of well drilling (1.0–1.5 m).

Testing of soils by static sounding was performed by TEST-AM equipment mounted on a PBU-2 drilling rig. The set of equipment is certified by the State Standard of Russia RU.C.28.005.A No. 9418, registered in the State Register of Measuring Instruments under No. 14976 and approved for use in the Russian Federation. The type of equipment is lightweight, with the ultimate force of the pressing probe up to 50 kN. The probe was pressed in by the hydraulic system of the drilling rig through a rod string with a diameter of 36 mm. A strain gauge probe of type 2 with a diameter of the base of the cone of 35.7 mm and an angle at the apex of 600. Before starting and during the work, the probe was calibrated and adjusted. The sensing data was recorded by a two-channel controller with the conversion of the unbalance of the strain gauge half-bridges to digital values, storing the results of sensing and transferring them to an IBM-compatible computer for further processing. The main error in the measurement of effort is not more than 5%

The processing of the results of static sensing was performed in accordance with the State Standard GOST 19912-2000, the Geoexplorer program provided by the equipment manufacturer.

Modern bulk soils and Quaternary alluvial deposits take part in the geological structure of the site. Soils traversed within the study area are characterized by a heterogeneous lithological composition; it is worth noting the complex nature of soil intercalation, interstitial interstitiality along strike, and a change in the lithological composition of soils in depth. The entire section is characterized by intercalation of the lenses of clays, silts, loams, sands, therefore, the engineering-geological elements were distinguished by the prevalence of the corresponding differences.

From the surface to a depth of 1.0–2.1 m, the wells passed bulk soil, heterogeneous in composition, represented by crushed stone, sand, construction waste, sandy loam, slag (IGE 1). The bulk soil is poured in a dry manner, without compaction, the duration of the filling is more than 15 years. Bulk soil of medium density, medium water saturation and saturated with water.

Bulk soils are underlain by mineral and organic-mineral cohesive soils. Mineral clay deposits are represented by:

- clay of gray and yellow-gray color, light dusty fluid-plastic, interlayers soft-plastic, mixed with organic substances (IGE 6), 0.4–5.7 m thick, with thin lenses of sand and sandy loam;
- loam of gray and yellow-brown color, heavy, refractory, gravel, interlayers mixed with organic substances, with thin interlayers of sand (IGE 13), 0.6–1.7 m thick.

Organic-mineral deposits are represented by:

- silts of gray and yellow-gray color, clayey, mixed with organic substances, with thin layers of sand and sandy loam (IGE 7), 10.8 m thick;
- silts of gray and yellow-gray color, loamy, mixed with organic substances, with thin layers of sand, sandy loam and loamy loam (IGE 8), 0.4–7.9 m thick.

Under the clay soils and in their thickness by the wells sand deposits passed, which were represented by:

- sand of gray color, dusty, medium density, saturated with water (IGE 2), with sandy loam interlayers, 1.4–1.9 m thick;
- sand of gray color, fine, medium density, saturated with water (IGE 3), with thin lenses of loam, with gravel, sometimes mixed with organic substances, 2.3–2.8 m thick;
- sand of gray color, medium size, medium density, saturated with water (IGE 4), with thin layers of loam, with gravel, with a thickness of 0.5–3.2 m;
- sand of gray color, gravelly, medium density, saturated with water (IGE 10), with frequent thin lenses of loam and sandy loam, 5.4 m thick;

Sand and clay deposits are underlain by coarse clastic soils represented by:

- pebble soil with sand aggregate up to 30%, dense, saturated with water (IHE 11), with sand layers with a thickness of 2.0 m;
- pebble soil with loamy soil, interlayers with sandy loam aggregate up to 30%, dense, saturated with water (IGE 12), with interlayers of sand uncovered with a thickness of 1.5–2.4 m.

The hydrogeological conditions of the study site are characterized by the distribution of the first alluvial sediment from the surface of the groundwater horizon, which is opened by wells at depths of 0.0–0.5 m (absolute marks 4.75–4.78 m).

The groundwater horizon is confined to sandy and coarse clastic deposits represented by sands of various sizes and pebble soils, as well as to lenses and thin layers of sand in clay deposits.

During the survey, the emergence of groundwater was recorded at the time of drilling, the steady level - after 24 h. A steady groundwater level is noted at the same depths.

By the type of circulation, groundwater is pore-stratal. The aquifer is fed by atmospheric precipitation infiltration, hydraulic connection with river waters, and supply of fractured waters from the side of the slope. Unloading of soil flow occurs towards the sea.

In the bulk soils, a top water has been uncovered, the sediment of sludge and clay serving as a bedding below it.

During intense floods and heavy rainfall, during the passage of typhoons, it is possible to irrigate bulk soils at their full capacity.

The wells that have been drilled earlier on this site, the groundwater horizon has been opened at depths of 1.0–1.8 m, which corresponds to absolute marks of 3.78–4.06 m. The establishment of the groundwater level is noted at depths of 1.0–1, 4 m, which corresponds to absolute marks of 3.78–3.46 m.

The study area is located within a terrain with seasonal freezing of soils. The standard depth of seasonal freezing (dfn) [1], with the sum of the absolute values of the monthly average negative air temperatures during the winter minus 25.50 C, on the exposed surface of snow 1.7 m.

3 Development of the Construction of Artificially Prepared Foundation Bases

As a result of the analysis of the results of preliminary modeling of the work of the design options for the geocomposite base, it was obtained that the design presented in Fig. 1 should be most satisfying the requirements of current regulatory documents on operational parameters.

The total thickness of the geocomposite base under the foundation slab is 1.0 m including a layer of sand to prepare the base. The location of the geogrid layers in the backfill material should correspond to the diagram in Fig. 1b Inert materials for layer-by-layer filling during the formation of the structure:

– a leveling layer with a thickness of 0.2 m of medium-sized sand;
– backfill between the layers of the geogrid and under the monolithic slab is 4×0.2 m with a total thickness of 0.8 m. It is carried out layer by layer with crushed stone of the fraction 5–40 mm, State Standard GOST 8267-93 *.

The power of a monolithic reinforced concrete slab with stiffening ribs should be 400 mm. The design of the designed geocomposite base is envisaged wider than the monolithic reinforced concrete slab by 5.0 m in each of the four sides, as well as the dimensions of the foundation pit for the base structure. The design of the broadened geocomposite base, being an broadened platform for redistributing the loads from the structure, allows to prevent the outburst of weak soil of the base from under the building, at the same time it is a damper unit, providing additional seismic stability of the structure as a whole [2, 3].

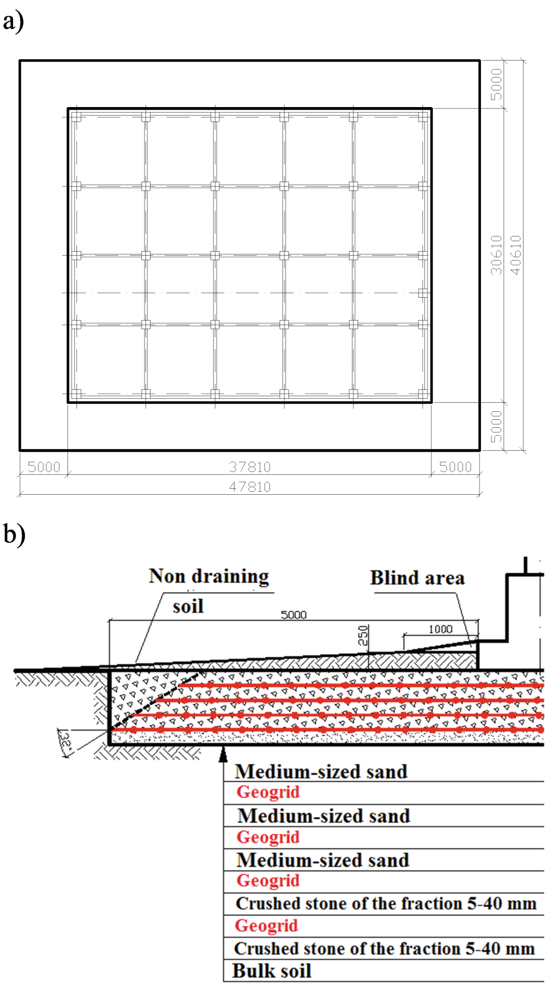

Fig. 1. The reinforcement design of the base of the structure with a geocell: (a) plan; (b) incision

4 Geotechnical Modeling Technique

Geotechnical modeling of the construction of reinforcing a weak foundation from silty clay and sandy soils for the construction of a kindergarten was carried out on the FEM models software package developed by geotechnicians in St. Petersburg. The basis of the software package is the finite element method, which allows solving three-dimensional thermophysical and stress-strain state problems of structures and their foundations with dimensions of several million degrees of freedom at an acceptable time (hours) on a regular personal computer, and in this regard it has no domestic, nor European counterparts [4–6]. The FEM models complex allows you to solve both micro and macro problems associated not only with standard representation designs, but also with amorphous media that change their physical and geometric parameters in space and time (hydraulic structures, global and local level parameter changes geological systems). Due to its capabilities, the FEM models software package is recognized by the Russian Society of Soil Mechanics, Geotechnics and Foundation Engineering as the basis for solving complex practical geotechnical problems.

To describe the operation of a weak base under load at this stage of design, an elastic-plastic model with a limiting surface described by the Coulomb-Mohr criterion was used. The choice of this model was determined by the fact that its parameters can be taken from existing materials from standard engineering and geological surveys [7, 8]. In this setting, numerical calculations are in good agreement with traditional engineering methods for calculating precipitation and allow us to describe with sufficient accuracy the deformation of structures on weak grounds. At the subsequent design stages, it is planned to apply the more subtle models of soil mechanics that we have developed, which allow us to more fully reflect the features of the behavior of soils identified during engineering and geological surveys.

At all stages of modeling of structures for reinforcing structures, an elastic-plastic model is used. The tasks are solved in a spatial setting.

The idealization of the soil base model is as follows. If the soil stress of the “characteristic volume” is less than the limiting $\sigma \neq \sigma pr$ under external loads, then the relationship between stresses and strains is described by Hooke’s law, (region I, Fig. 2), which for plane deformation can be written as

$$\left.\begin{aligned} \sigma_1 &= \frac{E'(\varepsilon_1 + \upsilon'\varepsilon_3)}{(1-\upsilon'^2)} \\ \sigma_3 &= \frac{E'(\varepsilon_3 + \upsilon'\varepsilon_1)}{(1-\upsilon'^2)} \end{aligned}\right\} \quad (1)$$

Here E′ and υ′ are flat analogues of Young’s modulus E and Poisson’s ratio υ.

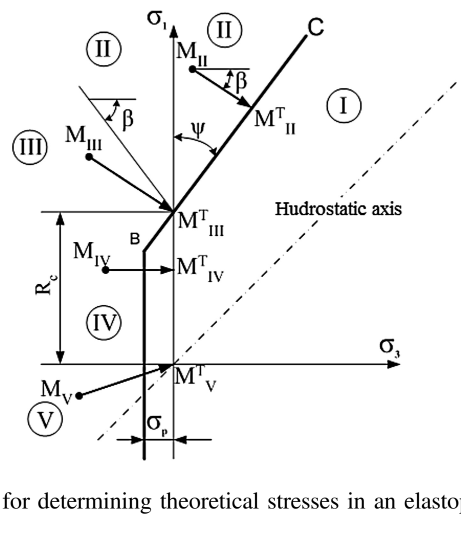

Fig. 2. Scheme for determining theoretical stresses in an elastoplastic soil model

The ultimate stresses in the tensile region are limited by the tensile strength σp (Fig. 2). Thus, region I in the tension zone is limited by the stress $\sigma 3 = \sigma_p$, and in the compression region, the Coulomb strength criterion:

$$\sigma_1 = R_c + \sigma_3 ctg\psi \tag{2}$$

Here R_c is the uniaxial compression strength.

If the point is outside the yield circuit, then the "theoretical" stresses are in the following order. If the point of total stresses MII falls into region II (the main zone of plasticity), then the "theoretical" point lies at the intersection of the yield point with the straight line. The angle β of the slope of the line is determined by the law of section and is given.

If the point of total stresses falls into zone III (point MIII, Fig. 2), then the theoretical stresses take values. In this case, the element will be torn in the direction of stress σ3, and stress σ1 will decrease to the level of soil resistance to uniaxial compression.

For region IV, in which the stresses σ1 do not exceed the uniaxial compression resistance. Finally, for region V, in which the element will be torn in all directions.

In the FEM Models program, the natural stress state is replaced by the hydraulic engineering compression tensor of the "characteristic volume" of the soil, which is summed with the actual stresses in the array:

$$\left\{\sigma_{1,3}\right\} = \left\{\sigma_{1,3}^{\Phi}\right\} + \left\{\sigma_{1,3}^{\Gamma}\right\} \tag{3}$$

Our assumption corresponds to the real picture of the natural stress state of weak soils.

5 Research Results

The used methodology and software package are implemented by the authors for many facilities under construction and operation in Russia and the Far Eastern Federal District [9–11]. Application of methods and approaches for calculating and designing geotechnical structures when using applications of the FEM-models software package has shown that it allows reliable and objective selection of materials and determination of the most rational parameters of geotechnical solutions.

When developing the reinforcement design options, as the initial data, the soil characteristics were used in accordance with the results of laboratory studies during the engineering-geological survey of the construction site foundation.

Powerful layers of sludge with a general deformation module E = 600 kPa (EGE-7) and E = 1200 kPa (IGE-8) lie at the base of the building (EGE - engineering geological element). The spatial diagram of the engineering and geological elements of the construction site is shown in Fig. 2, b. Directly under the building at the base are: - silt mixed with organic substances, with thin layers of sand and sandy loam (EGE-7) up to 11 m thick and silt mixed with organic substances, with thin layers of sand, sandy loam and loamy loam (EGE-8) up to 8 m.

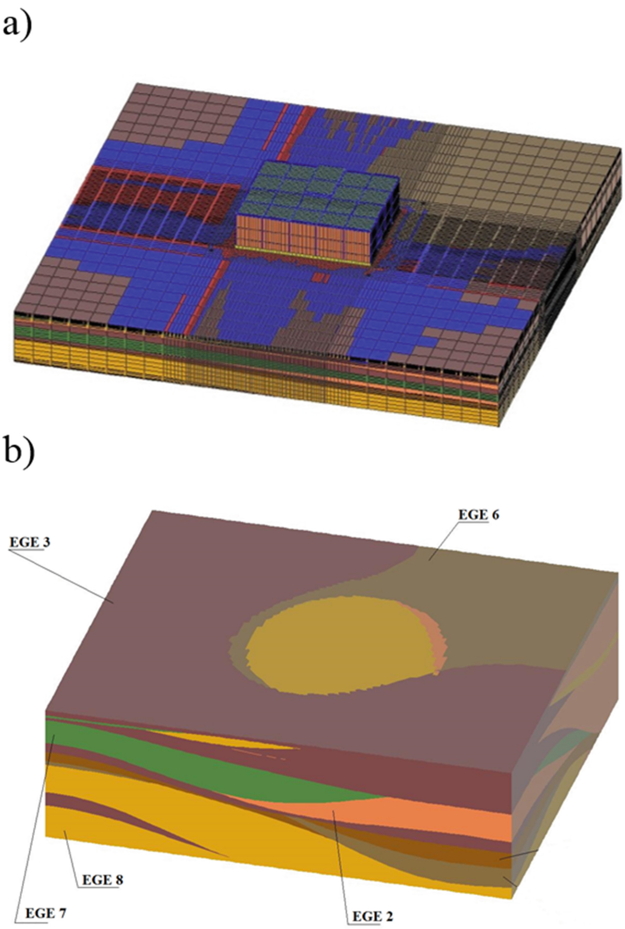

Fig. 3. Spatial design of the: (a) building; (b) ground: EGE 2 - dusty sand, medium density, saturated with water; EGE 3 - fine sand, medium density, saturated with water; EHE 6 - fluid plastic clay; EHE 7 - silt mixed with organic substances, with thin layers of sand and sandy loam; EGE 8 - silt mixed with organic substances, with thin layers of sand, sandy loam and loamy loam

The calculations were carried out using the finite element method using finite elements, which allowed us to study the stress-strain state of the base in the elasto-plastic stage [12].

To reduce the unevenness of sediments and zones of plastic deformations under the base of the foundation, a crushed stone pillow 1 m thick reinforced with 4 layers of geogrid along the height of the pillow is proposed [13–15]. The dimensions of the crushed stone pillow in terms of plan are greater than the contour of the building by 5.0 m in all directions (Fig. 3a).

To reduce precipitation and uneven precipitation, a calculation was performed at a thickness of a foundation ribbed slab 0.5 m thick with a crushed stone pillow 1 m thick reinforced with a geogrid in 4 layers with a Poisson's ratio of sludge ν = 0.45 (Fig. 4).

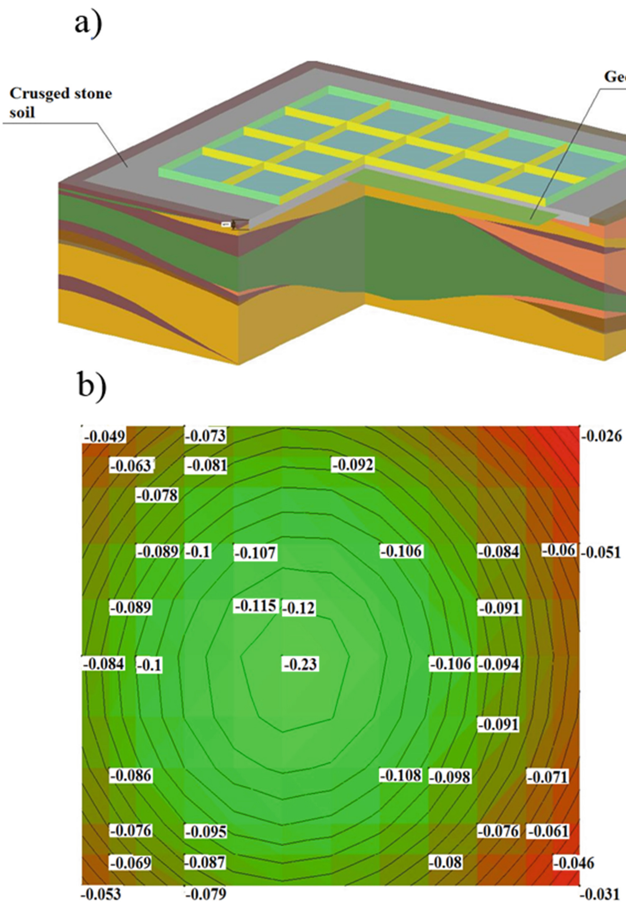

Fig. 4. A spatial section of the engineering and geological conditions of the base under the foundation slab 0.5 m thick with a crushed stone pillow 1 m thick reinforced with a 4-layer geogrid

The results show that the maximum building draft is 12.3 cm in the center of the building. In this case, the relative non-uniformity is ΔS/L = 0.004, which is equal to the limiting value ΔS/Lu = 0.004.

6 Conclusions

1. The geotechnical modeling site is located on Sakhalin Island. In geomorphological terms, the site is located on the right-bank floodplain terrace of the river, which is currently covered with bulk soil. The relief of the site is relatively flat, absolute elevations vary from 4.72 m to 5.28 m. Modern bulk soils and Quaternary alluvial deposits take part in the geological structure of the site.
2. According to the schematic map of seismic micro-zoning, the studied territory is located within the boundaries of the site with a seismic intensity of nine points. When conducting site research on micro seismic zoning, the seismic intensity was eight points.
3. Directly under the building at the base of the building are: - sludge with an admixture of organic substances, with thin interlayers of sand and sandy loam up to 11 m thick with a modulus of general deformation E = 600 kPa and sludge with an admixture of organic substances, with thin interlayers of sand, sandy loam and loam fluid (EGE-8) with a capacity of up to 8 m E = 1200 kPa.
4. To reduce the unevenness of sediments and zones of plastic deformations under the base of the foundation, it is proposed to install a crushed stone pillow 1 m thick reinforced with 4 layers of geogrid along the height of the crushed stone pillow with plan dimensions 5.0 m wider than the building outline in all directions.
5. To reduce settlement and uneven settlement of the foundation ribbed slab, it is advisable to make it 0.5 m thick with a crushed stone pillow 1 m thick reinforced with 4 layers of geogrid. According to the results of numerical modeling by the finite element method in the FEMmodels software package, the maximum settlement of the foundation slab is S = 12.3 cm, and its relative unevenness is $\Delta S/L = 0.004$. This design eliminates the relative unevenness of the deformation and reduce the values of settlement to acceptable values.
6. Due to the uniqueness and complexity of the facility, monitoring is necessary. All activities, as well as the volume and duration of monitoring at the construction site and in the zones of its influence should be carried out on the basis of regulatory documents.

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Automation of Railroad Construction Technology Using Surveying Methods

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Abstract. The paper describes the methods of geodetic support of railways during the automation of technological construction processes, which can reduce the cost of work, including geodetic location survey, the creation of a reference geodetic network, operational control, as-built surveys, etc. Peculiarities and specifics of solving engineering problems on railways are considered. The principle of operation and the design of the computer-aided design system ACS-3D, which provides geodetic data for calculating the spatial position of the working bodies of construction equipment, including coordinates, spatial orientation, and geometric parameters, are given. The structure and formats of digital projects are considered as an integral part of the automation of setting the track to the design position, including the spatial position of the track axis in the project coordinate system, geometric parameters, including the track clearance and design data. The specificity of railways in the creation of digital projects is given. The experience of using ACS-3D on the basis of global navigation satellite systems (GNSS) during the overhaul and reconstruction of the West Siberian Railway and the Trans-Baikal Railway is considered. The advantages of using geodetic methods for automating technological construction processes on railways are shown. The existing methods of setting the railway track in the design position are analyzed, their advantages and disadvantages are noted. The prospects for the use of integrated systems based on GNSS and WIN ALC are substantiated, which allow minimizing costs while solving the problems at different stages of repair.

Keywords: Railroad · Global satellite navigation systems · Automated control systems

1 Introduction

«Digital railroad» Program is dedicated to development of a unified high-precision time-coordinate network for the space of JSC "RZD" railroad network. One of the key interests of the program lies in automation of construction processes, as well as of monitoring and control of road infrastructure and its most vital operational and maintenance tasks. The most significant effect is experienced from automation of the heavy-duty tasks lying in

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repair and reconstruction of the railroad infrastructure, and in some of the operational tasks. One of these tasks is surveying support. Automation in surveying allows increasing the speed and effectiveness of work with the most significant benefits witnessed not in surveying tasks in general, but in various parts of construction processes, some parts of construction and maintenance work. One of the good examples would be ballasting of the railroad during reconstruction and monitoring for infrastructure quality. This approach is implemented through automation of controls of construction machines (bulldozer, land grader) and railroad construction and special-use machines (electric ballast vibrator, track renewal train, ballast cleaning machine). These systems considerably reduce operational costs for such works as geodetic coupling, development of control network, operational control, surveying, etc. [1].

One of the most important tasks of that projects is the development of automated control systems (ACS) for road and railroad construction machines utilizing geodetic survey equipment and methods. Another important task is the development of software for ACS operation, which includes digital projects, coordinate conversion systems to ACS coordinates, interactions with other common railroad machines (including those with standard controls).

2 Materials and Methods

The development of automated control systems (ACS) for railroad construction machines (electric ballast vibrator, track renewal train, ballast cleaning machine) utilizing global navigational systems (GNSS), spatial and surveying methods is one the most important parts of the automation of construction processes [2].

Automation control systems (ACS) utilize positioning data for calculations used in machine operation, positioning of its limbs and systems as well spatial navigation.

Acquired data is used for control of working attachments (shovel, bucket) of construction machines. Road construction machines are equipped with two types of control systems based on their functionality: indicating systems and automated systems. Indicating systems notify the operator about variations in one or more parameters. Automated systems not only notify the operator about discrepancies with the project, but also automatically control the working attachments to achieve the project set constructions position as well as correspondence of values for digital surface models with project values on ground, ballast, road clothing. Level graders, bulldozers, digging machines, packing machines are equipped with imported control systems and are widely used by construction companies. Leica, Trimble, Topcon are one of the main ACS producers. ACS operational principle is based on deployment of digital projects on the area of construction (repair) by comparison of actual and projected coordinates or geometric parameters (or other parameters in indicating systems) in ACS-3D. The main differences in railroad construction and repair machines ACS lie in constructional specifics, features of work attachments, significant variance in precision of corresponding spatial positioning of railroad elements, strict requirements to transport safety. For example, bar chain (work attachment of ballast cleaning machine) is located under the layer of ballast 0.7–0.8 m below the head point of the rail; track renewal device of the electrical ballast machine is located under the chassis which excludes the possibility of signal reception from navigational satellites. This is the reason why one can't use auto construction machine solutions for railroad applications. To triangulate the coordinates of the bar chain or the track renewal device the antenna should be positioned on the visible upper part of the chassis. Calculated coordinates then should be reduced to the actual height of the bar chain or the track renewal device in line with the phase center of the antenna. These specifics lie in the theoretical design of a kinematic and principle schematics of implementation of ACS using GNSS [3–5].

3 Results

Overview of an electrical ballast vibrator is in Fig. 1.

Fig. 1. Overview of an electrical ballast vibrator equipped with ACS-3D

Structural schematic of calculation of shift and raise for repositioning of the railway track to the project position using GNSS data is illustrated on Fig. 2.

A scheme of coordinate reduction of satellite antennas to the axis of the track is illustrated on Fig. 3.

Reduction value is calculated according to (1):

$$dS = \frac{H_2 - H_1}{P} * l \tag{1}$$

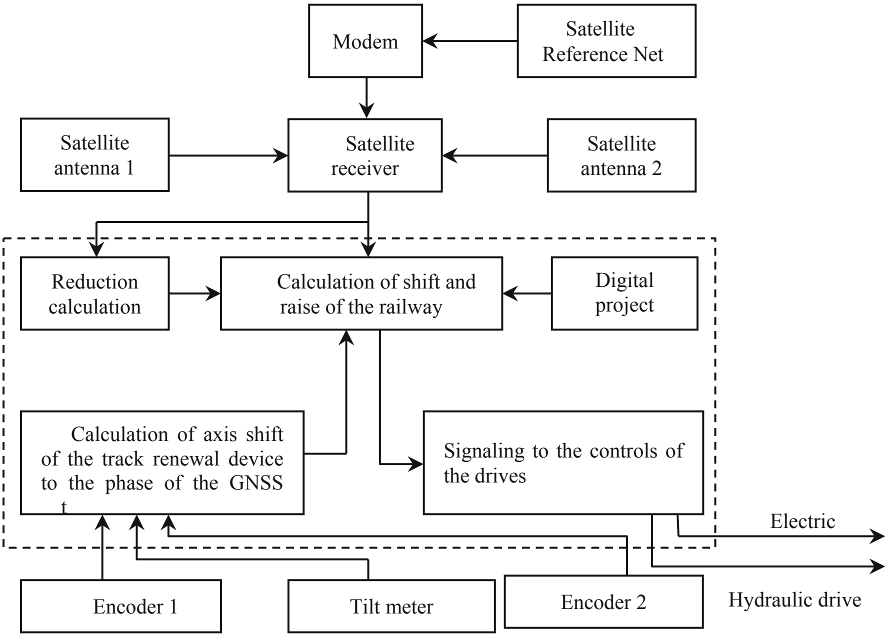

Fig. 2. Structural schematic of calculation of shift and raise and signaling in ACS-3D (EBV)

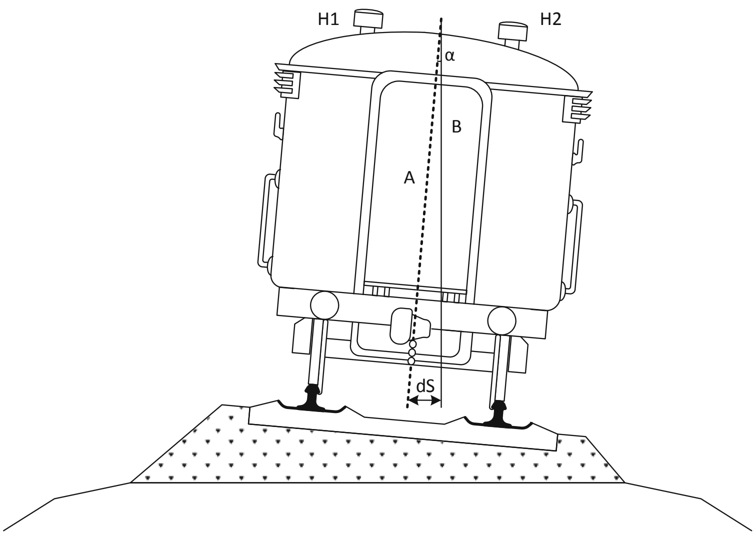

Fig. 3. Reduction of coordinates of the relative phase centers F1 and F2 on the track axis

where H_1 and H_2 – heights of satellite antennas, l – distance between satellite antenna's phase centers to the head of the track, P – distance between phase centers of satellite antennas. Data from tilt meters and g-meters turned out to be unreliable due to the inertia delays, which didn't compensate for the antenna shift. A two-satellite antenna setup (with the plane of the antennas perpendicular to the track) turned out to be the optimal one for defining the reduction values to the track axis (as in Fig. 3).

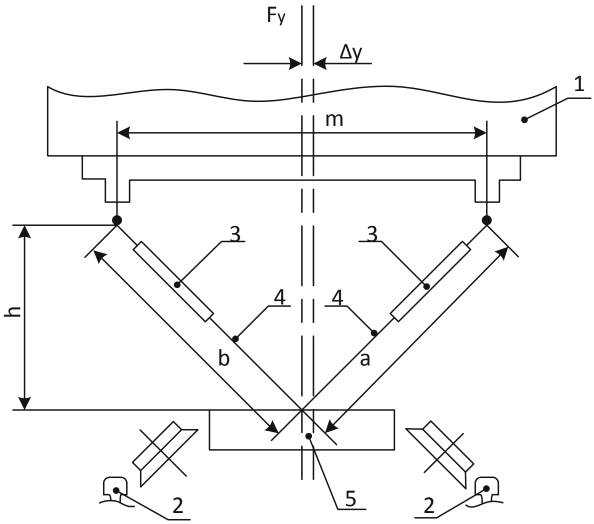

Fig. 4. Principal scheme of defining the position of the axis of track renewal device in relation to the relative phase centers of satellite antennas: 1 – chassis of the machine, 2 – track, 3 – encoders, 4 – cable-line devices, 5 – TRD axis, F_y – axis of the relative phase center, Δy – shift.

Position of the axis of track renewal device in relation to the relative phase center (average between phase centers coordinates) is calculated according to the scheme in Fig. 4.

Calculation of the planar and profile position of the axis of the track renewal device in relation to the relative phase center is performed according to Eqs. (2) and (3):

$$h = \sqrt{a^2 + R - \left(\frac{m^2 + a^2 - b^2}{2m}\right)^2} \quad (2)$$

$$y = \frac{m^2 + a^2 - b^2}{2m} \quad (3)$$

Where a, b – distances between fixed points of the measurement base m on the chassis of the machine to the axis of the track renewal device, R – radius of rotation of the cable-line system.

Principal and kinematic schemes differ while implementing the aforementioned technical solutions due to the specifics of machine types and designs of the work attachments to be controlled. The main difference in creation of ACS-3D for railway construction machines is the three-layered structure of data retrieval. It includes navigational measurements, reduction of coordinates to the track axis and positioning of construction machine work attachments in relation to the phase center of antennas. Data analysis and filtration systems include algorithms with coarse calculation mistakes exclusion; algorithms of control measurements with gyroscopic system; Happing smoothing filter; sliding average based on three points of the row (4) [6]:

$$\bar{X}_i = \frac{1}{4}(X_{i-1} + 2X_i + X_{i+1}) \quad (4)$$

where i – numerical order, $\bar{X}_i$ – sliding average value for i, X_i – actual value in the smoothing interval.

Some devices use fiber-optic VG type g-sensors, solid-state TG g-sensors. These sensors provide reliable data for filtration.

An integral part of the automation of track renewal process is development of digital projects (DP). Development of digital projects directly affects the cost and quality of the track renewal process, because the transformation of standard (traditional) projects to digital projects, including field and office work, is a resource consuming process which affects greatly the possible lifespan of the digital project between capital repairs.

Automotive road construction companies have vast experience with digital projects. They use projected surfaces that are the base of the Digital Projects (DP) for scheduling of dirt bad planning, construction of road clothing, coverage for ACS-2D, ACS-3D. Construction is carried out by bulldozers and level graders equipped with ACS-3D. Utilization of ACS-3D technologies significantly reduces operational costs, increases productivity as well as quality of operation [7].

4 Discussion

Some railroad specifics constitute requirements for the digital projects:

1. All the railroad infrastructure objects are tied to the axis of the track.
2. Building sizes are attached and controlled relative to the track axis.
3. Elements of traversal and longitude profile, including geometric parameters are tied to the axis of the track.
4. Projects for capital repair (reconstruction) are tied to the repair track and are calculated in relation to track axis, including spatial data.

These factors are considered while developing a digital project for the repair (reconstruction) of the railroad track. The structure and format of the DP include spatial position of the track axis in project coordinates, geometric parameters including sizes of buildings, project data also in relation to the track axis. A software/hardware system APK "Profil" is used for development of digital projects. The system allows obtaining spatial data of the track as well as a detail survey of the curves [8]. The development of APK "Profil" is dictated by the need to acquire spatial data and geometric features for digital project development. Spatial data is traditionally obtained through surveying, but the digital projects for ACS require 1–2 m spatial resolution which elevates the time and money costs of surveying works. Geometric parameters of the track are traditionally obtained with cable line methods by track-monitoring labs (ZNII 4, KVLP) which do not acquire spatial data. Thus, surveying can't be used in geometric parameter acquisition due to the cost constraints while traditional cable line monitoring methods can't obtain spatial data. APK "Profil" eliminates drawback of both methods by performing these two tasks simultaneously using the current coordinates while in motion. Additionally, output format of the files meets official requirements of JSC "RZD", in example calculation and visualization of curve data is done in accordance with form FP-5, geometric parameters in accordance with CP-515.

This is an example of a line of headings of the fields of the digital project (DP).

DP line for electric ballast vibrator (EBV): $x; y; h; alfa; pk; shift\_pk; dS; dH$;

where $x; y; h$ – coordinates of the current position based on GNSS data in local coordinate system MSK; *alfa* – deflection angle, degrees (degree percent); *pk* – staking, m; *shift_pk* – distance relative to the stack, m; *dS* – track shift; *dH* – track tilt (elevation), m.

Digital projects correlate fully to the project solutions, that is why before the start of the work, for transport safety reasons, DPs are tested over the repaired part of the track using a railroad navigational device.

Experiments utilizing ACS-3D with GNSS data at the North-Siberian railroad and Zabaykalskaya railroad in the amount of 900 km of capital repair and reconstruction of the track indicated high technical-economic metrics, reliability of the ACS and the possibility of autonomous operation of track renewal machines without initial surveying and network referencing as well as other preparational phases that are commonly used in traditional railroad track renewal methods. Picture 5 evidently demonstrates that there is no survey reference net present while the quality of the track renewal (at ballasting phase) using ACS-3D with GNSS data is high.

Productivity of surveying support increased by 4–6 times depending on the difficulty of the repair area, with higher productivity correlating to more difficult areas. Availability of a reference GNSS network significantly increases the usability of ACS-3D, possibly futureproofing its features, taking into consideration the intensity of GNSS reference net development in Russian Federation throughout the last 5 years (Fig. 5).

An analysis of the ways of setting the railway track to the design position shows that when setting the track to the design position, a copy string, plane laser systems (rotational levels), systems based on the calculation of shifts of WIN ALC type, complex systems with laser system and GNSS, for example, EM-SAT, are currently used. The structural diagram of methods for setting the railway track to the design position is shown in Fig. 6.

Fig. 5. Part of the railroad track (ballasting phase) after repositioning of the track to the project values with an electric ballast vibrator equipped with ACS-3D utilizing a satellite reference net

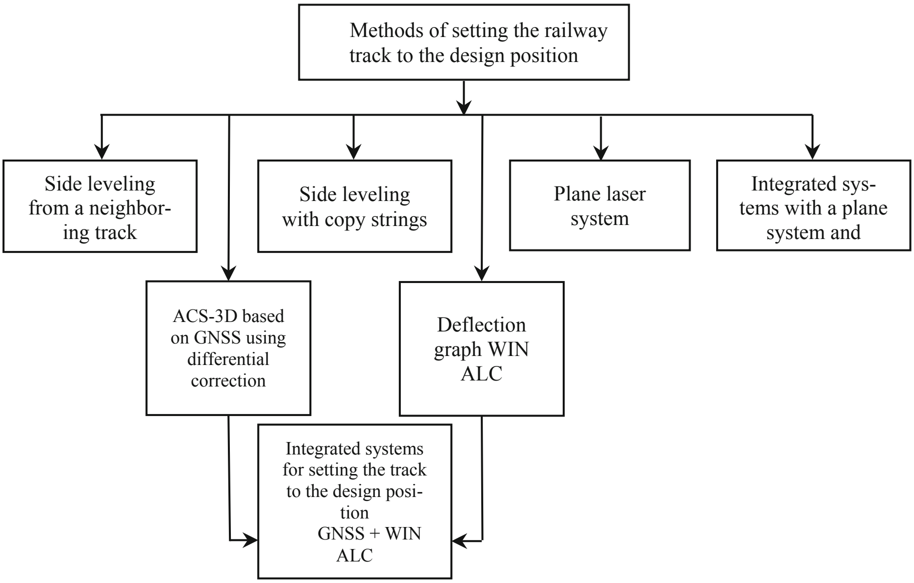

Fig. 6. The structural diagram of the methods of setting the railway track in the design position

Integrated systems allow minimizing costs at different stages of repair while ensuring assigned tasks, for example, at the stage of ballasting the railway track, setting is made in the design position using automatic control system based on GNSS without geodetic control works, which is mandatory with other setting methods, and at the stage of final surfacing WIN ALC, which provides both smoothing and final setting in the design position according to the graphs of the deflection obtained after the work of ACS based on GNSS. This reduces the time-consuming geodetic control work at the ballasting stage and full-scale survey of coordinates or geometric parameters for calculating deflection for WIN ALC. The advantage of an integrated system for setting the track to the design position is the creation of a single digital project for all construction vehicles working during the repair of railways. A single coordinate environment provides high quality work, eliminating errors.

Almost all of the above systems are used in Russia, but not all methods of setting the track to the design position have become widespread for various reasons.

Each of the above methods has advantages and disadvantages in comparison with the proposed method of setting the railway track to the design position. So, if we compare our proposed method and method using a copy string, the less expensive preparatory work and the exclusion of geodetic control works, which significantly reduces the cost of preparatory work, is an advantage of GNSS-based technologies. The disadvantage of GNSS in comparison with the use of a copy string is the relatively low accuracy and the necessity of using a satellite reference network, or the creation of temporary base satellite stations.

When assessing the prospects for the development of automated control systems (ACS) based on GNSS, it is necessary to consider the tendency to reduce the cost of GNSS and improve the accuracy of measurements, in addition, GNSS developers have recently created complex GNSS devices with inertial systems, which significantly improves the quality and reliability of spatial measurements.

Automated control systems (ACS-3D) based on GNSS and WIN ALC systems were used in 2017–2018 on the Trans-Baikal Railway and showed high results in ensuring the quality of work, technological compatibility and the possibility of using one digital project for ACS based on GNSS and WIN ALC. The essence of the integrated use of these systems lies in the fact that ACS on the basis of GNSS ensures that the railway track is in the design position at the stage of ballasting, and WIN ALC at the stage of final surfacing of the railway track, which makes it possible to efficiently use these surfacing system in complex, since WIN ALC operates in conditions of minimal (1–3 cm) track shifts due to high-quality operation of ACS-3D based on GNSS at the ballasting stage.

This complex for setting the track to the design position is, in our opinion, the most promising. The positive experience of operating on the Trans-Baikal Railway of Russian Railways, taking into account difficult conditions with a large volume of curves, including small radius curves, shows the potential for the propagation of complex track surfacing using ACS based on GNSS and WIN ALC.

Automated control systems (ACS) and indicator-type control systems based on the use of plane laser systems or complex systems with plane laser systems due to the complexity of the organization of work, the large amount of preparatory work and the influence of climatic conditions will not receive widespread use in Russia.

At the same time, certain types of work, for example, planning of the subgrade, providing control of work at various stages of construction using plane laser systems, are effective due to the lower cost of equipment.

Thus, the ACS-3D on the basis of GNSS under the conditions of the existing technology of repair work at Russian Railways, technical processes for repairs and the modern regulatory framework of Russian Railways fully comply with the requirements. And operating experience has shown that the systems are efficient and provide a reduction in rail repair costs. More than 1000 km of repairs are carried out annually with the use of GNSS-based ACS for various construction railway vehicles developed at the Siberian Transport University. ACSs are being developed for new types of construction railway vehicles.

5 Conclusions

1. Navigational methods of construction process automation allow skipping several preparational phases, such as surveying, continuous operation control as well as they reduce the costs on executive surveys.
2. Utilization of navigational data increases overall quality of operation in comparison to relative methods.
3. Number of required track renewal personal is reduced. Human factor errors are thus minimized accordingly.
4. Staff security is increased while working at the railroad tracks.
5. The most significant result of the research is the findings that it is much more effective to automate the construction process (planning of the dirt bad, ballasting and other types of work) using navigational methods than it is to automate the surveying itself.

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Perspective Constructions of Bridge Crossings on Transport Lines

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Abstract. When designing bridge crossings on highways and railways, classical beam or truss design schemes of structures made of steel or reinforced concrete are usually used, but at present, there is a significant increase in the movement speeds of individual vehicles, axle load and total train weight, and a decrease in temporary intervals between compositions. These factors lead to an increase in dynamic effects and necessitate the use of non-classical design schemes of artificial structures of the transport infrastructure. In the present study, it is proposed to use a three-span arch bridge crossing with a suspension central span structure as the basis for a unified bridge crossing; such an arrangement will allow changing the design length of the central span in a fairly wide range, reduce the total number of supports with an increase in the total length of the bridge crossing, and use such a design as a double-track railway, two- or four-lane road bridge. The calculations and the obtained results of assessing the displacements, internal forces and stresses in the nodes and elements of the proposed bridge crossing design allow us to conclude that the allowable limit magnitudes of the values found are sufficiently uniform load of all the main elements, the absence of pronounced large-scale stress concentrators.

Keywords: Bridge crossings · Overpasses · Finite element method · Railway devices crossings

1 Introduction

The modern development of transport systems, on the one hand, is characterized by an increase in the speeds of rolling stock and an increase in the useful mass of the transported cargo; in fact, this leads to an increase in axle load, and this applies to all types of vehicles. On the other hand, it is relevant and timely to consider the issues of unifying structural solutions of artificial structures, since from the point of view of modern economic efficiency, bridge crossings and overpasses are increasingly used to straighten sections of roads in the plan and profile. Often, when designing such structures, classical design schemes of structures made of both steel and reinforced concrete are used, it is possible to distinguish a spatial metal truss, a multi-span split

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and a continuous metal or reinforced concrete beam [1, 2], but since the onset of the indicated design diagrams and arrangements load-bearing elements, significantly increased the speed of the crew movement, the load on the axis and the total mass of the train, as well as reduced intervals between trains. Also, traditional bridge crossings imply the installation of supports, at almost the same distance from each other, with a possible slight increase in the main span, but in any case, it is assumed to build channel support parts, the construction of which is rather expensive.

2 Research Methods

In the present study, it is proposed to take the well-known three-span arch bridge crossing with a suspension central span structure as a basis for a unified bridge crossing; such an arrangement allows changing the design length of the central span in a fairly wide range, reducing the total number of supports while increasing the total bridge crossing length, and also using as a two-track railway, two- or four-lane road bridge. General view of the bridge crossing is presented in Fig. 1.

To prove the effectiveness of the assumed constructive solution, it is proposed to determine the internal forces and stresses in the structural elements of the bridge crossing (Fig. 1). As a calculation method, we apply the finite element method using as the main unknown displacements and turns of the design scheme nodes, since this method is widely used in the engineering and design community and is implemented in almost all modern, actively used and passed expert verification computing software complexes [3, 4].

The proposed design for adaptation to the finite element method is assumed to be represented as a set of standard type bodies (rods, plates, shells, etc.) interconnected by nodes [4, 5]. The type of a finite element is determined by its geometric shape, the dependencies between displacements of its nodes and nodes of the design scheme, Hooke's law for each element, and a set of stiffness parameters [6, 7].

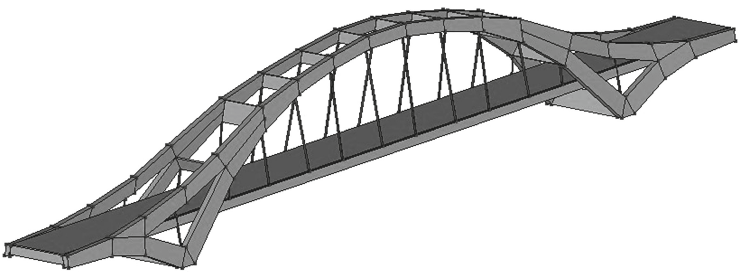

Fig. 1. General view of the proposed construction of the bridge crossing

The node in the calculation scheme of the finite element method in displacements is represented as an absolutely rigid body of infinitely small size. The position of the node in space is determined by six degrees of freedom - three linear displacements and three angles of rotation. The basic system of the finite element method in displacements is selected by imposing links on each possible displacement [6, 8]. Since the imposition of additional connections occurs only within the framework of mathematical modeling, but in reality, the efforts arising in these relations are equal to zero. This condition allows creating resolving equilibrium equations, which can be solved by determining all the necessary unknowns.

The possible movements of the finite element calculation scheme nodes are limited by external relations that prohibit some of these movements. The presence of such connections is due to the interaction of the base and foundation of the structure. Connections are located in the nodes of the foundation elements in the direction of the base.

When compiling the design scheme, five main types of finite elements were used:

1. the core element, working according to the spatial scheme and perceiving the longitudinal force N, bending moments M_y and M_z, lateral forces Q_z and Q_y, and also the torque M_k. Displacements of core elements were approximated by polynomials of the third degree in the absence of a shift [3, 4] and transcendental in its presence [8].
2. the four-node flat element whose deflections of points are described by an incomplete polynomial of the fifth-degree. The element is intended for the calculation of thin plates. There are three degrees of freedom in each of the FE nodes: w - vertical displacement (deflection); $\alpha = \partial w/\partial y$ - angle of rotation relative to the axis X; $\beta = -\partial w/\partial x$ - the angle of rotation relative to the Y axis. For such elements, the forces M_x, M_y, M_{xy}, Q_x, Q_y and the reactions at the nodes are calculated [4, 7].
3. the triangular shell element, the geometric shape of which on a small part of the surface can be assumed to be flat. Such an element is not joint, the field of normal displacements inside it is modeled using a fourth-degree polynomial, and the field of tangential displacements - using a first-degree polynomial [3, 8].
4. the quadrangular element of the shell, which is not joint, the field of normal displacements inside it is modeled by a polynomial of third-degree, and the field of tangential displacements is incomplete by a polynomial of second-degree [3, 7, 8]. Each node of finite elements of the shell has six degrees of freedom: U, V, W - linear displacements along the x, y and z axes; $\alpha = \partial w/\partial y$, $\beta = -\partial w/\partial x$, γ - angles of rotation relative to the x, y and z axes, respectively. The degree of freedom of U, V is membrane, and W, α, β - bending deformation. The angle of rotation γ in the local coordinate system of an element is always zero. It is introduced for joining elements that are not lying in the same plane and is necessary for the spatial work of the structure.
5. the connection of finite stiffness, this finite element is used to account for the compliance of the support link in the direction of one of the freedom degrees provided by the computing complex in the general coordinate system. This final element allows to simulate the work of an elastic base, for linear displacements it can be interpreted as compressive stiffness, causing a unit displacement of a node along a given direction [3, 6]. When modeling an elastic base for setting this

stiffness, the first coefficient of the bed should be multiplied by the surface area interacting with the node. For angular displacements, this finite element can be interpreted as shear stiffness, causing single turns in a given direction. To account for the elastic base, the second bed ratio should be multiplied by the surface area interacting with the node [4, 9].

Equilibrium equations of structural elements using the finite element method can be obtained applying the principle of possible displacements. If we assume that ū is the field of point displacements of a deformable element under the action of external loads, then δu is an additional small displacement of each point of the element [6, 10]. In accordance with the principle of possible displacements, the increment in the work of internal forces δU is equal to the work of external forces δW on possible displacements of the body. If represent the load applied to the element as the sum of the load q distributed over the volume of the element V and the load p distributed over its surface S, then can write

$$\int_V \sigma \cdot \delta\varepsilon \cdot dV = \int_V \bar{q} \cdot \delta\bar{u} \cdot dV + \int_S \bar{p} \cdot \delta\bar{u} \cdot dS \tag{1}$$

here $\sigma = \sigma_{ij}\bar{e}_i\bar{e}_j$ - the stress tensor, $\varepsilon = \varepsilon_{ij}\bar{e}_i\bar{e}_j$ - the strain tensor, $\bar{e}_i$ and $\bar{e}_j$ - unit units, i, j = 1, 2, 3.

The strain tensor can also be represented through the displacements of the nodes of the design scheme λ_k.

$$\varepsilon_{ij} = \frac{1}{2}\left(\frac{\partial \Phi_{ik}}{\partial x_j} + \frac{\partial \Phi_{jk}}{\partial x_i}\right)\lambda_k \tag{2}$$

Taking into account expressions (2) and Hooke's law, the equilibrium equation of element (1) can be represented as follows [4, 8, 10]

$$\int_V D\bar{\nabla}\bar{u} \cdot \delta(\nabla\bar{u}) \cdot dV = \int_V \bar{q} \cdot \delta\bar{u} \cdot dV + \int_S \bar{p} \cdot \delta\bar{u} \cdot dS \tag{3}$$

If we use expression (3) as applied to a finite element of a certain volume and surface area, taking into account the fact that $\delta\bar{u} = \Phi_i \cdot \delta\lambda_i$, then we obtain a system of linear algebraic equations expressing the equilibrium conditions of a finite element in matrix form

$$\{K\}\{\lambda\} = \{f\} \tag{4}$$

Where $K_{ij} = \int_V \nabla\Phi_i \cdot D \cdot \nabla\Phi_j \cdot \lambda_i dV$ - the stiffness matrix of the element in different directions, $f_i = \int_V \bar{q} \cdot \Phi_i \cdot dV - \int_S \bar{p} \cdot \Phi_i \cdot dS$ - the vector of forces applied at the element nodes, $\{\lambda\}$- the vector of nodal displacements, i, j = 1, 2, … N.

Equations of type (4) for the calculation of structures for strength under static loading, when solving them, the vector of nodal displacements is calculated, and then the displacements of all points of the body, deformation and stress are determined. To obtain the equations of motion of a finite element, it is necessary to introduce into the formula (4) the volume inertia forces obtained according to the D'Alembert principle, and then we obtain

$$\{M\}\{\lambda\} + \{K\}\{\lambda\} = \{f\} \tag{5}$$

where $M_{ij} = \int_V \rho \cdot \Phi_i \cdot \Phi_j \cdot dV$ - the mass matrix of the element, ρ - the density of its material.

When using the finite element method, the true form of point displacements inside flat or shell elements is approximately represented by various simplified dependencies [6, 11]. In this case, the error in determining stresses, forces, displacements, and deformations is of the order of $(h/L)^k$, where h - the maximum grid spacing; L - the characteristic size of the study area. The rate of decrease in the error of an approximate result is determined by the exponent k, which has a different value for the various desired functions.

When modeling the behavior of the proposed bridge crossing design, various static and dynamic loads and their combinations were taken into account. When performing a dynamic calculation of the system, decompositions into natural oscillation forms were used, taking into account wind flow pulsations of 6 forms, and 4 forms were taken into account when taking seismic action.

Also, in the calculation can be used additional unknowns that are not identified with the components of linear or angular displacements of the node as an infinitely small rigid body at a point coinciding with the center of the node. Additional unknowns include the second mixed derivative of the deformed surface of the plate, which is responsible for torsion, or the components of the transverse shear and compression deformations in layered shells. These values are auxiliary and are used to improve the accuracy of calculating the main unknowns of the scheme [8].

After determining the displacements, you can proceed to the definition of other functions that characterize the behavior of the structure under the action of various loads and their combinations. For core elements, the counting results are the forces that are calculated for the plane of the end section and in the center of the elastic part [10]. The calculated forces correspond to a given type of core procedure from the general tensor of forces (N, M_k, M_y, Q_z, M_z, Q_y). As a result of the calculation for the plate, volume and shell elements, displacements, forces and stresses are determined at the nodes, as well as at the center of the element gravity. Figure 2 show isopoles of longitudinal forces along the x axis, shear forces in the xy plane, bending moments M_y, transverse force Q_x (in a mode that does not show volume elements, since this force is small in them), respectively (the force values are presented in T/m^2, moment values in T*m/m).

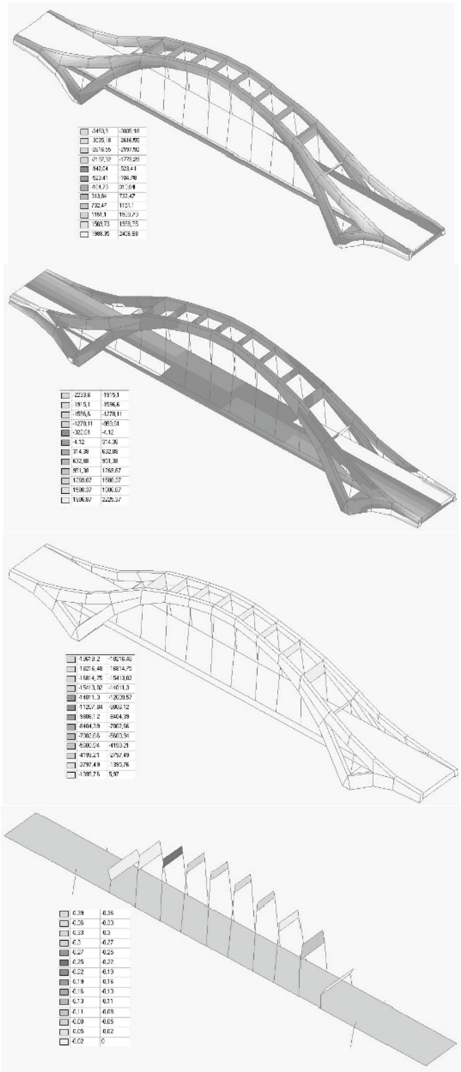

Fig. 2. The isopoles of longitudinal forces along the *x* axis, shear forces in the *xy* plane, bending moments M_y, transverse force Q_x

The results presented in Fig. 2 allow us to determine the most loaded places of the proposed bridge crossing design, stress concentrators, and also to understand the overall picture of the distribution of efforts and the nature of work of the entire structure as a whole. In general, it can be seen that the presented values are within acceptable limits, and their values in certain places of the structure show, in general, the uniformity of loading of all nodes and elements, without causing the appearance of extreme values of effort, which is an advantage of this bridge crossing design. The calculated forces and stresses corresponding to each of the dangerous combinations of loads found can be proposed to the designer and constructor for analysis.

To select unfavorable design combinations of forces, the principle of superposition is used; of all possible combinations, those that correspond to the maximum value of a certain reduced value selected as a criterion and dependent on all components of the stress state are selected:

– for rods such values are the extreme values of normal and tangential stresses at the control points of the section, these include the corner points of the cross section and the points on the faces, the coordinates of which are associated with the corner points of the core of the section.
– for elements that are in a plane stress state, the defining values are the envelope extreme curves of normal and tangential stresses, which are defined by the following formulas:

$$\sigma(\alpha) = N_x \cos^2 \alpha + N_z \sin^2 \alpha + T_{xz} \sin 2\alpha \quad (6)$$

$$\tau(\alpha) = \frac{1}{2}(N_z - N_x) \sin 2\alpha + T_{xz} \cos 2\alpha$$

– for slabs, a similar approach is applied; the quantities that are determined in this case are bending and torsional moments, calculated using the following formulas:

$$M(\alpha) = M_x \cos^2 \alpha + M_y \sin^2 \alpha + M_{xy} \sin 2\alpha \quad (7)$$

$$M_k(\alpha) = \frac{1}{2}\left(M_y - M_x\right) \sin 2\alpha + M_{xy} \cos 2\alpha$$

In addition to the internal moments, for the plates, the extreme values of the shear forces are determined.

– for shell finite elements, the stresses on the upper and lower surfaces of the shell are calculated taking into account membrane stresses and bending forces.
– for volumetric elements, the criterion for determining dangerous combinations of voltages is the extreme values of the average voltage and the main voltage of the deviator.

To obtain a more voluminous picture of the power characteristic distribution of the elements and nodes of the proposed bridge crossing design, it is proposed to determine also the main and equivalent voltages. The picture of their distribution will make it possible to reduce the number of compared values, to obtain more complete data on the operation of the structure as a whole and its individual elements [4, 11].

To calculate the principal and equivalent stresses, we use the assumption that the element passing through an arbitrary point and an arbitrarily oriented area, the normal to which v has directional cosines l, m, n with x, y, z axes, is acted upon by the normal stress σ_v and the shear stress τ_v with resultant S_v. At the same time, at any site, the resulting voltage is $S_v \leq \sigma_1$ and $S_v \geq \sigma_3$, where σ_1, σ_2 and σ_3 are the main voltages, with that $\sigma_1 \geq \sigma_2 \geq \sigma_3$.

For the general characteristics of the stress-strain state, the Lode-Nadai parameter is proposed.

$$\mu_0 = 2\frac{\sigma_2 - \sigma_3}{\sigma_1 - \sigma_3} - 1 \tag{8}$$

Value $\mu_0 = 1$ corresponds to pure compression, $\mu_0 = 0$ to pure shear, $\mu_0 = -1$ to pure stretching.

For flat and shell elements, it is proposed to determine the main stresses on the lower, middle and upper surfaces in order to better understand the stress-strain state of the element and analyze its work in the overall structure of the building.

For a complex stress state characterized by principal stresses, a certain hypothesis (theory of strength) is often used, which provides for the possibility of matching some equivalent stress σ_e with the limiting value corresponding to simple uniaxial tension (σ_0^+) or uniaxial compression (σ_0^-). The condition characterizing the absence of a limiting state in the material can be represented as

$$\sigma_e = f(\sigma_1, \sigma_2, \sigma_3, k_1, \ldots k_n) \leq \sigma_0^+ \tag{9}$$

where k_1, …, k_n - some material constants characterizing its mechanical properties.

Figure 3 shows the isopoles and isolines for the main stresses in the structural elements on the outer surface of the finite elements, the difference in the work is seen from the point of view of the conditional tension and compression of various surfaces of flat and shell elements. Taking into account the obtained data, it is necessary to plan the strengthening of reinforced concrete elements or select the cross-section and material of steel elements.

Figure 4 shows the equivalent stresses for the middle layer, in the form of isopoles and isolines. A pairwise comparison of Figs. 3 and 4 reveals the possibility of using as the resulting functions, showing the overall stress-strain state of the bridge crossing design, both the main stresses and equivalent stresses.

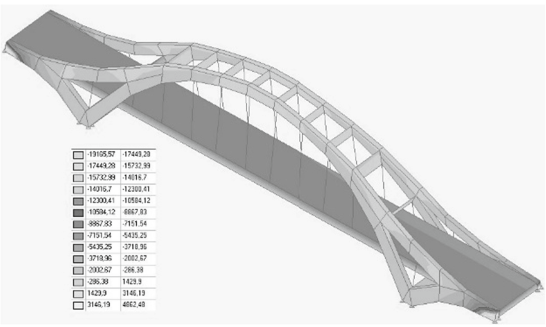

Fig. 3. The isopoles and isolines for the main stresses in the structural elements on the outer surface of the finite elements

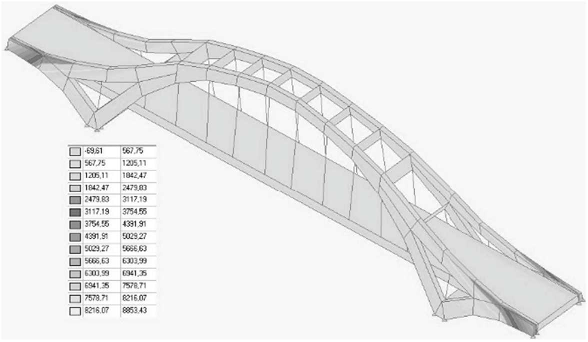

Fig. 4. The equivalent stresses for the middle layer, in the form of isopoles and isolines

3 Results

The calculations and the obtained results of evaluation the displacements, internal forces and stresses in the nodes and elements of the proposed bridge crossing design permit us to conclude that the allowable limit values of the found values; sufficiently uniform load of all the main elements, the absence of pronounced large-scale stress concentrators.

The proposed design allows setting different sizes of spans during the design, to reduce the number or even to avoid the installation of channel supports, to adapt this structure for passage for both rail and road transport. The bridge crossing design, a rather detailed mathematical model, which was considered in this article, can be manufactured at the factory, and then delivered and installed at the setting site, which can significantly reduce the final cost of construction, and make it an advantageous solution, for example, for railway devices crossings in various levels, in settlements and on the most loaded transport directions.

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Method for Detecting Fatigue Damage to Bridges by Analyzing Dissipative Processes in Metals Under Periodic Loading

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Abstract. The purpose of the work is to study the main parameters of energy dissipation in metals under periodic loads in order to detect fatigue cracks in the metal structures of railway bridges. The method of research is the method of infrared thermography. The objects of study are fatigue cracks. Dynamic tests of a beam with a fatigue crack in the loading ranges corresponding to real loading of span structures in terms of frequencies and amplitudes of oscillations were carried out. To study the influence of measurement conditions, measurements were taken at different distances from the infrared detector to the beam surface, with different recording lengths corresponding to the train passing time over the bridge, at different frequencies and oscillation amplitudes. For processing thermograms, a special technique and software are developed. As a result of the study, it was established that in all loading modes, the tip of the fatigue crack, which has an increased heat emission compared with the surrounding surface of the beam, is recognized uniquely and confidently by infrared thermography. With short recordings, the influence of environmental conditions is minimized. The developed method of processing thermograms, based on the integration of temperature increments under cyclic loading, makes it possible to completely eliminate the influence of extraneous factors.

Keywords: IR-thermography · Fatigue cracks · Steel bridges

1 Introduction

Fatigue damage occurs in the metal of the bridge structure elements in stress concentration sites (areas of weld breaks, sheet geometry changes, in welds when they are not of high quality, etc. [1–3]), under the effect of repeated loads from vehicles, wind. They are a common defect in metal span structures of railway bridges and account for about a half of all faults in welded span structures. The analysis of the bridge state has shown that about 5000 spans with such damages are in operation throughout the entire railways network of JSC Russian Railways [4]. At the same time, over the past 6 years, only on the West Siberian railway, the number of fatigue cracks has increased by 25% with an average service life of the structures no more than 40 years. Such the dynamic of faults indicates an increase the problem. To date, there are several ways to detect fatigue cracks in metal structures of bridges: visual inspection and methods of

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instrumental non-destructive control (acoustic emission, ultrasonic and magnetic resonance). All these methods have common drawbacks: they are rather laborious; require direct access to the object of inspection and preliminary preparation of the investigated surface.

The method of infrared thermography is based on the registration of thermal radiation from the surface. It is known that at variable loads the metal material is heated. This self-heating is caused both by internal friction (dissipation of the oscillation energy, most intensely flowing in stress concentration sites), and friction of the contacting surfaces of fixed joints (bolted, riveted, etc.). Heat release is a sign and indicator of fatigue damage [5–7].

The use of IR-thermography to detect fatigue cracks in metal structures is based on the principle of the thermoelastic effect described by Kelvin more than 150 years ago [8]. According to this effect, the heat release of arbitrary bodies during deformation depends on the difference in stresses at a particular point in the body at a different time period. At the tips of fatigue cracks, a stress concentration occurs, which causes plastic deformations in the region of the crack tip, which causes its growth with time. Part of the deformation energy is released as heat [9]. Since in the site of stress concentration the range of stress variation is greater than the nominal value of the body, then, according to the effect described above, the heat release will also be greater. This heat release is detected by an infrared radiation detector (thermal imager). Further, according to the IR survey data during processing, it is possible to determine the points of greatest heat release, and therefore the points of stress concentration, i.e. fatigue damage tips of structures. The existing experience of using IR-thermography to assess the technical condition of bridges [10–12] shows its viability. The method of IR-thermography provides the possibility of remote (contactless) detection of fatigue cracks, including hidden, not yet reached the outer surface or located on the non-face side, the relative ease of use (not exactingness to the state of the surface under study) and obtaining results directly at the time of the survey. At present, the development of the method is hampered by insufficient knowledge of the features of its application, the lack of methodological recommendations and a regulatory framework.

The purpose of this study is to research the main parameters of energy dissipation in metals under periodic loads to detect fatigue cracks in the metal structures of railway bridges. The study carried out laboratory tests of a beam with a pre-grown fatigue crack under various high-cycle loading modes and developed mathematical and software for processing thermograms to quickly and unambiguously identify the tips of the cracks.

2 Research Methods

On the railway network of JSC Russian Railways, typical metal span structures with a span length (for split span structures) from 18.2 m to 110 m [1] are operated. For the specified lengths of span structures, the natural vibration frequencies of such span structures in the first form are in the range from 2 Hz to 10 Hz [13, 14]. In the same ranges are forced oscillations during the passage of rolling-stock. During the laboratory experiment, the same loading conditions were recreated.

The test sample is an I-beam, the dimensions, cross-section and test loading scheme of which are presented in Fig. 1. The beam is made of structural steel St3. There is a fatigue crack with a length of 60 mm in the weakened lower belt of the beam.

The heat release registration was recorded using a Fluke Ti400 thermal imager, which has a temperature sensitivity NETD <0.05 °C, a frame rate of 9 Hz and an infrared detector matrix size of 320 × 240 pixels.

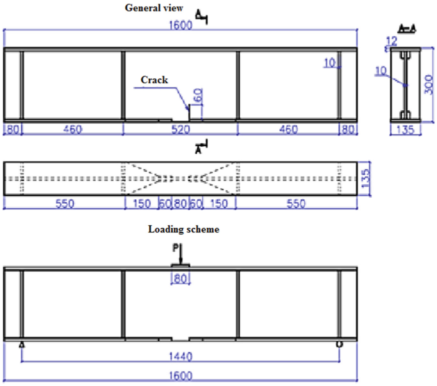


Fig. 1. Laboratory sample (dimensions in mm) and test loading scheme

It should be noted that the thermal imager does not register the surface temperature, but the intensity of its infrared radiation. The emissivity of any surface depends not only on its temperature but also on the emissivity ε_T. Absolute black body has the maximum radiating ability ($\varepsilon_T = 1$). For real surfaces, the emissivity depends on the state of the surface: roughness, presence and thickness of the coating, on the material [5]. Therefore, the sample in the study area was painted with matte paint, which also made it possible to evaluate the effect of the paintwork of real structures on the results of IR imaging.

Characteristics of loading modes were the frequency and amplitude of the pulsator, as well as the distance from the thermal imager to the beam. Cyclic loads of the beam were carried out on the GRM-2a installation with a pulsator with three different frequencies - 2.4 Hz, 4.2 Hz and 8.3 Hz, corresponding to the range of actual vibration frequencies of the span structures. For each frequency during the test, the oscillation amplitude of the pulsator varied from 0.2 mm to 0.4 mm. The static load applied to the pulsator before the dynamic test mode was switched on was 40 kN. The imager was installed at three different distances from the sample - 68 cm, 108 cm and 130 cm and at an angle of 90° to the surface under study. The measurements were carried out at a temperature of 23.1 °C, the sample was not protected from sunlight. A total of 16 different loading modes were performed. Record lengths were 60–96 s (the number of frame-thermograms – 513–876).

The process of testing the beam is shown in Fig. 2.

Fig. 2. The process of dynamic testing of the beam on the GRM-2a installation with a pulsator

During the tests, 16 thermograms (IR video files) were obtained, which were processed in the standard program Smartview 4.2, which is part of the thermal imager software, and in a specially designed program. Smartview 4.2 allows to view thermograms, overlay various filters on them, analyze the temperature of each image pixel in a specific period of time, and export radiometric data to text files.

Figure 3 shows the thermogram after processing in the standard program Smartview 4.2. For clarity of the result, four temperature markers are superimposed on the thermogram. A marker with a temperature of 23.3 °C (left figure) is set to the tip of the fatigue crack. The remaining 3 markers are installed within a radius of 5 cm from the crack tip.

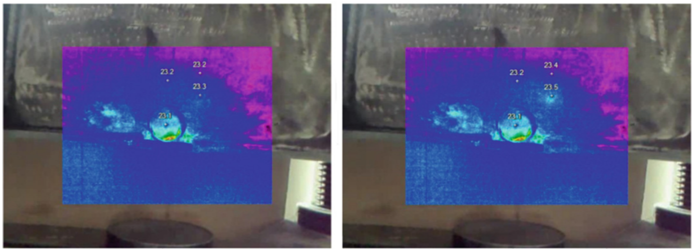


Fig. 3. Thermogram of dynamic tests of the beam. Characteristics of the mode: frequency 4.2 Hz, amplitude 40 mm, distance from the thermal imager to the beam 68 cm.

As can be seen from Fig. 3, in the site of the crack tip during cyclic testing, there is a local increase in the surface temperature of the beam wall from 23.3 °C (left figure) to 23.5 °C (right figure). The IR-camera recorded the correct position of the crack tip, as evidenced by a visual inspection of this beam site.

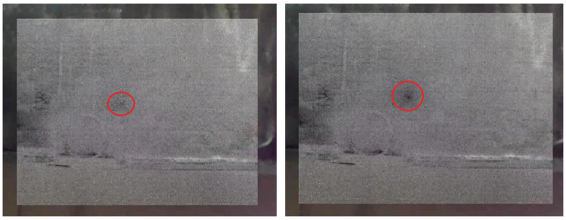


Fig. 4. Thermogram of dynamic tests of the beam. Characteristics of the mode: frequency 4.2 Hz, amplitude 0.3 mm, distance from the thermal imager to the beam 108 cm

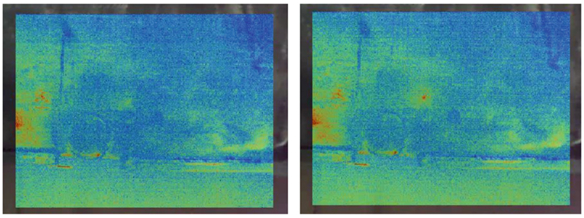


Fig. 5. Thermogram of dynamic tests of the beam. Characteristics of the mode: frequency 8.3 Hz, amplitude 0.4 mm, distance from the thermal imager to the beam 68 cm

Figures 4 and 5 show similar thermograms of tests for other loading modes. Characteristics of the mode for Fig. 4: Frequency 4.2 Hz, amplitude 0.3 mm, distance from the thermal imager to the beam 108 cm. Characteristics of the mode for Fig. 5: Frequency 8.3 Hz, amplitude 0.4 mm, distance from the thermal imager to the beam 68 sm. These thermograms are similarly superimposed with a variety of filters, allowing more clearly displaying temperature changes.

3 Additional Processing of Results

After processing the thermograms in the standard program Smartview 4.2, a set of N matrices of the size n × m is obtained, which must be kept in an understandable form, such as selected graphic. The procedure for saving an image is simple in its essence - it is necessary to map each value of the matrix to a certain color value of the corresponding pixel in the resulting image.

In the simplest case, the procedure is as follows: a texture is prepared (an ordered vector of colors), then each element of the matrix is uniquely assigned an element from the texture. For the case when it is necessary to save the image in grayscale, the texture will contain 255 colors: from white, which corresponds to the maximum value in the matrix, to black, corresponding to the minimum.

However, it is not always convenient to use such a linear color conversion. In some cases, the difference in values may be quite large, and then a similar color ratio will not show anything. In the case when several values in the matrix are noticeably more than others, it is convenient to use logarithmic texturing. For this, each element of the matrix is linearly mapped to the interval [1; 10], then the decimal logarithm is taken from the resulting value. Thus, each element of the matrix is converted to a number on the interval [0; 1], which is already linearly correlated with color.

Since it is not always necessary to save values with a large dynamic range, consider another method that is more suited to the process under study. Each element of the matrix aij will be assigned a color as follows. Map this element to the interval [0; 1] using only the data of the i-th row, we denote the result obtained as rij. Similarly, we will do the same using the data of the j-th column, we obtain the element cij. Now, instead of the original matrix element, we will use the value cij × rij for color matching. Thus, we find that the maximum elements in their row and in their column will correspond to lighter shades than all the others.

Since one image carries a fairly small amount of useful information, we will try to increase its number by analyzing the data over time. To do this, consider two simple transformations that will help identify the points needed for analysis. We integrate the time data obtained from the thermal imager:

$$I_{xy} = \int_t \Delta f(x, y, t)dt = \sum_{k=0}^{N-1} (f(x, y, t_{k+1}) - f(x, y, t_k)) \tag{1}$$

In Table 1, the results of calculation by formula (2) are given with the prefix I2. The color matching was performed as described above.

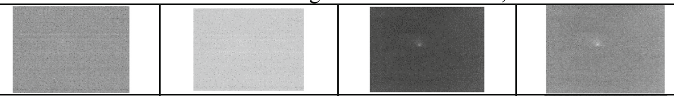
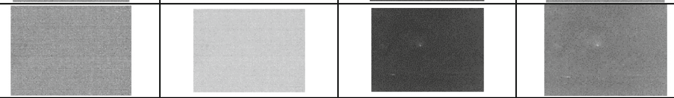
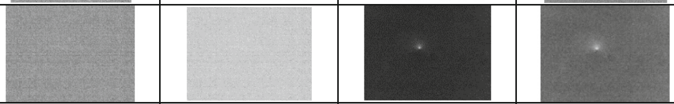
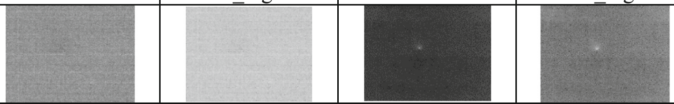
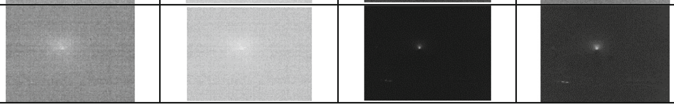
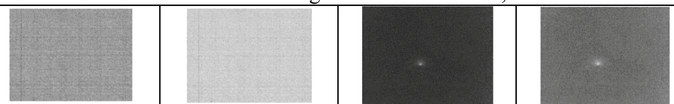
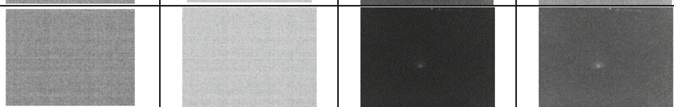
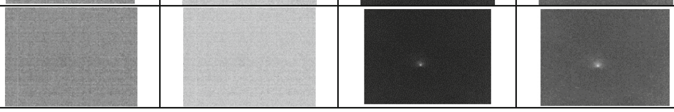
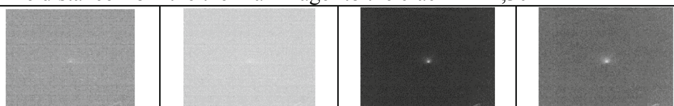
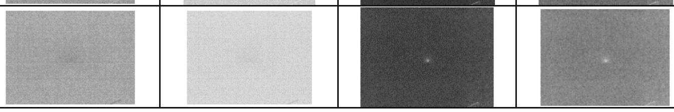
Since the data obtained reflect a cyclic process, we actually obtain the integration of the periodic function over the full period. In order to avoid this and get information about the oscillations, apply the following formula.

$$I_{xy2} = \int_t \Delta f^2(x, y, t)dt = \sum_{k=0}^{N-1} (f(x, y, t_{k+1}) - f(x, y, t_k))^2 \tag{2}$$

In Table 1, the results of calculation by formula (2) are given with the prefix I2.

The values obtained by formulas (1) and (2) are normalized and distributed on a logarithmic color scale (I_log, I2_log).

Table 1. Graphic representation of the processed thermograms

	I	I_log	I2	I2_log
The distance from the thermal imager to the crack L = 0,68 m				
f = 2.4 Hz; A = 0.2 mm				
f = 8.3 Hz; A = 0.2 mm				
f = 2.4 Hz; A = 0.3 mm				
	I	I_log	I2	I2_log
f = 8.3 Hz; A = 0.3 mm				
f = 2.4 Hz; A = 0.4 mm				
f = 8.3 Hz; A = 0.4 mm				
The distance from the thermal imager to the crack L = 1,08 m				
f = 2.4 Hz; A = 0.3 mm				
f = 8.3 Hz; A = 0.3 mm				
f = 2.4 Hz; A = 0.4 mm				
f = 4.3 Hz; A = 0.4 mm				
The distance from the thermal imager to the crack L = 1,30 m				
f = 2.4 Hz; A = 0.4 mm				
f = 8.3 Hz; A = 0.4 mm				

4 Discussion

As follows from the results of processing thermograms shown in Figs. 4 and 5, the site of increased heat release at the crack tip is well diagnosed by infrared thermography. Increasing the informativity and recognizability of the problem site can be done by applying the developed algorithm, the results of which are presented in Table 1. As follows from this table, the crack tip is best distinguished when using formula (2) almost regardless of the distance to the surface under study.

Another conclusion is that the sites with greater loading have an increased heat release in comparison with the surrounding area, the energy dissipation here is more intense.

Since, in essence, temperature increments with changes in load were analyzed, the results obtained open up the prospect of using thermal imaging to determine the stress state of structures and predict durability by the intensity of energy dissipation under cyclic loading.

The use of short records (no more than 1–2 min) allows minimizing the influence of the environment - wind gusts, heating by the sun, etc.

The described method makes it possible to accurately and stably fix the tips of fatigue cracks in a contactless way under various loading modes.

Since the survey conditions corresponded to real (the loading modes of the sample correspond to the actually possible forced oscillations of structures under a moving load, the presence of a paint and varnish coating; the maximum survey distance of 130 cm corresponds to that possible when inspecting bridges, the recording time corresponds to the train passing time over the bridge), IR-thermography can be effectively used in inspections and examinations of bridges.

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Stability of the Supporting Subgrade on the Tracks with Heavy Train Movement

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Abstract. The purpose of the study is to ensure the stability of the main area of the roadbed on the lines of the operating domain of heavy train movement. The analysis of the existing problem of insufficient bearing capacity of the soils of the main area of the subgrade was made. The existing methods for enhancing the surface of the roadbed are described, and their drawbacks are revealed. A method for enhancing the soils of the main railway track area by the method of cold regeneration (recycling) is proposed. To study the problem, a finite element method was applied in the form of displacements. A three-dimensional finite element model is presented. The characteristics of the model elements accepted for the calculation are described. Isopoles of displacements of the railway path model, shrinkage and normal stress graphs of the main area of the roadbed were obtained. The construction of a soil-concrete layer with a thickness of 20 cm made. An increase in the normal transverse axis of the stress path is noted by more than 4.5 times. This is due to the increased rigidity of the main area. The values of the normal longitudinal axis of the stress path vary in direction, but the module has not changed significantly. The effectiveness of the structure of the sub-ballast concrete layer lies in the increased mechanical and strength characteristics of clay soils. This allows increasing the carrying capacity of soils, preventing their transition to the limit state and the necessary deformations.

1 Introduction

The development of heavy train movement is a key direction in increasing freight capacity, both on the railway network of the Russian Federation and on foreign railways [1, 2]. The United States, Canada, Australia, Sweden and the countries of South Africa have followed this way [3]. The increase in weight standards is associated with increasing traffic volumes, as well as with an increase in the efficiency of individual areas of railways and the network as a whole [4, 5].

At present, a concept has been developed for the ground progress of heavy train movement on the railways network of Russian Railways. The operation of trains of increased weight and length has become the preferred mode of freight traffic [6]. Also, transportation allows increasing the performance of each train car by increasing the mass of the transported cargo [7]. Fuel and energy costs and maintenance costs for locomotives from 4.5–7.0% for train cars weighing 6–12 thousand tons [8] are also

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reduced, train idle times, the amount of shunting work at stations, and transportation costs [9] are decreased.

On the other hand, heavy trains have a destabilizing effect on all the structural elements of a railway path. In conditions of high vibrodynamic effects on the reliability of the railway path design, increased demands are made [10].

First of all, this refers to the reliability of rails on heavy-load directions [11]. This is especially important in small radius curves [10] and end sections of continuous tracks, as well as equalizing spans and places of temporary restoration of rail tracks [13]. Safety of transportations largely depends on the number of these elements failures [14, 15] and on the whole rail track [16]. Lateral wear is the main limitation of the service life of rails in small radius curves [12, 17]. It is influenced by many factors [18].

Increased axial loads up to 25 tons/axle necessitated the improvement of thermal hardening of the rails, increasing their hardness to extend the life cycle of superstructures. This issue is in close connection with the reliability of intermediate rail fastenings [5, 19] and their performance parameters in conditions of heavy train movement and difficult climatic conditions [5, 20]. The design of reinforced concrete sleepers [21] should ensure uniform transfer of loads on the rail base.

One of the weak points in the conditions of heavy train movement is the roadbed [22]. To date, it has not been given due attention. Today’s state of roadbed for most of its length is a roadbed made of clay soils. It was built over a century ago and is not designed to withstand the increased loads from heavy trains. These factors led to an increase in the rate of accumulation of residual deformations of the roadbed top. The main area of the roadbed was the site of the path deformations concentration.

Over the past 10 years, there has been an increase in the defective roadbed by more than 50%, its facilities by 7%. The number of restrictions on train speeds due to the condition of the roadbed has increased by more than 30% [23]. The deficiency of the roadbed in the sections of the circulation of heavy trains exceeds the network average by 2 times, is 18% and continues to grow.

2 Existing Solutions to the Problem

In sites with insufficient bearing capacity of the main area, the surface of the roadbed is strengthened [24]. Typical solutions are the laying of geogrids and a protective sub-ballast layer of crushed-stone-sand-gravel mix (CSSG) [25]. These methods are widely used on the Russian Railways network. Their use is not always justified and cost-effective.

CSSG protective layers drain the water. Under them, the top of the roadbed is moistened, losing strength. This in turn leads to the deformation of clay soils under heavy loads. The stability of the top of the roadbed, and hence the path as a whole, is reduced. The cost of arranging protective layers increases significantly with an increase in the distance of the CSSG transportation.

When laying the geogrid, labor costs increase significantly, since these works are not technological, the rate of work production is significantly reduced. In addition, the geogrid also does not ensure the preservation of stable moisture of the roadbed during its operation.

In this regard, the purpose of the study is to ensure the stability of the main area of the roadbed on the lines of the heavy train movement.

3 Research Method

To bring the strength of the working area of the roadbed composed of clay soils in accordance with the requirements of heavy train movement can be known methods of stabilizing soils. Today they are actively used in Russia in the construction of highways. One of these is the method of cold soil regeneration (recycling).

To assess the effect of the soil-concrete layer on the stress-strain state of the roadbed, the SCAD Office software was used. It created two volumetric models of single-track railway (see Fig. 1).

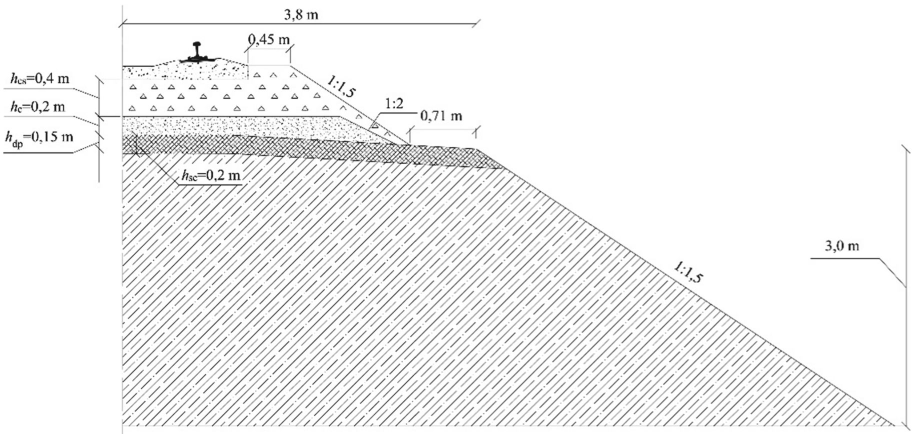


Fig. 1. Transverse profile of the volume model of a railway path with a roadbed, reinforced soil-concrete layer

The structure of the superstructure was adopted as follows: rails of the type R65, bonding KB-65. In the design scheme, the influence of a rigid terminal on the rail feather and rail lining is replaced by the action of a system of forces. The rail is pressed against the lining with a force of 20 kN. Ferroconcrete sleepers, rectangular cross section. The thickness of the crushed stone ballast under the sleeper $h_{cs.}$ = 0.40 m, the thickness of the sand cushion $h_{c.}$ = 0.2 m. The shoulder of the ballast prism is 0.45 m. The laying of the slopes of the ballast prism is 1:1.5.

The roadbed construction: the height of the embankment is 3 m, the width of the roadbed in the level of the edges corresponds to category I and is 7.6 m. The drain prism has the shape of a trapezoid in transverse outline with a height h_{dp} = 0.15 m and a width of 2.3 m. The roadside of the roadbed is 0.71 m. The laying of the slopes of the embankment is 1:1.5.

The first model of the railway path is standard design. In the second model with a reinforced roadbed, in the place of the drain prism there is a soil-concrete layer of thickness $h_{sc} = 0.2$ m.

Table 1 shows the characteristics of the elements of the path taken for calculation.

The rails are applied to the load, imitating the impact of a wheel pair, equal to 122.5 kN (at the rate of 25 tf/axis). The finite element model of the railway is shown in Fig. 2. The calculation was performed by the finite element method of the form of displacements.

Table 1. Characteristics of the path elements

Element or layer railway path	Modulus of elasticity, MPa	Poisson's ratio	Volume weight, t/m^3
Rail	210000	0.30	7.80
Laying TsP143, TsP328	10	0.47	1.25
Metal lining	206010	0.3	7.80
Concrete sleepers	36002.7	0.20	2.50
Ballast crushed stone 25–60 mm	180	0.30	2.00
Sand cushion	120	0.30	2.10
Roadbed	60	0.30	1.60
Concrete layer	400	0.30	1.95

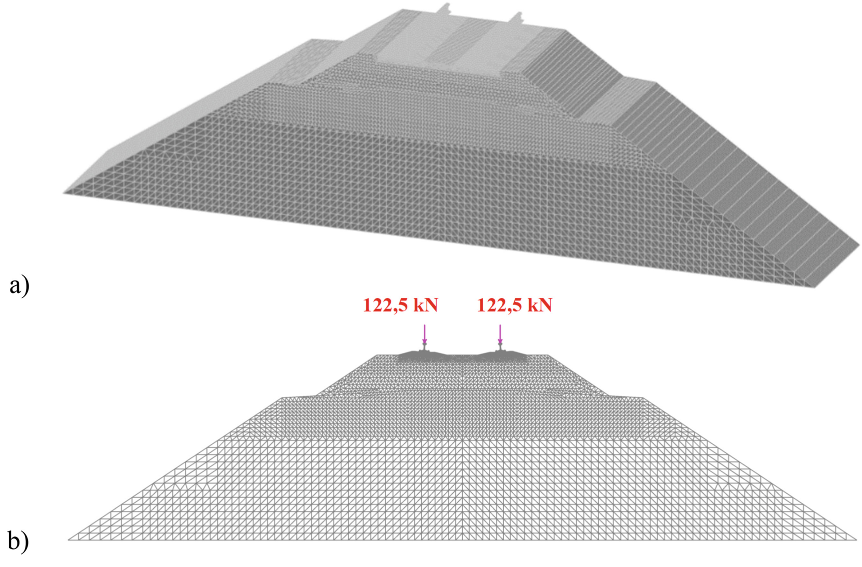


Fig. 2. Finite element model of a railway path: (a) general view; (b) front view

4 Results

As a result of the calculations, the isopole displacements were obtained. The graphs of normal stresses in the *X, Y, Z* planes are plotted. Figure 3 shows the isopole displacements in the direction of the horizontal axis *X,* in Fig. 4—in the direction of the vertical axis *Z.* The displacements along the *Y* isopole axis are not given by virtue of their small size. The graph of vertical shrinkage of the main area of the roadbed without reinforcement and reinforced with a soil-concrete layer 20 cm thick is shown in Fig. 5.

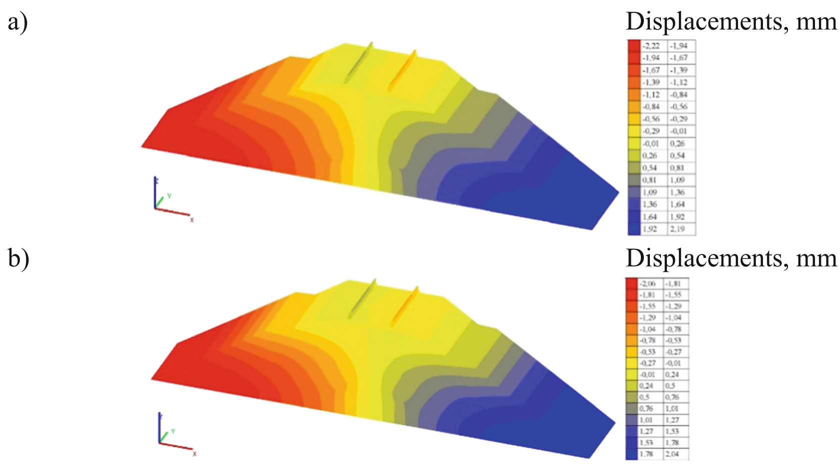


Fig. 3. Isopole displacements of a railway path along the *X* axis: (a) without reinforcement; (b) with reinforcement of a soil-concrete layer

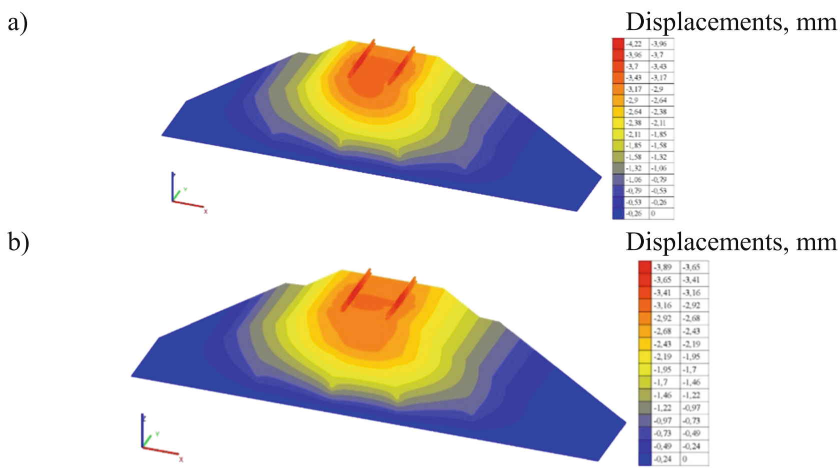


Fig. 4. Isopole displacements of the railway path along the *Z* axis: (a) without soil concrete; (b) with soil concrete 20 sm

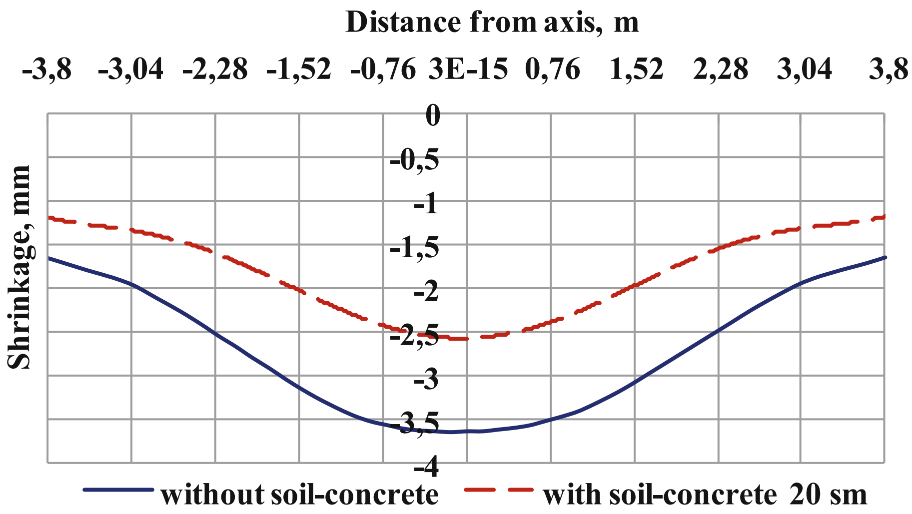


Fig. 5. Vertical shrinkage of the main area of the roadbed

Figure 6 shows the graphs of normal stresses in the level of the main area of the roadbed.

5 Discussion of the Results

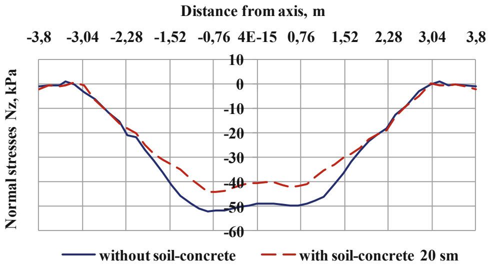
As a result of the soil-concrete layer design in the level of the main area of the roadbed with a thickness of 20 cm, the values of the vertical shrinkage of the main area decreased by 30% from 3.65 mm to 2.53 mm (see Fig. 5). The greatest decrease in shrinkage is observed along the axis of the path.

The vertical stresses N_z in the level of the main area of the roadbed also decreased by 10 kPa (see Fig. 6). The greatest stress reduction occurs in the sub-sleeper area. At the edges of the roadbed it is reduced to a minimum. This is due to a more uniform distribution of stresses in the construction of the soil-concrete layer.

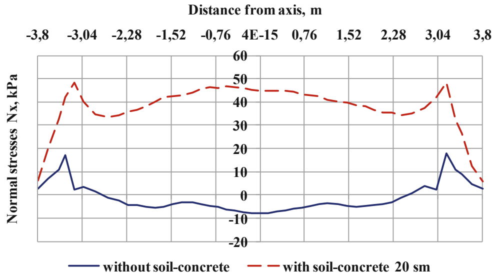
As a result of the analysis, an increase in transverse normal stresses N_x was found (see Fig. 6). On the main area of the roadbed without soil concrete, the N_x stresses are more uniform. In the reinforced roadbed on the main area, on the contrary, there is uneven stresses. Maximum values are observed near the axis of the path. The design of sub-balanced soil-concrete layer in the level of the main area of the roadbed increases the rigidity of the path, the movements are reduced. At the same time, the horizontal stresses N_x are increased.

The values of the longitudinal normal stresses N_y vary in direction. Modulo N_y voltages do not change significantly (see Fig. 6).

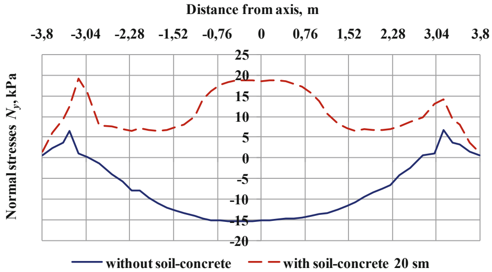
In paper [26], similar results were obtained, but for vibrations of soil particles. The design of the soil-concrete layer made it possible to reduce influence zone of voltage pulsations. The magnitudes of the vertical oscillation amplitudes also decreased, but the horizontal oscillations along and across the axis of the path above the slab increased.



a)



b)



c)

Fig. 6. Normal stresses on the main area of the roadbed: (a) along the *Z* axis; (b) along the *X* axis; (c) along the *Y* axis

The effectiveness of the subbalanced soil-concrete layer design in this case is to increase the mechanical and strength characteristics of clay soils. This allows increasing the carrying capacity of soils, preventing their transition to the limit state and preventing deformations of the shifts. This was confirmed by Kolos [26]. In this case, the more slip lines will be in the reinforced soil, the higher will be the carrying capacity of the main area.

With a properly selected composition of the mixture and compliance with the technology of its installation and compaction, it is possible to increase the carrying capacity of the main area soils to 600 MPa or more. This will make the soil strong and hydrophobic in a short time.

6 Conclusion

A method of ensuring the stability of the main area of the railway path roadbed at the operating domain of heavy train movement is proposed. The effect of the soil-concrete layer on the stress-strain state of the roadbed has been investigated.

The results of the study allow us to recommend arranging a subbalanced soil-concrete layer on existing railway lines without conducting full-scale experiments. The technology of strengthening the soils of the main area of the roadbed by the method of cold regeneration can be used in the construction of the second ways, during the reconstruction and overhaul at the closed section. The greatest effect will be in areas where there are extended deformations of the main area.

Further research will be the justifying for the rational thickness and width of the reinforced soil-concrete base for various conditions. It is also necessary to develop technological processes for railroad tracks repairing with the use of soil stabilization by the method of cold regeneration.

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Measurement Method of Non-continuous Noise in Industrial Buildings of Railway Enterprises

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Abstract. It is necessary to evaluate the noise regime in the industrial premises when engineering and reconstructing railway transport enterprises, and on this basis to develop arrangements to reduce noise in there. The noise at railway enterprises is inconstant in terms of time and space. To calculate its energy characteristics, the article proposed a statistical energy model and a numerical method for its implementation The accuracy of the proposed model and its implementation method is estimated by comparing the experimental and calculated data in the car-repair depot room. When comparing it was found that the calculated graphs of the decay of the reflected energy in time coincide with the experimentally obtained decays. The error in calculating of sound pressure levels does not exceed 3.0 dB, which corresponds to the accuracy of measuring noise in a production environment. The proposed computational model, in contrast to the existing methods, makes it possible to determine changes in the spatial-temporal characteristics of inconstant in terms of time noise in premises with any complex space-planning parameters. The calculation model and the numerical method of its implementation make it possible to make a reliable assessment of changes in the noise regime under the action of non-continuous noise sources and to develop measures to reduce noise in rooms of complex shapes in the presence of large objects in them. An example of using the calculation model for assessing the acoustic efficiency of the device of sound-absorbing cladding in the department of a car repair depot is given.

Keywords: Railway transport enterprises · Industrial facilities · Not-continuous in time noise · Noise calculation · Dimensional model

1 Introduction

At the stage of design and reconstruction of industrial enterprises of railway transport, it is necessary to assess the noise regime in industrial premises and, if necessary, develop measures to reduce noise. To solve these problems, it is necessary to have a calculation method that objectively evaluates the processes of formation and propagation of noise in the specific conditions of industrial buildings. The noise regime in industrial facilities of railway enterprises is created by a large amount of simultaneously and alternately

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operating equipment and tools. For example, in diesel locomotive, electric locomotive, and wagon repair shops, the main sources of noise are riveting guns, grinding and drilling machines, wrenches, operations of bending, straightening, truing and stripping of metal, etc. Noise levels in the shops are 85–95 dBA. In this case, the noise of individual equipment reaches levels of 100–119 dBA. Since the time of technological operations is short, the noise emitted while operating is estimated as non-continuous in time. In many technological areas, for example, in the areas of metal riveting and dressing, unstable noise is characterized as pulsed, having the features of effects on the human body [1].

The distribution of sound energy in rooms with intermittent noise sources is spatio-temporal in nature. Sound energy changes not only in the space of the room, but also in time. This feature requires the use of a computational model for calculating the energy characteristics of non-continuous noise, which allows to solve two related problems. When solving the first problem, the value of sound energy should be determined at each point of the volume, created by individual pulses of the emitted energy source. When solving the second problem, its change in time should be found.

The final result of the solution will allow to obtain the spatio-temporal energy characteristics of the sound field of the room at any point in the volume at any instant of time of observation. This makes it possible not only to determine the equivalent sound pressure levels of non-continuous in time noise, but also to analyze its other characteristics and features, for example, to determine the parameters of impulse noise, the information about which is necessary when developing measures to reduce it [2].

The article proposes a calculation model that allows to determine the energy characteristics of noise when exposed to indoor noise sources with a non-continuous in time sound power. The model makes it possible to carry out calculations for non-continuous noise in rooms of complex shape and in the presence of large-sized objects and equipment. Similar conditions are typical for industrial premises of railway transport enterprises.

In developing the computational model, the following tasks were solved: a computational model that allows one to evaluate the spatio-temporal changes of non-continuous noise in rooms of complex shape in the presence of large-sized objects was proposed; a numerical method for its implementation was developed; an experimental evaluation of the proposed calculation method was made.

2 The Computational Model of Non-continuous Noise in the Premises of Complex Shape with Large-Sized Equipment

When developing a computational model and choosing methods for its implementation, it is necessary to take into account factors affecting the formation of the noise regime in the rooms [3]. In case of railway transport enterprises, the most important of them are: the nature of the reflection of sound from the surfaces of rooms and objects; dimensions, proportions and complexity of the shape of the premises; the presence of large-sized items in the volume of premises, for example, in the form of locomotives and wagons.

It is known that the nature of sound reflection most significantly affects the formation of reflected sound fields [4]. In experimental studies of noise fields in the industrial facilities of railway transport enterprises, we found that in the presence of a large amount of equipment and other objects that are scattering sound and the complex shape of the volume of the premises, the nature of the reflection of sound from surfaces is close to diffuse reflection [5]. As a result of this, reflected sound fields are formed in the rooms, which have a feature of diffusivity in the isotropic distribution of sound rays. The main industrial facilities of railway transport enterprises are, as a rule, large disproportionate (long and flat) volumes. Studies of the formation of reflected energy in long and flat rooms show that the reflected energy is not distributed evenly throughout the volume, but decreases as it moves away from the noise source. By this means, in disproportionate industrial premises, with the diffuse nature of sound reflection, reflected sound fields are formed for which a feature of diffusivity in the isotropy of the angular directivity of the reflected sound rays remains, but the second feature of diffuseness, namely, the uniformity of the distribution of reflected energy over the volume, is not provided. Such reflected sound fields, according to the definition given in study [6], are quasi-diffuse. To calculate the energy characteristics of quasi-diffuse fields, methods based on a static energy model have been developed [7]. Methods are used in solving problems of assessing the noise regime and developing means to reduce it in buildings and structures for various purposes [8, 9]. A similar approach to assessing the distribution of reflected sound energy in rooms has been used at present and in foreign practice [10–16].

On the basis of statistical energy model, a method for calculating noise when sources of sound power not-continuous in time acted on the premises was previously developed [7]. However, the method has limited capabilities. It allows to perform the calculations in the premises of the correct rectangular shape and in the absence of large-sized equipment and other similar items.

Taking into an account the quasi-diffuse nature of the reflected sound field formed in industrial facilities, a combined computational model is proposed in which the numerical statistical energy method is used to estimate the distribution of reflected energy in space, and the temporary energy changes at each point are estimated based on the classical diffuse theory of acoustics.

The sound pressure levels of non-continuous noise at the computational points of the room are determined by the direct energy coming from the source and the reflected component of the energy arising from the reflections of direct sound from the fences. When calculating direct energy, as a rule, there is no difficulty. It is more convenient to calculate the energy characteristics of a reflected field that is non-continuous in time on the basis of a pulsed idea of the processes of radiation and the propagation of sound energy. In this case, knowing the time-varying acoustic power of the source W_{t}, radiated in the time interval $\{t_{\mathrm{H}} \div t_{\mathrm{K}}\}$ (Fig. 1) and calculating the density of reflected energy ε_{pl}^{rfl} from individual pulses with power of W_{t}, emitted over the time interval Δt (Fig. 2), we can obtain by summing complete information about the change in the density of reflected sound energy over time at the computational point of the room at the time moment τ.

$$\varepsilon_{\tau}^{rfl} = \sum_{m=1}^{M} \varepsilon_{\text{plm}}^{rfl} \quad (1)$$

where M – amount of pulses from which the values $\varepsilon_{\text{plm}}^{rfl}$ are determined at the time moment τ at the computational point.

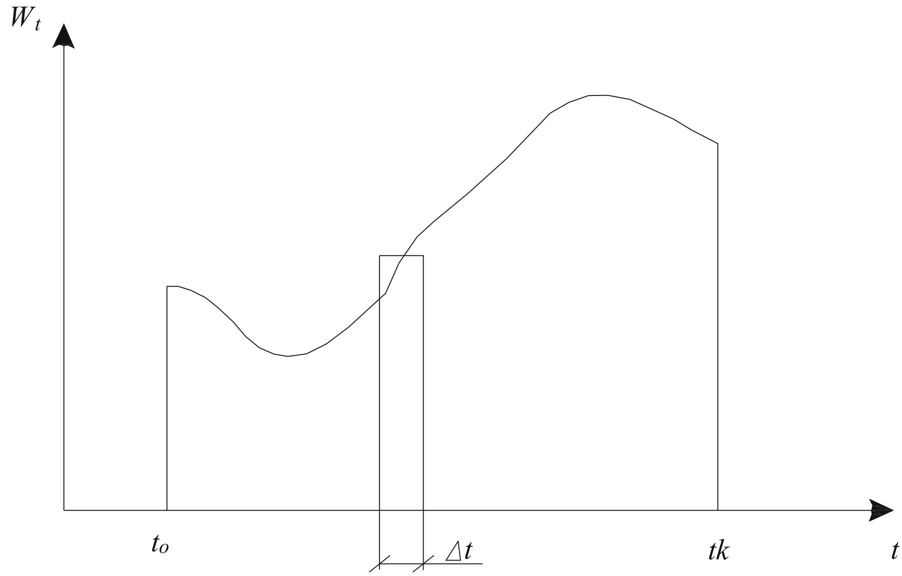

Fig. 1. Scheme of the emission of an energy pulse by a source of non-continuous sound power

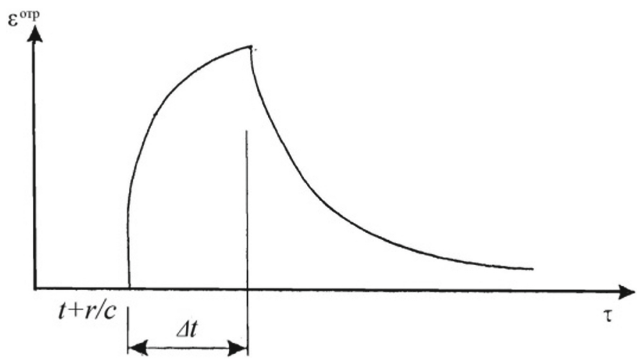

Fig. 2. Scheme of changes of the reflected sound energy of the pulse at the computational point: t – time of the pulse emission W_t by source; r/c – time of the pulse arrival into the computational point; Δt – pulse duration

It should be noted that the impulse idea of the processes of formation of reflected sound fields of premises is widely used in solving practical problems of building and architectural acoustics under the action of sources of constant and variable acoustic power, and primarily in studies of reverberation processes [17, 18]. In case of a pulsed approach to assessing the non-continuous noise regime in industrial premises, it is necessary that the source be broadband, and the analysis of changes in sound energy should be carried out in a frequency band in which a sufficient number of modes are excited with a pulse duration Δt [19].

The density of reflected energy at each computational point depends on its location relative to the noise source and the fences, and is also determined by the shape and acoustic parameters of the room.

The problem of the spatial distribution of reflected energy is solved by determining the density of reflected energy ε_p^{rfl} at the computational point with a constant power source W_p. Knowing the ratio $\varepsilon_{\mathrm{p}}^{rfl}/W_p$ for a specific computational point, then we can find the maximum density of reflected energy at this computational point under the action of any energy pulse W_{t}. In this case, density $\varepsilon_{\mathrm{plt}}^{rfl}$ will be determined as

$$\varepsilon_{\mathrm{plt}}^{rfl} = \frac{\varepsilon_p^{rfl}}{\mathrm{W}_p} \cdot \mathrm{W_t} = \varepsilon_1^{rfl} \cdot \mathrm{W_t} \tag{2}$$

where ε_1^{rfl}- the density of reflected energy per unit of sound power of the source at a specific computational point.

When solving the problem of a temporary change in the reflected energy at the computational point, it can be considered with sufficient accuracy for practice that the changes in the reflected pulse energy in time in a quasi-diffuse sound field correspond to changes that occur in a diffuse sound field. In this case for In this case, to evaluate changes in the density of reflected sound energy over time after the emission of an energy pulse with acoustic power W_{t} it is possible to use the following dependencies (see Fig. 2):

$$\varepsilon_{pl_{\mathrm{m}}}^{rfl} = \begin{cases} 0, & \text{if } \tau \le \mathrm{t_m} + \mathrm{r/c} \\ \varepsilon_1^{rfl}\, W_m \left[1 - \exp\left(\frac{-\alpha_{mid} c(\tau - t_m - r/c)}{l_{mid}}\right)\right], & \text{if } \mathrm{t_m} + \mathrm{r/c} < \tau < \mathrm{t_m} + \mathrm{r/c} + \Delta\mathrm{t} \\ \varepsilon_1^{rfl}\, W_m \left[1 - \exp\left(-\frac{\alpha_{mid} c \Delta t}{l_{mid}}\right)\right] \exp\left(\frac{-\alpha_{mid} c(\tau - \mathrm{t_m} - r/c - \Delta t)}{l_{mid}}\right), & \text{if } \tau > \mathrm{t_m} + r/c + \Delta\mathrm{t} \end{cases} \tag{3}$$

where c - speed of sound in the air; r - distance between source and computational point; α_{mid} - average sound absorption coefficient of building envelopes; l_{mid} - average length of free path of the sound in the room.

The equations for describing the reflected pulse energy are written under the assumption that the reflected energies increase and decay according to the Sabin dependence. If necessary, you can use the Eyring equation, replacing α_{mid} with $-\ln(1-\alpha_{mid})$.

Using (1) and (3), you can get an expression for the energy density at the computational point for a moment of time τ when the source of variable acoustic power in the time interval $\{t_{\mathrm{H}} \div t_{\mathrm{K}}\}$

$$\varepsilon_{\tau}^{rfl} = \varepsilon_{1}^{rfl}\left[1 - \exp\left(-\frac{\alpha c \Delta t}{l_{mid}}\right)\right] \sum_{m=1}^{M} W_m \exp\left(\frac{-\alpha_{mid} c(\tau - \mathrm{t_m} - r/c - \Delta t)}{l_{mid}}\right). \quad (4)$$

This way, to solve the problem of the spatio-temporal distribution of reflected energy from an non-continuous noise source, it is necessary to have information about the density of reflected sound energy ε_p^{rfl} when a constant power source is used in the room W_p.

In the difficult-to-size premises and in the presence of large-sized objects there for calculating the value ε_p^{rfl} the numerical statistical energy method should be used [20, 21]. The method for diffuse reflection of sound from fences implements a mathematical model that describes the distribution of the density of reflected energy in a quasi-diffuse sound field in the form of a second-order partial differential equation

$$\eta \nabla^2 \varepsilon_p^{rfl} - c m_a \varepsilon_p^{rfl} = 0 \quad (5)$$

with boundary conditions

$$\bar{q}\big|_{dS} = (1 - \alpha_s) I_p\big|_{dS} - \frac{c \cdot \alpha_s}{2(2 - \alpha_s)} \varepsilon_p^{rfl}\bigg|_{dS}. \quad (6)$$

As

In expressions (5) and (6) $\eta = 0.5 c l_{mid}$ - coupling coefficient of flux density and density gradient of diffusely reflected energy in a quasi-diffuse sound field [22]; m_{a}-spatial attenuation coefficient of sound in air; α_s - sound absorption coefficient on the considered surface element dS; I_p - the intensity of direct sound energy incident on the element dS taking into account the angle of incidence of sound rays.

The first term of the right-hand side of the boundary conditions (6) determines the input of diffusely scattered energy into the room volume from the surface of the element dS when direct sound is incident on it. The second term determines the absorption intensity of the diffusely scattered energy incident on the element dS.

In the case of a numerical solution of Eq. (5) with boundary conditions (6) in accordance with the method given in [20], the room is divided into elementary volumes, within which the nature of the change in the density of reflected energy can be assumed linear. When dividing into volumes, the position and dimensions of large-sized objects in the room are taken into account, which in the general case can also be sources of noise. For each elementary volume, an equation of balance of diffusely reflected sound energy is compiled. The total density distribution of diffusely reflected energy is found from the solution of the resulting system of equations. A computer program has been developed to implement the numerical method.

The final result of the calculation of sound pressure levels will be determined by the sum of the direct sound energy densities of the pulse ε_{τ}^{dir} and the reflected sound energy ε_{τ}^{rfl} at the computational point at any calculated time τ

$$L_\tau = 10\lg\left[\left(\varepsilon_\tau^{dir} + \varepsilon_\tau^{rfl}\right)c/I_0\right] \tag{7}$$

where I_0 - sound intensity at the threshold of hearing.

The value ε_τ^{dir} is determined for elementary volumes that are in direct line of sight with the sound source. With a complex shape of the sources, the calculation of ε_τ^{dir} arriving at the volume of *i, j, d* is performed by the ray tracking method [20, 21].

$$\varepsilon_{ni,j,d}^{dir} = \sum_{k=1}^{K} \frac{W_t}{N} \exp\left(-m_a R_{ki,j,d}\right)/cS_{red}, \tag{8}$$

where N - the number of rays emitted by the source upon emission of an energy pulse W_t; K - the number of rays that have arrived at the elementary volume i, j, d; S_{red} - reduced cross-sectional area of elementary volume, taken equal to the cross-sectional area of a sphere corresponding in volume to volume of the i, j, d-element; $R_{ki,j,d}$ - distance passed by the ray from the source to i, j, d volume.

3 Experimental Verification and Use of the Computational Model

A computer program has been developed to implement the proposed computational model. The program allows to study the changes in the energy characteristics of non-continuous noise fields, including those from pulsed noise sources.

The computational model was checked by comparing the calculation results with experimental data. The studies were carried out in the repair department of the wagon repair depot. In a room measuring 30 × 18 × 9 m, there are two wagons with dimensions of 14 × 3 × 4.5 m. During experimental studies, a unit for riveting friction strips worked in the room. The setup emitted pulsed noise with duration of 0.30 s with a periodicity of 1.50 s. The layout of the room with the location of the wagons, the noise source and measurement points are shown in Fig. 3. The acoustic characteristics of the room and source for eight octave bands are shown in Table 1.

Below is a detailed assessment of the distribution of sound energy in the repair department for an octave frequency band with a geometric mean frequency of 500 Hz. The peak acoustic power level of the noise source is 115 dB. The average sound absorption coefficient of the fencing of the room and wagons is 0.12. Indoors, at a frequency of 500 Hz, a background noise of 75 dB is observed. Background noise is almost evenly distributed throughout the room.

In accordance with the methodology proposed in the article for estimating the spatio-temporal characteristics of a non-continuous sound field, the distribution of sound energy from a long-acting noise source located at the site of a periodic one has been previously calculated. The calculation was performed by a numerical statistical energy method using a three-dimensional model of the reflected sound field. In the calculation, the entire space of the room was divided into 3080 elementary volumes with a face size of 0.90 m. Table 2 shows the calculated data for 7 characteristic points of the room, obtained during the operation of a constant noise source with a power

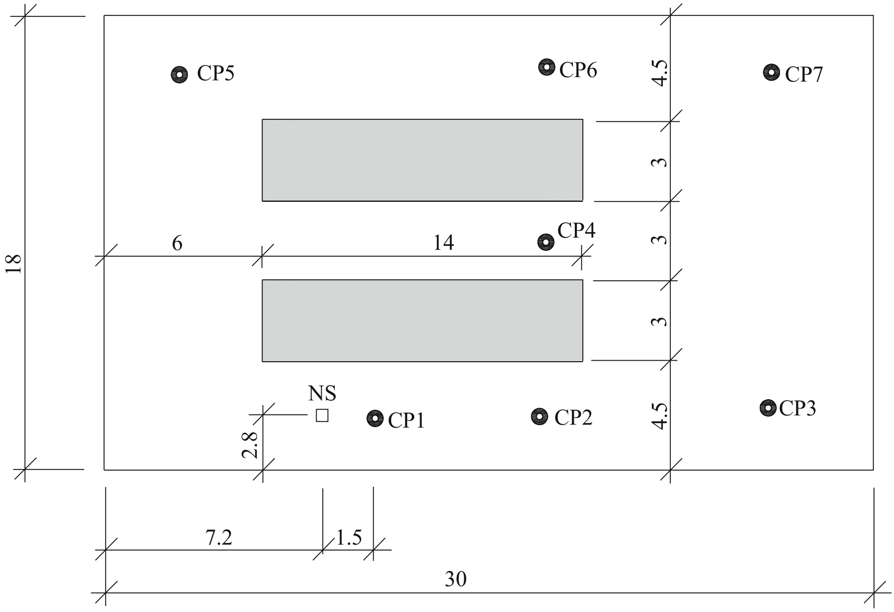

Fig. 3. Wagon repair room layout: NS – noise source; CP1 ÷ CP7 - computational points

Table 1. Acoustic characteristics of the noise source and the room

Characteristic	The value of the characteristic for the geometric mean frequencies of the octave bands of the analysis, Hz							
	63	125	250	500	1000	2000	4000	8000
Maximum level of sound source acoustic power, Db	116	115	117	115	114	117	117	116
Average sound absorption coefficient of fences and wagons	0.10	0.10	0.10	0.12	0.12	0.12	0.12	0.12
Sound absorption coefficient of ceiling lining	0.2	0.25	0.6	0.8	0.7	0.9	0.9	0.8

$W_p = 115$ dB. The table shows the values of the levels of direct L_{dir}, reflected L_{rfl}, general L_{tot} noise and values $\varepsilon_1^{rfl} = \varepsilon_p^{rfl}/W_p$, necessary for calculating noise from a source of time-variable acoustic power.

In accordance with expression (4), using the data from graph 7 of Table 2, the changes in the sound pressure levels at the computational points in time were

Table 2. Results of calculation of the constant noise

№ c.p.			Coordinates of points, m		Direct sound, L_{dir}, dB	Before sound-absorbing ceiling lining			After sound-absorbing ceiling lining
	X	Y	L_{rfl}, dB	L_{sum}, dB		ε_p^{rfl}/W_p, s/m	L_{rfl}, dB	L_{sum}, dB	ε_p^{rfl}/W_p, s/m
1	2	3	4	5	6	7	8	9	10
PT1	9	2.8	97.8	98.0	100.9	$58.68 * 10^{-6}$	95.3	99.7	$31.51 * 10^{-6}$
PT2	18	2.8	82.3	94.6	94.8	$26.82 * 10^{-6}$	89.7	90.4	$8.68 * 10^{-6}$
PT3	26	2.8	77.5	92.9	93.0	$18.14 * 10^{-6}$	85.9	86.5	$3.62 * 10^{-6}$
PT4	18	9	–	93.2	93.2	$19.43 * 10^{-6}$	86.3	86.3	$3.97 * 10^{-6}$
PT5	3	15	–	94.3	94.3	$25.03 * 10^{-6}$	88.5	88.5	$6.58 * 10^{-6}$
PT6	18	15	–	92.5	92.5	$16.54 * 10^{-6}$	84.4	84.4	$2.56 * 10^{-6}$
PT7	26	15	–	92.2	92.2	$15.44 * 10^{-6}$	83.7	83.7	$2.18 * 10^{-6}$

calculated. Figure 4 shows calculated by expression (5) and experimentally obtained graphs of changes in sound pressure levels over time. It can be seen that the results of calculations and measurements correlate with each other well. The discrepancies do not exceed 3 dB. The resulting calculation model allows us to analyze changes in variable noise in the space of a room and in time. The model makes it possible to evaluate the effect of construction-acoustic measures of reducing noise on the sound field of a building, for example, by installing sound-absorbing cladding. This is clearly seen in the graphs of Fig. 4. If there is no sound-absorbing ceiling lining, under the action of a non-continuous noise source, the sound pressure level at point CP1 reaches a maximum value of 100.5 dB. In the time intervals between the emissions of energy pulses, the level decays to 76.5 dB and exceeds background noise by 1.5 dB. In this case, the level difference in time reaches 100.5 – 76.5 = 24.0 dB. At point CP6, the level difference in time is respectively equal 91.7 – 75.5 = 16.2 dB. When a sound-absorbing lining is installed, the sound-absorption coefficient equal to in the octave band with f_{mid} = 500 Hz α_{obl} = 0.80 (see Table 1) the average sound absorption coefficient of the room will be $\alpha_{mid \cdot obl}$ = 0.375. In this case, the background noise of the room will decrease by approximately $\Delta L \approx 10\,\mathrm{lg}(\alpha_{mid.obl}/\alpha_{in}) = 10\,\mathrm{lg}(0.375/0.12) \approx 5\,dB$ and will be $75 - 5 = 70$ dB. An increase in the average room sound absorption coefficient leads to a decrease in the reverberation time and, accordingly, to a sharper attenuation of sound energy. The minimum levels in this situation are determined by the values of the background noise levels. In this case, the level period at point CP1 will be 25 dB, and at point CP6 it will be 14.8 dB. It can be seen that the excess of pulsed noise over background noise remained almost within the same limits. To reduce the level difference, it is necessary to apply noise control measures in the source itself.

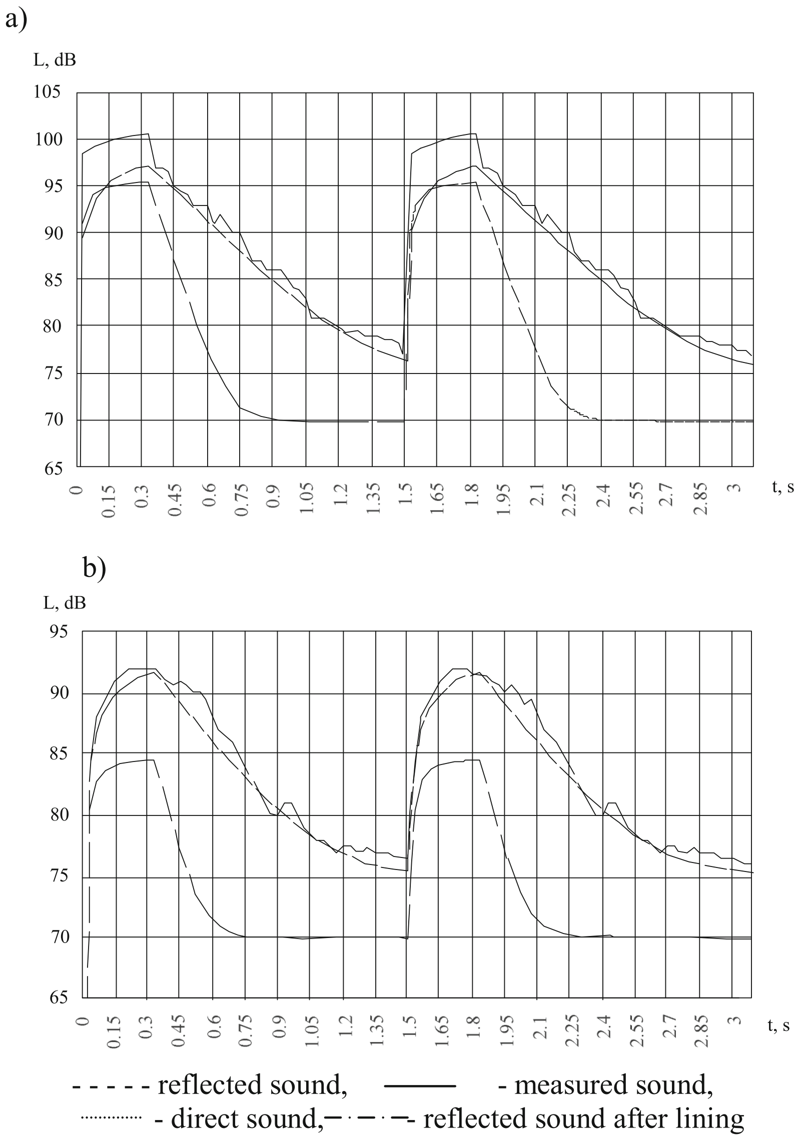

Fig. 4. Graphs of changes in sound pressure levels at design points CP1 (a) and CP6 (b) from a source of periodic action, taking into account background noise

4 Conclusions

In general, the results of the work allow us to draw the following conclusions:

1. To calculate the non-continuous noise in the industrial facilities of railway transport enterprises in the presence of large-sized objects in the form of wagons and locomotives, the statistical energy model of the reflected sound field proposed in the work should be used.

2. To implement the proposed computational model, it is necessary to use the numerical method of energy balances. The accuracy of the numerical method is confirmed by experimental data. The discrepancy between the results of calculations and experiments does not exceed 3 dB in both the space of the room and in time.
3. The computational model and the numerical method of its implementation make it possible to make a reliable assessment of changes in the noise regime under the action of non-continuous noise sources and to develop measures to reduce noise in rooms of complex shapes in the presence of large-sized items.

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Operational Reliability and Durability of Roads with Cement Concrete Coatings

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Abstract. Cement-coated roads are widespread in the world. The leaders in the length of the network of roads with cement concrete coatings are countries such as the USA, Belgium, Germany, Italy and China. Modern technologies for the production of building materials and products based on them must meet at least five fundamental criteria: technological availability and efficiency, resource and energy conservation, environmental safety, natural balance, biocompatible and economic feasibility, ethical acceptability of the use of materials in practice. All these criteria correspond to methods for improving the operational characteristics of cement compositions by activating a mixing fluid with various material and field effects. It is shown that, compared with control non-activated samples, the strength of samples in the cement-water system increases by an average of 33%, of cement-sand samples by 20%, and at the same time of cement-concrete samples by 25%. Thus, the activation of water in the cement-water system will ensure the operational reliability of roads with cement concrete pavement.

Keywords: Cement-concrete coatings · Cement · Water · Activation · Mixing fluid · Compression strength · Setting time · Cement-sand mixture · Concrete · Density

1 Introduction

Cement-concrete coatings of roads have high transport and operational characteristics, such as strength, the actual modulus of elasticity, etc., providing significant adhesion of the car wheels to the coating, the ability to withstand high traffic loads [1, 2], and also reduce the influence of climatic and adverse soil conditions, including frost heaving.

It is known that, in areas of seasonal freezing, defects in asphalt concrete pavement are widespread in the form of cracks, which often form in the first three years of operation of the road [3], the appearance of cracks on the pavement in winter can be caused by low-temperature cracking or uneven elevation of the pavement surface in the result of frost heaving [4, 5].

The obvious advantages of cement concrete coatings include: service life (25 years or more), absence, or rather, tens of times longer than that of non-rigid pavements, a bowing deflection of the road structure, low susceptibility to temperature fluctuations, high values of the coefficient of adhesion of wheels of automobile vehicles with

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coating, increasing traffic safety due to the increased reflective properties of cement concrete coatings, reducing fuel consumption by 7–10% compared with non-rigid road pavements.

However, along with the listed advantages, cement concrete coatings also have a number of disadvantages, for example, the high cost of cement concrete coatings, the need to use expensive sets of machines for installing such coatings, the high need for cement, the lack of effective repair technologies, low resistance to anti-ice reagents and others. Perhaps the main of these shortcomings is the lack of effective technologies for the repair of cement concrete coatings. On concrete roads, as well as on asphalt concrete roads, defects are formed during operation (peeling and chipping of the surface layer, formation of potholes, chips at transverse and longitudinal joints, the formation of through cracks and destruction of concrete in these areas, the appearance of potholes, roughnesses in the joint zone, subsidence of prefabricated slabs or individual sections of the road surface) [6, 7].

The growth of the fleet, the increase in traffic intensity and the increased carrying capacity of vehicles are associated with the need to increase the requirements for the strength and durability of the roadway. This, in turn, makes the construction of cement concrete roads especially relevant.

One of the most effective ways to solve this problem is, in our opinion, the activation of the mixing fluid of cement systems by physical, chemical and combined external influences.

It is known that binding properties are peculiar neither to cement on its own, nor to water, but to the “cement-water” system. Therefore, an increase in the performance characteristics of cement stone is possible with activation and modification of each components of the cement system separately, and of the system as a whole [8–11].

Water is one of the most valuable minerals on Earth, and drinking water shall be considered a priceless gift of nature. However, despite the acute shortage of drinking water all over the world, it is still widely used in many technological processes, and its consumption is increasing year by year [12]. The building sector and the construction materials industry are the largest consumers of clean water. Therefore, the sustainable use of water resources and improving the efficiency of water use in various construction technologies are among the most crucial tasks of modern material sciences.

The reduction of water consumption is possible on the way of modifying its properties by physical, chemical, and combined external effects. Various methods of water properties management in order to increase its reactive capacity in relation to binders of various industrial use, and first of all, in relation to cement, are described in scientific and technical and patent literature [13–15]. Research in development of resource and energy-saving technologies for the production of construction products are highly relevant, as cement and cement based systems are the highest production volume and at the same time the most demanded products in industry f required they should be used only for brief notes that do not fit conveniently into the text.

The main objective of our study was to increase the strength of the cement concrete pavement of roads by means of directional activation of the mixing fluid of cement systems.

The research deals with modifying addition effect of inorganic salts as a chemical external effects. The effect of water mixing in forced rotary centrifugal apparatus is studied as a physical effect. A combination of the first two types of external effects is taken as a combined effect.

Modern thinking about the structure of water are still controversial. However, numerous researches in this area indicate structural and energy transformations in water environment, even with minor external effects.

At the same time, the electrophysical, electrochemical and other parameters of activated water change in comparison with the controlled non-activated water. So the studies [16] show, that the increase or decrease of the electrical capacity of an aqueous sodium chloride solution and tuned circuit Q-factor under different effects reflects an increase or decrease of water dipoles mobility in an alternating electric field and indirectly indicates a decrease or increase of the structure degree of water and aqueous solution of salt.

The studies of Krivoborodov and Elenova [17] show the efficiency of cement systems processing in forced rotary centrifugal apparatus and the development of an complex additive for the accelerated hardening of cement stone. The authors of this work believe that the combined effect on the studied systems will not only increase the technological availability and efficiency of obtaining the cement composition, but also to a certain extent solve the problems of resource and energy conservation, environmental safety, natural compatibility and economic feasibility of the developed technology to increase the hydraulic activity of cement and on this basis to create cement-sand and cement concrete compositions with enhanced operational characteristics tics in the construction of roads with cement concrete coatings.

2 Research Methods

During the experiments, two mechanical devices, Turbula laboratory gravity based mixer, and MP4/1 planetary mill were used as RPE mixers. "Turbula" mixer is equipped with 2.6 L bowl. The bowl is made of stainless steel 12x18H10T, the bowl speed is 10–75 rpm, supply voltage is 50 Hz.

Planetary mill MP4/1 is equipped with four milling pots, the volume of one milling pot is 1 L, the speed of planetary disk is 50 rpm, of milling pot is 90 rpm, the installed capacity is 1 kW, power supply is 380 V. The experimental technique is to activate tap water for 5, 10, 20 min. The activation is performed in series in both devices.

Salts of sodium chloride and calcium chloride are used for chemical activation. The selection of salt-modifiers was based on the fact that these salts are capable not only to modify the water structure, but also to cause the acceleration of hydration processes of cement hardening, the increase of its freeze resistance and other operational properties.

The studies [29, 30] show, that the electric capacity of 0.1 M sodium chloride solution decreases less noticeable with increasing frequency of reactive current from 1 to 3000 kHz in comparison with distilled water, and the nature of the decrease, given other conditions being equal, depends on the distance between the capacitor sheets. Figure 1 presents some results of these studies.

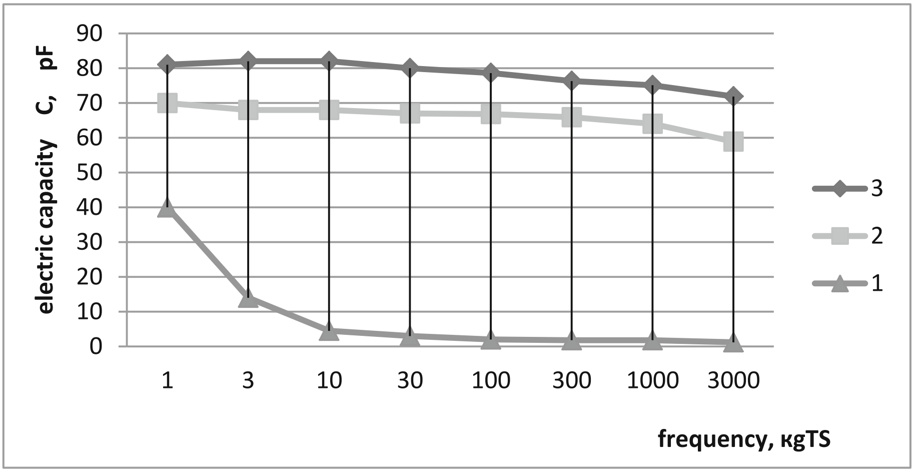

Fig. 1. The dependence of the electric capacity of distilled water and aqueous sodium chloride solution and calcium chloride on the frequency of the reactive current: (1 - distilled water; 2 - an aqueous sodium chloride solution with a concentration of 10^{-1} M; 3 - an aqueous calcium chloride solution with a concentration of 10^{-1} M)

So at frequencies of 30, 100, 300 kHz and the distance between the sheets from 2 to 10 cm, the quality factor decreased, respectively, from 97 to 50%.

At the same time it was found that the quality factor of the oscillatory circuit in comparison to the electric capacity seems to be a more sensitive parameter for evaluating structural and energy transformations in water and aqueous electrolyte solutions.

Similar studies were conducted with calcium chloride solutions, the latter being more characteristic in terms of the effect on changes in the electro-physical parameters of water and aqueous solutions over time. It is the reason that the solutions of sodium chloride and calcium chloride were chosen with a combined effect.

The combined effect applying, the solutions of these salts with a concentration of 0, 1 M are processed in the RPE and then the cement is mixed with processed liquid. Cubic samples with a side of 20 mm are molded on the basis of the cement of the same type and class (CEM I 42.5 N), and control samples with unprocessed water are prepared for each sample set. The samples are tested for 3, 7, 14, 28 days. The tests are carried out in accordance with standard procedures.

At the second stage of the study, the structural and mechanical characteristics of cement-sand and cement concrete samples prepared with water activated by the above method were studied. The composition of cement-sand mixtures corresponded to the ratio of cement - sand 1:3. Sand was used with a particle size module 2.1 satisfying the requirements of GOST.

The composition of cement concrete compositions with a density of 2400 kg/m^3 corresponded to the following ratio of ingredients per 1 m^3, cement - 400, sand - 620, crushed stone - 1200, water - 180 l/m^3. Control and test samples were prepared according to the same technology with a size of $15 \times 15 \times 15 * 10^{-2}$ m, kept under normal conditions for 7 and 28 days. And then tested for compressive strength.

In all cases, at one test point for a mixture of the same composition, at least six samples were prepared to confirm the statistical reliability of the results.

Control and test samples were prepared in an identical way, ceteris paribus with one unique difference: for the preparation of the test samples, a mixing fluid activated by a combined method was used.

3 Results and Discussions

The experiments on water processing by combined effects revealed that the highest rates are observed in chemical modification of potassium chloride solution and physical processing of the tested solution in RPE2. These data are represented in paragraph 4 of Tables 1 and 2 shows these data in the third row in each column. The results of the presented experiments are shown in Tables 1 and 2.

Table 1. The changes of setting time for systems cement+activated water and cement+non-activated water

System and methods of processing	Processing time	Start time (hour)	End time (hour)	Interval
1. Inactive control	0	0.45	12	11.55
2. Active in RPE 1	5 10 15	0.46 0.35 0.30	10 9 8	9.54 8.65 7.65
3. Active in RPE 2	5 10 15	0.35 0.30 0.28	9 8.5 8	8.65 8.2 7.72
4. Combined	5 10 15	0.30 0.28 0.25	8.5 7.5 6.0	8.2 7.22 5.75

As we can see from Table 1, the setting time of cement paste mixed with activated water is reduced by an average of 20–30%, which complies with the literature data [16, 27, 31].

According to the modern concept of building material sciences, any created material shall meet seven fundamental criteria:

The results of tests for the strength of cement stone at different periods of hardening are presented in Table 2.

As can be seen from Table 2, in all cases, the strength of the hardening structure at 28 days of age under normal conditions of structure formation exceeds the strength of the control sample by an average of 20%, and by the combined method it is higher in apparatus 2 than in apparatus 1 and 33% higher than the strength by compression of the control sample. The test results of cement-sand samples for compressive strength for 7 and 28 days are presented in Table 3.

Table 2. Cement stone strength (in MPa) in various periods of hardening (T. – Turbula; M. – MP4/1 planetary mill; K. – The combined effect)

Time frame	Period of hardening (day)			
	3	7	14	28
5 min	T.33 M.41 K.45	T.32.5 M.45 K.47	T.37 M.47 K.50	T.40 M.50 K.53.5
10 min	T.35.0 M.44.0 K.47.0	T.37 M.47 K.50	T.43 M.50 K.52	T.45 M.52 K.55
20 min	T.50.0 M.52.0 K.55.0	T.52 M.57 K.57	T.55 M.60 K.62	T.57 M.62 K.65
30 min	T.45 M.50 K.52	T.47 M.50 K.57	T.54 M.56 K.72	T.57 M.64 K.80
Control	T.21 M.47 K.50	T.33 M.50 K.52	T.42 M.52 K.55	T.51 M.57 K.60

Table 3. The strength of cement-sand compositions (in MPa) at various periods of hardening

System and methods of processing	Period of hardening (day)	
	7	28
Control sample	20.0	40.0
Test sample	27.5	48.0

As can be seen from Table 3, the strength of the studied samples increases by 20%. The test results of cement concrete compositions prepared with ordinary and activated water are presented in Table 4.

Table 4. Strength of cement concrete compositions (in MPa) at various hardening periods

System and methods of processing	Period of hardening (day)	
	7	28
Control sample	14.0	20.0
Test sample	17.5	25.0

As can be seen from Table 4, the strength of the studied samples increases by an average of 25%. At the third stage of the study, cement beam mixtures of the optimal composition obtained by mixing the ingredients with water activated by a combined method prepared model beam structures that were tested in laboratory conditions using standard certified equipment.

At the same time, both control and test samples were reinforced in the same way using iron reinforcement of the same type and quality.

4 Conclusions

Laboratory tests showed that in all cases the strength of the samples studied exceeded the control, which indicates the preference for using the proposed technology to ensure operational reliability and durability of roads with cement concrete coatings.

Obviously, the main distinguishing features of the proposed technology is its technological availability, efficiency and economic feasibility.

Water, as the most accessible component for modifying concrete mixtures, allows the creation of ecologically absolutely safe and environmentally compatible technologies. In the most general case, in our opinion, according to the modern concept of building materials science, any material created must meet seven fundamental criteria:

- technological efficiency and accessibility;
- energy and resource saving;
- environmental safety and natural compatibility;
- economic feasibility;
- aesthetic expressiveness;
- ethical acceptability of use;
- social usefulness.

Thus, the experiments showed the promise of mechanochemical activation of the mixing fluid with the indicated types of exposure and the possibility of producing cement stone, cement-sand and cement concrete compositions with high performance characteristics, which will allow the construction of roads with cement concrete coatings that ensure the operational reliability of transport structures.

Further research will be aimed at performing full-scale tests and monitoring of cement-concrete coatings prepared using activated water at pilot sites equipped on the road network of the study region.

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Physical and Mechanical Characteristics of Soil Within the Culvert Pipes Location of Roads

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Abstract. The physical and mechanical characteristics of roadbed soil within the sections of one of the roads of Novosibirsk conglomeration in the culvert pipes locations were studied and analyzed in order to identify their impact on the pavement performance. The engineering and geological elements have been identified, for which correlation-regression analysis of the soils physical and mechanical characteristics were performed and their statistical parameters were determined. It has been established that there is pavement surfacing unevenness in 93% of cases, the root cause of which is the presence of loosen areas of the roadway. It is noticed that the soil physical and mechanical characteristics improve with a distance from the culvert pipes. The stages for assessment of soil physical and mechanical characteristics are proposed based on a sample experimental determination of the deformation modulus for typical engineering and geological elements by means of calculation of the main characteristics according to the correlation-regression equations, and designing the reconstructive measures.

Keywords: Highway · Culvert pipes · Roadbed · Pavement · Soil physical and mechanical properties · Correlation-regression analysis

1 Introduction

A distinctive feature of roads in the locations of culvert pipes is accumulation of deformations caused by uneven soil compaction [1–4], the impact of traffic loads of moving vehicles, climatic conditions and a height of the pavement base above the culvert pipe [5]. In this regard, the actual trends for improving the efficiency of traffic-operational condition of the road during maintenance and repair are the timely and accurate assessment of the physical and mechanical characteristics of roadbed soil.

The national project "Roads Quality and Safety" provides for the introduction of new roads and bringing the existing ones to the world level.

Therefore, there is the need for new technologies, methods and techniques to improve the quality of roads construction and overhaul, including those which are based on the study of the roadbed soil physical and mechanical characteristics [6–9].

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2 Study Methodology

The study object was the sections of one of the highways of the Novosibirsk Region in the culvert pipes location since the barrier areas contain the greatest pavement deformations and surface unevenness [10–15]. The methodical approach to the study is presented in Fig. 1.

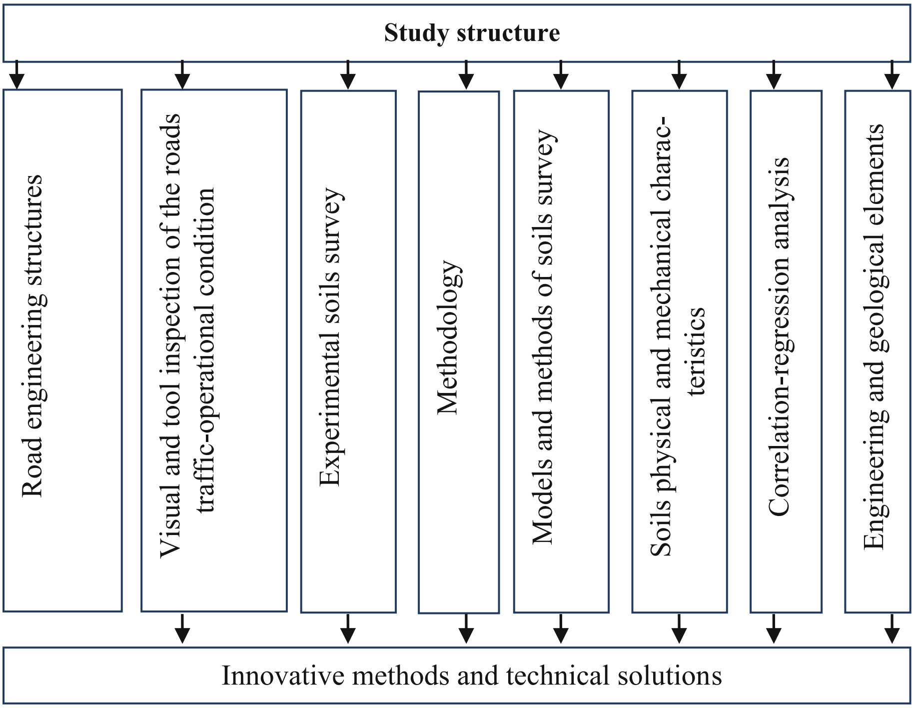


Fig. 1. Study structure

It is focused on the following works:

– analysis of design and construction documentation, existing regulatory documents;
– visual and tool inspection of pavement and culvert pipes;
– study of the soils properties with identification of engineering and geological elements (EGE);
– performance of correlation-regression analysis of the physical and mechanical characteristics of road soils within the culvert pipes locations;
– preparation of the methodology for assessing the soils physical and mechanical characteristics during maintenance and repair of roads within the culvert pipe locations.

The analysis of design and construction documentation, existing regulatory documents includes the search for materials, archiving and comparison with the real road sections.

Visual and tool inspections included the reconnaissance with engineering survey; observation of pavement deformation; determination of the index of pavement longitudinal evenness, detection of defects [16]. The culvert pipe and its technical condition is shown in Fig. 2.

a) 1999 b) 2018

Fig. 2. Culvert pipe and its technical condition in 1999 and 2018.

The general view of the Novosibirsk Region road sections with asphalt concrete pavement defects is shown in Fig. 3.

a) b)

Fig. 3. Asphalt concrete pavement defects of the Novosibirsk Region road sections.

For each section of the road in the culvert pipes locations, a fault report on the current condition of the pavement surfacing is prepared including indication of the defect, location and length of the defective section to compare the actual and maximum permissible evenness parameters.

3 Studies

It was experimentally revealed that there are cracks on the pavement, the opening of which reaches 20 to 70 mm that is unacceptable according to ODN 218.0.006-2002.

The actual and maximum allowable depths of the clearance under the 3-meter rail were established and summarized in the fault report.

The analysis has allowed to conclude that the clearance depths in the sections: 44 + 194 km of road “K-17r”; 72 + 365 km of road “K-17r” i.e. a longitudinal evenness is not provided, that is, it does not satisfy the requirements, according to ODN 218.0.006-2002 under the conditions of longitudinal evenness.

Unevenness is observed in the form of settlement in barrier areas, holes, cracks and is 93% of adverse events. A pavement settlement was observed in 73% of those cases.

At a distance of 30 m from the culvert pipes on both sides, improvement in the physical and mechanical characteristics of the roadbed soil was noted, including decrease in humidity, which indicates an improvement in the strength properties of the roadbed soil.

The soil characteristics were determined by monoliths taken from 4 holes (Fig. 4).

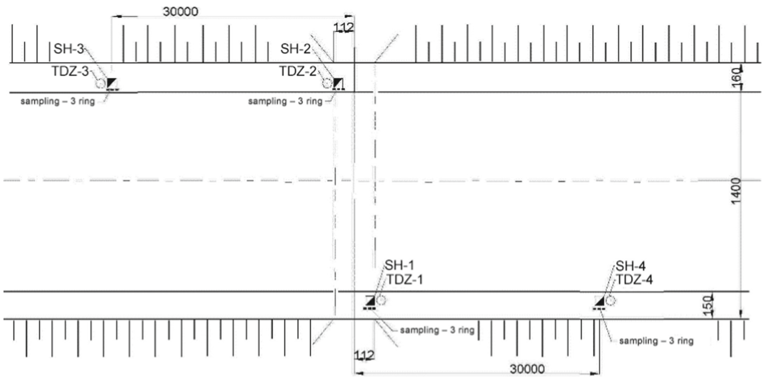


Fig. 4. Roadways layout

After selection of monoliths, the soils’ physical and mechanical properties were studied in the laboratory, the respective reports were completed.

4 Results

When comparing the physical and mechanical characteristics of the soil, engineering and geological elements were identified during the study. The physical and mechanical characteristics of the roadbed soil are given in Table 1 as per EGE.

Table 1. Physical and mechanical characteristics of the roadbed soil as per EGE.

EGE description/soil type	Density of soil particles, ρ_s	Density of soil with natural humidity, ρ	Dry soil density, ρ_d	Porosity, n	Porosity factor, e	Humidity, W	Degree of saturation, Sr	Humidity on the limit of liquidity, W_L	Humidity on the limit of plasticity, W_P	Plasticity number, Ip	Liquidity index, I_L	Modulus of deformation, E, MPa	Internal friction angle, φ, degree	Specific cohesion, C, MPa
EGE-1p/solid sandy silt, compact	2.69	1.88	1.66	38	0.620	0.13	0.56	0.27	0.22	5	< 0	10.3	28.8	0.020
EGE-1 s/solid sandy silt, middle density	2.69	1.77	1.55	42	0.739	0.14	0.51	0.28	0.23	5	< 0	8.3	26.9	0.018
EGE-1r/solid sandy silt, loosen	2.69	1.67	1.46	46	0.841	0.14	0.45	0.27	0.22	5	< 0	3.8	25.7	0.014
EGE-2p/Light loam with bands of heavy one, silty, compact	2.70	1.90	1.64	39	0.650	0.16	0.67	0.32	0.22	10	< 0	9.8	25.6	0.026
EGE-2 s/Light loam with bands of heavy one, silty, medium density	2.71	1.84	1.55	43	0.746	0.19	0.69	0.33	0.22	11	< 0	7.8	24.4	0.023
EGE-2r/Light loam with bands of heavy one, silty, medium density	2.71	1.75	1.48	45	0.830	0.19	0.61	0.33	0.22	11	< 0	6.0	23.1	0.022

Analysis of the obtained results has shown that the greatest difference was in the soils compaction degree measured in both laboratory and field conditions. In this case, the worst value of soil compaction was obtained in the immediate vicinity of a culvert pipe. This has allowed to conclude that the prime cause of pavement surfacing uneveness over the barrier areas is the formation of loosen areas in the culvert pipes annulus.

The papers [17–20] are devoted to the study of mutual influence of soil parameters. It seems advisable to use the correlation-regression analysis based on the results of laboratory studies of the roadbed soil to establish the statistical regularities of the mutual influence of soil parameters.

The calculations were performed in the EXCEL statistical block. The matrix of paired correlation coefficients of the soil physical and mechanical characteristics presents the absence of a relationship between the depth of pavement settlement (clearance) above the culvert pipe (r), soil density (ρ), angle of internal friction (φ), specific adhesion (C), deformation modulus (E). At the same time, the connections between the pairs of soil characteristics are strong, close to functional. The analysis results of the regression dependence E = f (ρ) are given in Tables 2, and 3.

Table 2. Results of regression statistics

Parameter	Day
Correlation coefficient	0.964065
Coefficient of determination	0.929422
Standardized R-square	0.917659
Standard error	0.402153
Observations	8

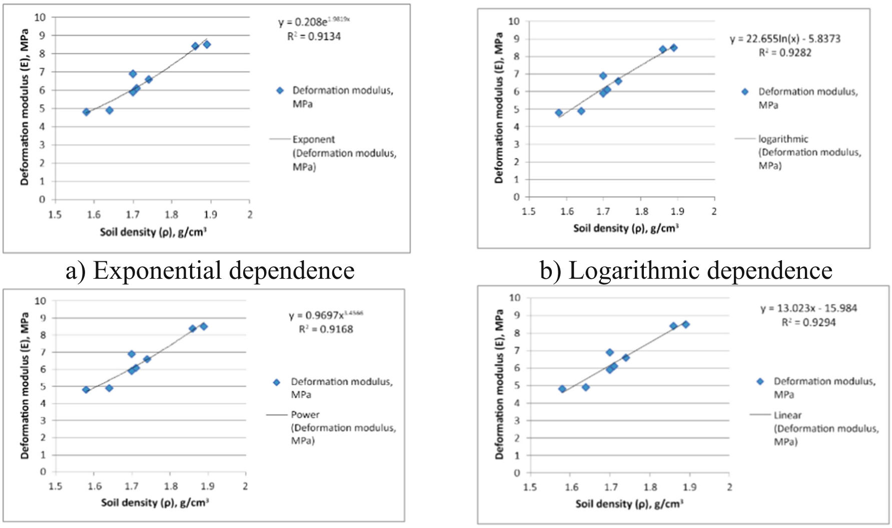
Table 3. Statistical parameter values

	Coefficient	Standard error	t-statistics	P-value	Low 95%	Up 95%	Low 95.0%	Up 95.0%
Y-intersection	−15.984	2.534848	−6.30569	0.000742	−22.1865	−9.78143	−22.1865	−9.78143
ρ	13.02256	1.46504	8.888876	0.000113	9.437737	16.60739	9.437737	16.60739

t- Student criterion ($t_p > t_{table}$) confirms the coefficients reliability of the linear dependence of the deformation modulus on the soil density. However, the regression equation may be non-linear. The reliability of relationship selection correctness is established by the Fisher criterion (F is the criterion). When $F_p > F_{table}$, the regression equation is considered as to be statistically significant.

Figure 5 represents the dependency diagrams of deformation modulus to soil density, the regression equations and the coefficients of determination.

The coefficients of deermination exceed 0.9 that allows taking any of the regression equation from the above, in this regard, statistical studies were performed based on a number of culvert pipes, increasing a number of observations and improving the representativeness of the sample.



a) Exponential dependence b) Logarithmic dependence

c) Power dependence d) Linear dependence

Fig. 5. Dependence of the deformation modulus on soil density in the culvert pipe annulus

The following regression equations were obtained (Table 4).

1. E = f (r, ρ, φ, C); E = −0.012 * r + 1,449 * ρ + 1.675 * φ − 543.222 * C − 35.5426. Coefficient of determination (R2-square) is 0.99.
2. E = f (ρ, φ, C); E = 1.439 * ρ + 1.55 * φ − 466.34 * C − 33.3424; R2 is 0.98.
3. C = f (φ, ρ); C = 0.0027 * ρ + 0.0014 * φ − 0.03; R2 is 0.99.

Table 4. Regression models of soil physical and mechanical characteristics - 20 km

Item No.	km	E = f(ρ)	K determ.	E = f(φ)	K determ.	E = f(C)	K determ.
Paired regression equations in the culvert pipes annulus							
1	20	$y = 0.208e^{1.9819x}$	0.91	$y = 0.1196e^{0.1379x}$	0.98	$y = 1.6749e^{84.937x}$	0.97
		$y = 22.655\ln(x) - 5.8373$	0.93	$y = 25.793\ln(x) - 80.163$	0.98	$y = 8.3645\ln(x) + 41.327$	0.93
		$y = 0.9697x^{3.4566}$	0.92	$y = 1E\text{-}05x^{3.9759}$	0.98	$y = 1432.1x^{1.3006}$	0.96
		$y = 13.023x - 15.984$	0.93	$y = 0.8966x - 19.344$	0.98	$y = 550x - 2.15$	0.96
Paired regression equations for two holes at a distance of ±30 m from culvert pipes							
2	20	$y = 0.9074e^{1.1315x}$	0.40	$y = 0.4793e^{0.0892x}$	0.59	$y = 2.8947e^{52.325x}$	0.54
		$y = 13.964\ln(x) - 1.2006$	0.40	$y = 16.99\ln(x) - 50.78$	0.53	$y = 5.399\ln(x) + 29.09$	0.50
		$y = 2.0907x^{2.0475}$	0.41	$y = 0.001x^{2.5901}$	0.59	$y = 196.09x^{0.8158}$	0.55
		$y = 7.7258x - 6.9088$	0.39	$y = 0.5859x - 10.576$	0.53	$y = 347.8x + 1.1673$	0.50
Paired regression equations for four holes at a length of 60 m							
3	20	$y = 0.3475e^{1.6773x}$	0.76	$y = 0.2175e^{0.1165x}$	0.85	$y = 1.9631e^{75.461x}$	0.83
		$y = 19.189\ln(x) - 4.0822$	0.75	$y = 21.549\ln(x) - 66.074$	0.81	$y = 7.4462\ln(x) + 37.512$	0.80
		$y = 1.2603x^{2.9492}$	0.76	$y = 8E\text{-}05x^{3.3615}$	0.85	$y = 797.8x^{1.1584}$	0.83
		$y = 10.941x - 12.514$	0.75	$y = 0.748x - 15.229$	0.81	$y = 488.35x - 1.1567$	0.81

The regression equations for holes at a distance of ±30 m from culvert pipes taking into account the longitudinal evenness (r) are expressed in the following form:

1. r = f (E); (the depth of the pavement settlement as a function of deformation modulus), y = −0.064 * x + 7.95 with a multiple R equal to 0.398, R2 = 0.159 that indicates a weak correlation of these parameters. This also indicates that the statistical dependence of the longitudinal evenness (wheel tracking) on the deformation modulus increases with distance from the pipe. This is confirmed by the following equation:
2. r = f (E, ρ, φ, C); r = − 7.586 * E + 79.507 * ρ − 5.572 * φ + 4371.8 * C + 21.467 at multiple R equal to 0.729, R2 = 0.532.

For each EGE, the regression equation was analyzed, their average parameters, variations and coefficients of variation were determined. For dependences of the deformation modulus on the soil density ρ, [g/cm^3], on the angle of internal friction φ, [deg] and on the specific adhesion C, [kPa] in the dependencies recommended by the authors, these coefficients are taken based on their average values. The dependences of the modulus of deformation E on the soil density ρ for EGE 1p in holes Nos. 1, 2 are given in Tables 5, and 6.

Table 5. Statistical dependences of the modulus of deformation E on the soil density ρ for EGE 1p in Hole No. 1, Hole No. 2 for exponential and logarithmic dependencies

km	$E = ae^{b\rho}$	a	b	E = cln(ρ)-d	c	d
20	$E = 0.208e^{1.9819\rho}$	0.208	1.982	E = 22.655ln(ρ) − 5.8373	22.655	5.837
72	$E = 0.0708e^{2.4585\rho}$	0.071	2.459	E = 26.043ln(ρ) − 9.2286	26.043	9.229
156	$E = 0.0021e^{4.3461\rho}$	0.002	4.346	E = 41.857ln(ρ) − 19.171	41.857	19.171
180						
205	$E = 0.0103e^{3.3356\rho}$	0.010	3.336	E = 33.983ln(ρ) − 15.835	33.983	15.835
226	$E = 0.0836e^{2.3491\rho}$	0.084	2.349	E = 26.208ln(ρ) − 9.5861	26.208	9.586
228	$E = 0.0353e^{2.8546\rho}$	0.035	2.855	E = 28.516ln(ρ) − 10.572	28.516	10.572
289						
303	$E = 0.029e^{2.9331\rho}$	0.029	2.933	E = 29.154ln(ρ) − 11.241	29.154	11.241
327	$E = 0.0184e^{3.23\rho}$	0.018	3.230	E = 33.992ln(ρ) − 13.646	33.992	13.646
334	$E = 0.1769e^{2.0158\rho}$	0.177	2.016	E = 21.451ln(ρ) − 5.8673	21.451	5.867
		Sa_i	Sb_i		Sc_i	Sd_i
		0.634	25.505		263.859	100.984
		a_{av}	bav		c_{av}	d_{av}
		0.070	2.834		29.318	11.220
		Vara	Varb		Varc	Vard
		0.198	2.364		20.406	13.334
		K Vara	K Varb		K Varc	K Vard
		2.809	0.834		0.696	1.188
	Recommended dependency			Recommended dependency		
	$E = 0,.070e^{2.834\rho}$			E = 29.318ln(ρ)-11.220		

Table 6. Statistical dependences of the modulus of deformation E on the soil density ρ for EGE 1п in Hole No. 1, Hole No. 2 for power and linear dependencies

km	$E = f\rho^g$	f	g	$E = k\rho - h$	k	h
20	$E = 0.9697\rho^{3.4566}$	0.970	3.457	$E = 13.023\rho - 15.984$	13.023	15.984
72	$E = 0.4237\rho^{4.4915}$	0.424	4.492	$E = 14.297\rho - 19.678$	14.297	19.678
156	$E = 0.0525\rho^{7.8304}$	0.053	7.830	$E = 23.255\rho - 36.447$	23.255	36.447
180				$E = 12.580 * \rho - 17.030$	12.580	17.030
205	$E = 0.1033\rho^{6.2897}$	0.103	6.290	$E = 18.045\rho - 28.322$	18.045	28.322
226	$E = 0.4615\rho^{4.2907}$	0.462	4.291	$E = 14.362\rho - 20.045$	14.362	20.045
228	$E = 0.3006\rho^{5.1024}$	0.301	5.102	$E = 15.978\rho - 22.59$	15.978	22.590
289				$E = 16.361 * \rho - 23.494$	16.361	23.494
303	$E = 0.2461\rho^{5.3489}$	0.246	5.349	$E = 16.013\rho - 22.946$	16.013	22.946
327	$E = 0.1962\rho^{5.8726}$	0.196	5.873	$E = 18.736\rho - 27.412$	18.736	27.412
334	$E = 0.842\rho^{3.5219}$	0.842	3.522	$E = 12.308\rho - 15.426$	12.308	15.426
		Sf_i	Sg_i		Sk_i	Sh_i
		3.596	46.205		174.958	249.374
		f_{av}	g_{av}		k_{av}	h_{av}
		0.400	5.134		15.905	22.670
		Varf	Varg		Vark	Varh
		0.917	4.373		10.947	21.021
		K Varf	K Varg		K Vark	K Varh
		2.295	0.852		0.688	0.927
	Recommended dependency			Recommended dependency		
	$E = 0.400\rho^{5.134}$			$E = 15.905\rho - 22.670$		

In relation to a culvert pipe on a specific site, it is advisable to use the dependency with the lowest coefficient of parameter variation from four recommended ones.

The use of correlation-regression analysis for roads quality assessment combined with experimental studies allows significantly reducing the time and cost for testing the soils physical and mechanical characteristics that will increase the efficiency of repair planning, improve the quality and safety of roads. In case of structural failure and unevenness beyond the standard tolerances, the repair of this road section is required. To develop a draft for its repair or reconstruction, it is necessary to determine the modulus of deformation and the soil physical and mechanical characteristics. Their obtaining by known methods requires a large amount of drilling and experimental studies in the laboratory, implementation of these activities and is time consuming, takes considerable time and requires significant costs. Their reduction is achieved using the following step-by-step method.

In general, it is possible to identify the following stages of assessing the soils physical and mechanical characteristics during maintenance and repair of roads within the culvert pipe locations:

- **Stage 1:** Wells drilling in depth and sampling of roadbed soil and pavement materials, their analysis to determine an EGE type and the assessment of a degree of coincidence with those given in this study.
- **Stage 2:** According to the selected type of EGE, the regression dependencies of the deformation modulus are selected, and according to the recommended regressions equations, the deformation modulus and soil physical and mechanical characteristics are calculated.
- **Stage 3:** Reconstructive measures are being developed. If more accurate calculations are required, stage 2 provides for the laboratory determination of one of the soil characteristics: ρ, φ, or C.

The regression equations are selected and the deformation modulus and other soil parameters are calculated. So, if density ρ is obtained during laboratory tests, then φ and C are calculated. If φ or C is obtained, then E and ρ are calculated. Then the necessary calculations to strengthen the soil within the culvert pipes location or at a distance from it are performed. The feasibility of applying new methods, design solutions and technologies to strengthen the roadbed are assessed.

The economic effect is calculated on the basis of a difference in costs of performing work on soils examination and testing, and repairs according to the known method.

5 Summary

The performed assessment of soil physical and mechanical characteristics within the culvert pipes has allowed to conclude that the presence of loosen areas of the roadway, an increase in soil moisture in the annulus are the primer cause of road pavement unevenness. Statistical relations of soil parameters as per EGE allow reducing the amount of field work, laboratory tests and applying their calculated values when developing design solutions for determination of the repair work composition.

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Influence of Temperature and Soil Thermal Expansion on Cracking of Dirt Road Surface During Seasonal Freezing

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Abstract. Low-temperature cracks reduce the road surfaces quality, increase the cost of their repair. This problem is relevant in the regions with seasonal soil freezing. Analysis of the literature showed that, despite the large research work, the multidisciplinary problem of low-temperature cracking requires further research. In the present work, the object of study is a two-layer structure as a model of a straight section (segment) of an unpaved highway in the stage of seasonal freezing. Subject of research: the conditions for frost cracking in the upper layer of the road during seasonal freezing. Objective: to simulate the conditions for transverse cracking in the upper layer during seasonal freezing of the dirt road, taking into account the influence of temperature on the coefficient of thermal expansion. The paper presents a mathematical model of the frost cracks formation. The results of the modeling are consistent with data known in the literature. From a practical point of view, the results can be used to predict the state of logging roads at the stage of soil freezing in the off-season periods.

Keywords: Dirt road · Seasonal freezing · Low-Temperature cracks · Soil thermal expansion · Modeling

1 Introduction

Regarding the relevance of the topic of this work, we note the following. Approximately one fourth of the world's forest resources are located in Russia, which is a country's competitive advantage in the system of world economic relations. However, the potential of rational use of forest resources is not realized sufficiently. The insufficient length of logging roads per unit area of forest land is amongst the main reasons for the backlog. The characteristics of the current state of the transport infrastructure are given in the Strategy for the Development of the Forest Complex of the Russian Federation for the Period up to 2020. The length of forest roads in the Russian Federation was at the time of the preparation of Strategy 1.5 km per thousand hectares of forest land; in Finland there are 12.3 km of forest roads per one thousand hectares of forest land [1], in Austria and Germany, 36 km and 45 km, respectively. At the date of the preparation of the Strategy, in Russia the share of year-round roads with hard

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surface in the total volume of forest roads was 11.2% (181 thousand km), year-round dirt roads accounted for 32% (514 thousand km), the rest were temporary roads.

Thus, at present, the relevance of applied research focused on the improvement of technologies for the construction logging roads remains. In this paper we deal the problem of modeling the conditions for the appearance of transverse cracks in the upper layer of the road during seasonal freezing. A large number of works are devoted to solving problems related to this field of applied research.

Currently, the bulk of the harvesting and hauling takes place in the winter period [2]. The influence of weather conditions on the volumes of timber hauling by temporary ice and snow-ice logging roads in the conditions of the Karelian Republic was studied in [3], were the prevalence of winter timber hauling volumes was confirmed, but it was predicted that with changing climate scenarios for Karelia, the expediency of a year-round operation transport infrastructure would increase. Nevertheless, the problems of improving winter forest roads remain relevant now and in the near future. To substantiate this remark, we present the data from [4], in which it was found that a series, whose elements are daily temperature values for 10 years (2007 … 2017) for one of the regions of Krasnoyarsk Territory, contains an almost insignificant linear trend: the temperature increased approximately by 0.02 °C per year.

The duration of the functioning of winter forest roads covered with compacted snow, snow-ice and ice roads was determined in [5] and is 100 … 130 days a year in the conditions of the Republic of Karelia. In the conditions of the above-noted region of the Krasnoyarsk Territory – 158 days a year for a road with snow cover and 188 days for an ice road [4].

Technologies for the construction of forest roads, including winter forest roads, are regulated in Russia by the set of rules SP 288.1325800.2016.

The literature analysis showed that a large number of works, reviews of which are given in [6–12], are devoted to multidimensional studies focused on improving forest roads. However, despite the large amount of research, a number of problems require further study. These include the problem of improving the operational reliability of winter forest roads. Various aspects of this problem are considered in publications [1, 4–14].

In this paper, attention is focused on the issues of mechanical interaction of the layers of the road structure during the offseason period, when the depth of frost penetration, and hence the thickness of the above-mentioned upper layer, have not reached their limit values. The physical and mechanical properties of the material of this layer during freezing change significantly. The transition of water to the ice state is accompanied by a restructuring of the frozen ground, an increase in its strength, and a decrease in water permeability. At the same time, the properties of the material of the underlying layer, the temperature of which is non-negative, almost do not change. Thus, the segment of the forest dirt road can be considered as a two-layer structure. In real situations, this segment interacts mechanically with vehicles and also resists negative temperatures. Further, only the effects of negative temperatures are taken into account. The result of such an impact is deformation of the segment and (under certain conditions) the appearance of cracks, which in the literature are called frost cracks [7, 15]. It should be noted that frost cracks appear not only in road surfaces, but also in frozen soil [7, 11, 15]. This means that issues related to the frost-cracking are relevant both for roads with hard asphalt concrete pavement and for unpaved forest roads in the initial stage of freezing.

The object of study: a two-layer structure as a model of a straight section (segment) of a highway in the freezing stage.

The subject of the research: the conditions of occurrence and the parameters of frost-cracking in the upper layer of the road during seasonal freezing.

The objective: to simulate the conditions for the occurrence of transverse cracks in the upper layer during seasonal freezing of the dirt road.

2 Materials and Methods

Physical and mechanical conditions formed during soil freezing [15] lead to the appearance of tensile forces in the upper layer of the soil. If the resistance of the soil to stretching is not enough, a crack appears. From the variety of cracks, only the transverse cracks that appear when roads freeze after a certain number of freeze-thaw cycles are considered below. The object of the study is a straight section of a forest road, the length of which is limited by two transverse cracks. The task is to determine the length of the section. If the length of this area is infinite, then there are no cracks. However, the evidence from the practice shows that frost cracks appear both on the surface of soil massifs [15] and in the upper layers of roads [7, 11, 16–18].

Well-known methods of mathematical modeling of mechanical systems are used in this article, taking into account the conditions for the formation of frost-cracking [7, 9, 11–19].

The physical and mechanical conditions for the formation of frost-cracking cracks were investigated in [15], in which the problem of the temperature field of a half-space filled with soil at a negative temperature on its surface was solved. The temperature on the surface of this half-space is lower than at a certain depth. Therefore, it is legitimate to assume that in the autumn-winter interseasonal period the upper layer of this half-space consists of frozen soil and rests on a layer of soil with non-negative temperature.

Thus, under certain conditions, in the interseasonal period “autumn– winter”, it is possible to consider a layer of frozen soil as an analogue of asphalt concrete road pavement. Thereafter, to simulate the interaction of the layer of frozen soil with the underlying soil layer, techniques well known in the analysis of stresses and deformations of asphalt concrete pavements can be adapted [7, 17, 18, 20].

The freezing of the frozen soil layer is accompanied by tensile deformations, which cause the above-mentioned transverse cracks. To determine tensile forces and related shear forces, consider a road segment with the length limited by two transverse cracks. The presence of cracks means that there are no tensile forces at the ends of the segment (tensile forces existed prior to the destruction of the material and the opening of the cracks). From the geometrical point of view, a simplified model of a segment is a parallelepiped the dimensions of which are determined by the thickness of a layer of a frozen soil, the width of the road and the length of the segment. The segment relies on the underlying soil layer with a non-negative temperature and interacts with it through friction and adhesion forces, which are distributed over the contact area and are directly proportional to the displacements (shear) of one layer relative to another. In this case, the proportionality coefficient is equal to k (N/m^3). The physical meaning of this coefficient is defined in article [16], in which the approach used by us in modeling the conditions for the appearance of frost cracks is also presented. The values of this coefficient vary in a large interval and can be determined from experimental data. It is necessary to take into account that the linear dependence of forces on shear deformations takes place to a certain limit. At a sufficiently large magnitude of shear forces, one layer slips relative to another; in this case, the movement (shift) of one layer relative to another occurs without an increase in forces in the plane of contact of the layers [21].

With a decrease in temperature, the length of the segment decreases, but the shear forces of friction and adhesion, which act in the area of the contact of the layers, prevent the decrease in length. Thus, from a physical point of view, the interaction of the layers is accompanied by the tensile strains of the upper layer and the shear strains of one layer relative to another. Taking into account the symmetry of the problem, we find that the tangential forces and the corresponding shear deformations in the middle of the segment length are zero and increase in magnitude in the direction from the middle of the segment length to its ends. On the other hand, tensile deformations increase in the direction from the ends of the segment to its middle.

In this work, the methods of mathematical modeling of mechanical systems have been used [13, 18]. To check the adequacy of the simulation results, well known published data were used.

3 Results and Discussion

By formalizing the above approach to modeling the state of the road segment under investigation, it can be shown that when the temperature decreases by $\Delta t = t - t0$, the maximum values of tensile forces Nmax and stresses σmax, as well as shear forces Tmax and tangential stresses τmax can be determined by the formulas [18]:

$$N_{max} = -k \cdot B \cdot \alpha \cdot \Delta t \cdot L^2/8, \quad (1)$$

$$\sigma_{max} = -k \cdot \alpha \cdot \Delta t \cdot L^2/8 \cdot H, \quad (2)$$

$$T_{max} = -k \cdot B \cdot \alpha \cdot \Delta t \cdot L^2/8, \quad (3)$$

$$\tau_{max} = -k \cdot \alpha \cdot \Delta t \cdot L. \quad (4)$$

Here $\Delta t < 0$ is the temperature difference. The coefficient k, as it is noted above, characterizes the force of friction and adhesion distributed over the contact area of the layers [16, 21]; B, H and L – respectively, the width, thickness and length of the upper layer of the segment; α is the coefficient of thermal expansion [19]. The justification of the formulas presented requires separate consideration, beyond the scope of this article.

Using the above formula for σmax and well known estimates of tensile stresses σ_m, which can lead to the appearance of frost cracks [19], from the condition $\sigma_{max} = \sigma_m$ we find the maximum segment length without cracks at $\Delta t = t - t_0 < 0$:

$$L_{max} = (-8 \cdot \sigma_m \cdot H/k \cdot \alpha \cdot \Delta t)^{1/2}. \quad (5)$$

The value L_{max} also determines the distance between frost cracks. Figure 1 shows an example of visualization of dependence (5), if $\sigma_m = 0.5$ MPa, $H = 0.1$ m, $k = 5 \ldots 250$ MN/m^3, $\alpha = 2 \cdot 10^{-4}$ °C^{-1}, $t_0 = 0$ °C, $t = -1 \ldots -20$ °C.

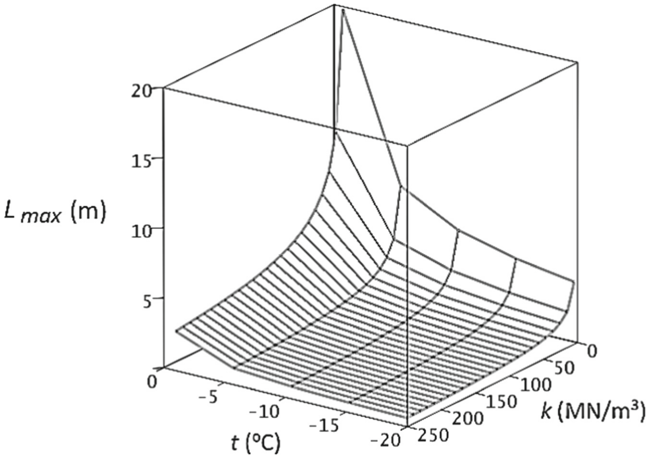

Fig. 1. Dependence L_{max} (t, k), if σ_m, H and α are constant.

For finite values of α, if $t \to 0$ or $k \to 0$, then $L_{max} \to \infty$, i.e. theoretically, in this case there are no frost cracks. Lowering the temperature t and increasing the adhesion of the layers k leads to a decrease in L_{max}; in this example, the minimum value is $L_{max} = 0.442$ m.

It is noteworthy that when it freezes, the greatest intensity of the processes of changing the structure of the segment in question takes place in the vicinity of a point with coordinates t and k close to zero; the intensity of these processes rapidly decreases with increasing t and k (see Fig. 1).

From a practical point of view, a decrease in k models a decrease in adhesion between the top layer and the base, which is taken into account when justifying measures aimed at preventing the formation of cracks in asphalt concrete pavements. Such measures also include an increase in the thickness of the asphalt layer [20, p. 72].

If $\Delta t \neq 0$, then with an increase in the strength of the material of the upper layer (σ_m) and its thickness H, the distance between the cracks L_{max} (5) increases, and therefore the number of cracks per unit length of the road decreases. These notes are valid for roads with concrete or asphalt concrete pavement, the thickness of which H is almost unchanged when it freezes. The principal difference of the dirt road is that when it freezes, the thickness of the upper layer H increases; in addition, the strength σ_m of the frozen ground as a material of this layer increases. Modern ideas about the patterns of changes in the strength of soils at negative temperatures are discussed in sufficient detail in the articles [12, 19, 22, 23].

Using a simplified approach to the analysis of the patterns of influence of the above σ_m and H on L_{max}, suppose that the thickness of the top layer of frozen soil H and the strength of the material of this layer σ_m at $t = -10$ °C are equal, respectively, to H_{10} and σ_{m10}. Suppose also that σ_m and H vary in proportion to $|\Delta t|$ with coefficients β_H and β_σ, respectively. Then $H = H_{10} \cdot \beta_H \cdot |\Delta t|$, $\sigma_m = \beta_\sigma \cdot \sigma_{m10} \cdot |\Delta t|$. The coefficients β_H and β_σ can be determined using well data. Let $\beta_H = \beta_\sigma = \beta = 0.1$ °C^{-1}. Then, using (5), we get:

$$L_{max} = (8 \cdot \sigma_m \cdot H/k \cdot \alpha \cdot |\Delta t|)^{1/2} = \beta \cdot (8 \cdot \sigma_{m10} \cdot H_{10} \cdot |\Delta t| / k \cdot \alpha)^{1/2}. \quad (6)$$

Detailing the dependence (6), we consider an example. Let $\sigma_{m10} = 0.2$ MPa, $H_{10} = 0.1$ m, $\beta = 0.1$ °C^{-1}, $t_0 = 0$ °C, $t = -2 \ldots -10$ °C, $k = 0.5 \ldots 20$ MN/m^3, $\alpha = 2 \cdot 10^{-4}$ °C^{-1}. For this set of numerical values, the visualization of dependencies (6) is presented in Fig. 2.

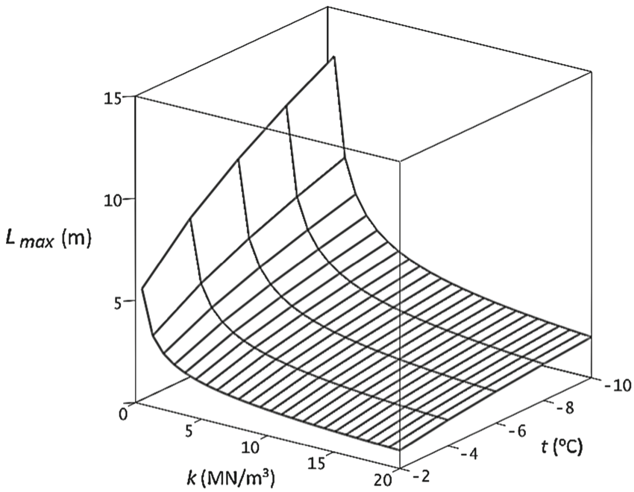

Fig. 2. Dependence L_{max} (t, k), if $\alpha = 2 \cdot 10^{-4}$ °C^{-1}

It should be noted that the thermal expansion coefficient of frozen soil α non-linearly depends on temperature, and this relationship for a number of soils has a local maximum at a temperature of approximately –3 °C [19, p. 162]. This means that at the same temperature, dependence (6) has a minimum, which, from a physical point of view, corresponds to the smallest distance between frost cracks in the ground. For example, according to published data [19, Fig. 2], we find that for frozen loam at $t = -2; -3; -5; -10$ °C, α values are equal, respectively, $2 \cdot 10^{-4}$; $3 \cdot 10^{-4}$; $2 \cdot 10^{-4}$; $5 \cdot 10^{-5}$ °C^{-1}. Taking $t_0 = 0$ °C and $t = -2; -3; -5; -10$ °C, we obtain by the formula (6) at $k = 0.5$ MN/m^3 the values of L_{max}, respectively, 6.9; 5.7; 8.9; 25.3 m. The minimum value of 5.7 m is an estimate of the distance between frost cracks.

Checking the adequacy of this assessment, we turn to the published data [24, p. 976], according to which "the formation of a polygonal pattern of the microrelief on the day surface of the soil is connected with frost cracks. The polygons have a diameter of 2 … 6 m and a crack width of 3 … 5 cm". Thus, the value of the distance between frost cracks (5.7 m) found by the formula (6) is realistic.

It is important to pay attention to the fact that in the considered case the minimum value of L_{max}, equal to 5.7 m, is reached at $t = -3$ °C. Consequently, temperature deviations from −3 °C over time will not lead to the appearance of new frost cracks in the ground. This conclusion, obtained as a result of modeling using formula (6), is confirmed by the data published in [24, p. 976] data on the evolution of cryogenic cracks, according to which "in some cases a crack occurs once and in this place is no longer repeated for many years".

As noted above, the frozen ground is the material of the upper layer of the unpaved logging road. In the construction of such roads, a mixture of forest soil and soil (soil) is used as a local material [1, 14]. In this regard, to assess the adequacy of the distance between frost cracks presented above, data on the polygonal structure of the relief of four varieties of gray forest soils published in paper [25] are of interest. "Morphologically, it looks like the alternation of hillocks and basins of a round and oval shape, the diameter of the hillocks is from 5 to 20 m, and the elevation above the basins is from 0.5 to 3 m. The beginning of the formation of the microrelief is referred to the late Pleistocene, when during the cooling period the polygonal cracking of the surface occurred and the cracks were filled with vein ice" [25, p. 44]. In this case, the diameter of the mounds from 5 to 20 m can be considered as a characteristic distance between frost cracks, which does not contradict the value of 5.7 m presented above.

As noted above, the considered cracks in the initial stage of their evolution are formed at a temperature of approximately −3 °C. This circumstance allows us to formulate the following assumptions: the thickness of the layer of frozen soil at this stage is small. A temperature of –3 °C is typical for freezing in the interseasonal period, when the soil moisture is high and therefore the adhesion of the layer of frozen soil to the underlying layer of thawed soil with clay impurities is small. Accordingly, the coefficient of adhesion k in formula (6), taken as 0.5 MN/m^3, is also small. Clarification of the values of this coefficient requires the continuation of studies taking into account the results [26] relating to the construction of roads.

4 Conclusions

The paper demonstrates the possibility of using mathematical modeling of mechanical systems for analyzing the conditions for the formation of frost cracks in soils. The considered task is to predict the distance between frost cracks in the ground. Practical examples of the numerical implementation of the proposed approach are presented. According to the results of the study, we can formulate the following conclusions:

- a methodology for mathematical modeling in actual problems related to the analysis of the state of temporary forest roads has been developed;
- the developed method ensures sufficient adequacy of the simulation results and does not require cumbersome calculations;

– the results of the study performed do not contradict the well known data;
– the conclusion of the work of V. P. Merzlyakova [19] stating that the coefficient of thermal expansion should be considered as an important characteristic of frozen soil along with its other characteristics has been confirmed;
– the practical significance of the work is determined by the fact that the presented results can be used in the substantiation of technical solutions for the improvement of winter forest roads;
– research prospects are associated with the specification of data on the interaction of the layer of frozen soil, interacting with the underlying layer of thawed soil.

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Dependence of Trapping Nets' Protective Properties on Structural Layout

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Abstract. The paper presents the conditions for ensuring safety of execution of construction and assembly works during the construction and reconstruction of buildings and structures for various purposes based on the use of trapping nets, which in some cases are the only possible means of preventing industrial injury in case of a possible fall of a person or objects from a height. The basic component elements of trapping nets which have metal brackets and synthetic nets fixed on them are given. The paper considers the structural layout of a scratching device with fixed brackets and net overhung or fixed on frame, when brackets are installed with a given stationary inclination in the process of a falling item catching, and the net is located at a certain height from the bracket mounting axis. For falling items, the resulting dynamic loads were determined depending on the impact acceleration and the time of displacement of the object, taking into account its stationary position relative to the net itself or moving along it when the item is in places of maximum deflection of the net. Based on the results of the studies, it was found that it is preferable to install brackets at maximum possible angle with respect to building, ensuring catching of a falling item, and scratchers mounting must be made at insignificant height with respect to brackets.

Keywords: Construction operations · Protective fences · Occupational safety standards system

1 Introduction

An essential condition of arranging safe execution of construction and assembly works at heights is the use of collective protection equipment, in the structure of which catching devices with netting materials can be used. Such devices allow preventing a possibility of injuries when humans and items fall from structures of buildings and facilities being erected [1–3]. Main elements of a catching device are metal brackets installed on structural units with bearing supports, and synthetic nets mounted on them with ropes or metal frames [4, 5].

Preliminary, based on the studies carried out, there were identified such key parameters of catching devices as bracket required reach ensuring guaranteed catching of items falling from various heights, and also acceptable distances between brackets which will the most likely exclude colliding of such items with the brackets [6, 7]. So,

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in case of workstations located on a building structural components, on encasement or scaffolding, reach of a catching device from the border (edge) of level differences achieving 7 m, net endpoint horizontally may be equal to 3.5 m, and optimal distance between brackets – at least 6 m.

At the same time, when items fall on a catching device, such factor as possible occurrence of dynamic overloads should be taken into consideration; such overloads are characterized by ratio of effective acceleration values to acceleration of gravity, which may result in structural damage of catching devices, injury of an employee who fell down and other unintended consequences. When falling down on a catching device surface, impact action occurs and its value depends on the degree of speed change by end value over a particular period of time (τ). Indicators of shock pulse depending on impact acceleration (a) and time (t) are shown in Fig. 1.

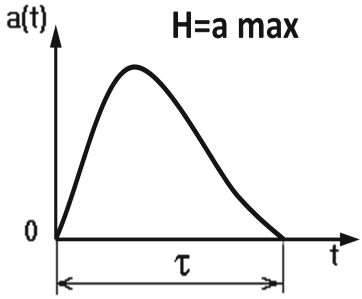

Fig. 1. Character of impulse while item falling on net surface of a catching device

Impact upon a falling item at contact with surface of a catching device depends on the mass and speed of its movement. And the mass itself does not influence on the speed. Different falling speed of items with different mass is connected to air resistance. If before falling an item is in rest, the intensity of its movement is interrelated with the height and acceleration of gravity. The latter value depends on the level the item it was initially located, but this impact is insignificant and can be neglected. In practice, item falling speed is characterized by the height of its position prior to falling [8].

Due to this, it is necessary to select schemes ensuring minimum overloads with account to various structural layout of catching devices.

2 Analysis

Let's consider the scheme of a catching device with rigidly fixed brackets and a net overhung or fixed on the frame (Fig. 2). In this case brackets are installed so that the bracket inclination α, measured from horizontal axis remains constant in the process of catching (brackets possible elastic deformations are neglected). Net is located at the height H from the bracket mounting axis. Based on the fact that net area in section is approximately equal to 10 m^2 is much bigger than mesh size which does not exceed 25 cm^2, net can be considered a flexible membrane in the future [9].

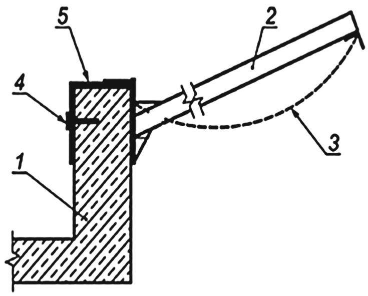

Fig. 2. Installation diagram of a backscratcher with rigidly fixed bracket 1 – building wall 2 – rigidly fixed bracket 3 – net 4 – anchor for mounting G-clamp to the building wall 5 – G-clamp for bracket fixing

It is necessary to find a reaction of such system when an item with mass m falls down on it, with the speed V_0, and speed vector is directed at angle β to vertical. After the item falls down on nets, the can be either motionless with respect to the net itself, or move on it being at all times on all maximum deflection spots.

3 Statement of Problem

Let's consider in detail a case when an item is standing motionless with respect to net itself which usually happens if the item falls down close to the net center. Taking into account that the net has considerably low tension in the direction perpendicular to the bracket and net displacement perpendicularly to its plane, net fluctuation equation can be recorded [10].

$$\mu\frac{\partial^2 \boldsymbol{u}}{\partial \boldsymbol{t}^2} = \frac{\partial}{\partial \boldsymbol{x}}[(\mathrm{To} + \mathrm{x}\mu\mathrm{g}\ \sin\Psi)\frac{\partial \boldsymbol{u}}{\partial \boldsymbol{x}}] + \mathrm{mg}\ \cos\Psi\ \mathrm{f(x)}; \sin\Psi = \frac{\boldsymbol{Lsin\alpha - h}}{\sqrt{\boldsymbol{L}2 + \boldsymbol{h}2 - 2\boldsymbol{hlsin\alpha}}} \tag{1}$$

where u – net displacement (membrane);
t – time;
μ – net reduced density equal to $\mu = \frac{\rho}{s}$;
ρ – net surface density;
S – net area;
T_0 – net initial tension;
Ψ – angle between the net and normal to building wall;
h – distance between points of net and bracket mounting;
L – bracket length.

Member xμg sinΨ in Eq. (1) describes changes in net tension by height due to its weight, and member mg cosΨ f(x) – is the impact of external force acting perpendicularly to the net and distributed by law f(x). Let the falling item have linear size 2l, and center-of-gravity falls into a point with coordinate x = d_1 (d – width of one section of the trapping net).

$$\text{Then } f(x) = \begin{cases} \frac{\cos\pi\,(x-d_1)}{2\ell}; & d_1 - \ell \le x \le d^1 + \ell; \\ 0 & 0 \le x < d^1 - \ell; \\ & d^1 + \ell < x \le d \end{cases} \quad (2)$$

Equation (1) should be supplemented with initial and boundary conditions

$$U/X_{=0} = 0;\ U/X_{=0} = 0;\ U/t_{=0} = 0 \quad (3)$$

Taking into account that the net mass (about 3 kg) is much lower than that of a falling item, solution of Eq. (1) with conditions (3) can be written down as follows

$$u_1(x,t) = u_1(x) + u_2(x,t) \quad (4)$$

u_1 describes the net permanent position

$$\boldsymbol{u_1(x)} = \left\{ \left(\frac{2l}{\pi a}\right)^2 \cdot b \cdot \cos\frac{\pi(x-d_1)}{2l}, \quad \begin{matrix} d^1 - \ell \le x \le d^1 + \ell; \\ 0 \le x \le d_1 - \ell \\ d^1 + l < x \le d; \end{matrix} \right. ;\ \boldsymbol{d} = \sqrt{\frac{To}{\mu}};\ b = mg\cdot\cos\varphi\cdot\mu; \quad (5)$$

u_2(x,t) describes net fluctuations together with a fallen item from permanent position

$$u_2(a,t) = \sum_1^\infty \left[an \cdot \cos\frac{\pi n}{d} \cdot at + 6n \sin\frac{\pi n}{d} at\right] \sin\frac{\pi n}{d} x;\ a_n = \frac{86\ell}{d\cdot a^2\cdot\pi} \cdot \mathbf{Fn};$$
$$Fn = \frac{\frac{\cos\pi\cdot n\cdot\ell}{d}}{\left(\frac{\pi n}{d}\right)^2 - \left(\frac{\pi}{2l}\right)^2};\quad b_n = -\frac{2l}{a\cdot i\cdot n} \cdot Fn;\quad c = Vo \cdot \cos(\varphi - \beta) \quad (6)$$

By substituting obtained expressions (5) and (6) in (4), we will obtain solution for Eq. (1) in an explicit form. Displacement of a fallen item center-of-gravity that is of interest to us is described by expression **u ($\mathbf{d_1}$; t)**. It is obvious that maximum displacement should be expected at $\mathbf{d_1} = \frac{d}{2}$, i.e. in the net center.

4 Results

Function u (d; t) was numerically calculated as parameters L, h, α, t vary. Here, it was found out that the characteristic time of a falling item catching process is approximately 0.06 s.

Dependence of maximum displacement of a fallen item center-of-gravity u_{max} and on bracket installation angle α for bracket different lengths L and net installation height h is shown in Fig. 3. Calculations showed that as bracket installation angle increases, u_{max} drops first, then increases, and as bracket length increases, u_{max} increases too. Dependence u_{max} on H is weak, however one can note that as H increases u_{max} decreases a little. With the help of graphs presented in Fig. 3 one can find an optimal (by criterion of minimum overloads affecting human body) angle α for bracket installation at the given bracket length L and height of their mounting h. For instance, for L = 3.5 m and h = 1 m, maximum bracket installation angle ensuring catching of a falling body will be $\alpha = 0.74$ rad with account to the fact that at such an angle, all items will be caught by the this net falling from height H = 6 m and with initial component speed $v_0 = 3$ m/s. Minimum possible angle α shall be identified from condition that the body will be cast away from a catching device, and as experiments show, is equal to approximately 0.26 rad. Minimum overloads affecting human body will be achieved at as high as possible value of u_{max}. Studying the site corresponding to curve at $0.26 \le d \le 0.74$ rad, one can see that the highest value of u_{max} is achieved at $\alpha = 0.26$ rad. Accordingly, in this case, the bracket is better to be installed at angle $\alpha = 0$.

26 rad ($\alpha \approx 150$) to horizon.

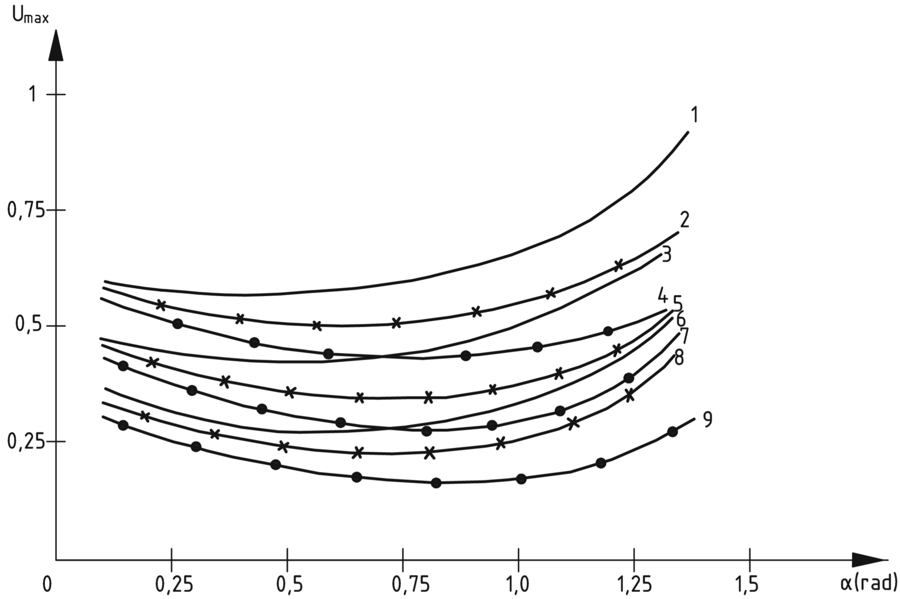

Fig. 3. Graph of dependence of maximum displacement $\mathbf{u_{max}}$ on bracket installation angle $\boldsymbol{\alpha}$**rad** in case of no movement of item along the net

Values of curves 1, 2, 4 correspond to bracket length 3.5 m
Values of curves 3, 5, 7 correspond to bracket length 3.0 m
Values of curves 6, 8, 9 correspond to bracket length 2.5 m.
Designation of net mounting height from the bracket basis

——— - 0.6 m —×—×— - 1.0 m •—•— - 1.4 m

If a falling body falls close to the net edge, it moves along it, at all times on all maximum deflection spots.

Let's consider this case in more details, assuming that the body is falling down vertically with speed v_0. It is obvious that in the spot of net maximum deflection where fallen body speed is zero, energy relation is done when kinetic and potential energy of a falling item completely transitioned into the energy of the net elastic deformation:

$$\frac{mv^2}{2} = \frac{K[d\ (Umax) - d]^2}{2} - mg\ Umax; \tag{7}$$

Where

d – width of unexpended net;
$u_{\mathbf{max}}$ – width of extended net;
k – net clastic coefficient.

Zero level of potential energy is at the height of body contact with the net. Let $R_{\mathbf{0}}$ – distance of the body center-of-gravity to building wall at contact with the net, and R - distance of the body center-of-gravity to building wall at its complete stop. Experiments showed that it is possible to take

$$R \approx \frac{Ro}{Umax + 1}, \quad \text{then}\, d = \sqrt{L^2 + n^2 - 2h \cdot L \cdot sin\alpha};$$

$$d(Umax) = \sqrt{R^2 + (U\overline{max}Ro \cdot tg\alpha)^2} + \sqrt{(L \cdot \cos\alpha - R)^2 + [U + (L\cos\alpha - \mathrm{Ro})tg\alpha]^2} \tag{8}$$

Equation (7) was solved numerically with varying parameters L, h, α, R_0. Calculation results are shown in Fig. 4.

Values of curves 1, 2, 6 correspond to bracket length 3.5 m
Values of curves 3, 5, 8 correspond to bracket length 3.0 m
Values of curves 4, 7, 9 correspond to bracket length 2.5 m.
Designation of net mounting height from the bracket basis

——— - 0.6 m —×—×——— - 1.0 m ●—●——— - 1.4 m

As can be seen from this Figure, for this case of items falling on the net which is the most common in the practice of construction operations while erecting buildings and facilities, characteristic is maximum displacement $\mathbf{u_{max}}$ with monotonically increasing function of bracket installation angle $\boldsymbol{\alpha}$, which significantly increases with bracket length increase and net mounting height **h** decrease from the level of construction sites location.

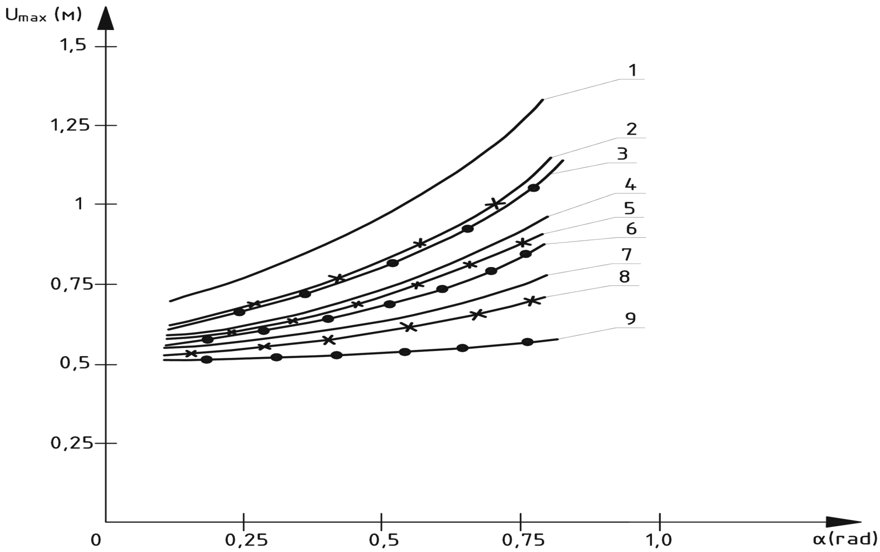

Fig. 4. Graph of dependence of maximum displacement $\mathbf{u}_{\mathbf{max}}$ on bracket installation angle $\boldsymbol{\alpha}$ in case of item movement along the net.

5 Findings

On the basis of the results of the studies carried out, one can see that it is preferable that brackets for reducing dynamic loads are installed at maximum possible angle to horizontal plane with fulfilling of required condition of ensuring a falling item catching. Corresponding to these values of trapping net system parameters, the value of maximum displacement is 1.28 m. Based on this, it is possible to recommend catching devices with as long as possible brackets and with nets mounting at insignificant height from the brackets.

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Capture of Large Objects by the Earthmoving Machine's Implement During Operation on Motor and Toting Roads

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Abstract. The goal of the current work is to ensure the efficiency of the operation of the implement of the earthmoving machine while capturing large stone objects during work on transport facilities, motor and toting roads. The problem of creating special purpose implements for removal of mudslides with large-scale inclusions remains urgent and unresolved as of today. Methods of mathematical modeling of the interaction of the implement of the earthmoving machine with a large stone object in static and in motion were used in the research. Additionally, the priorities of geometry of object capture have been formulated. It is shown that the objects captured may lie in different angular orientations. During the capture process, when the jaws are compressed, the object can move and rotate inside the implement. For many tasks, the capture geometry needs to be considered a set of different angular orientations of the object, for which you should use the known conditions of conversion of coordinates for rotation. This complex movement is described by the equations of the transformation of parallel transfer and turn. Mechanical grabbing devices are analyzed (capture devices). An example is used to illustrate specific problems of holding a captured object by two parallel working elements when the elements are touching two flat surfaces of the object. A description of the developed design of the grab is provided. The technical result of the proposed solution is to improve the efficiency of the hydraulic excavator with a hydraulic jaw through coordinated synchronous control of moving parts of working equipment (bucket and jaw), reliable fixation of the moment of transition from one mode of operation of the equipment to another and further coordinated-synchronous operation of the equipment in each of the modes.

Keywords: Grips · Implements of earthmoving machines · Stability · Design · Kinematic scheme · Mathematical model · Interaction · Design method

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1 Introduction

The problem of creating special purpose implements for removal of mudslides with large-scale inclusions remains urgent and unresolved as of today [1–4].

Preliminary patent studies have shown that the implement of the earthmoving machine on A.S.USSR No. 1715995, IPC E02F 3/28, opubl. in BI No.8, and a bucket of quarry excavator on A.S.USSR No.1684432, IPC E01992 г2F3/40, in BI No.38, have general disadvantages in the form of limited functional and technical characteristics and capabilities, which lead to a decrease in the efficiency of work when removing the accumulation of mud-slides, including the loss of productivity. Technical solutions are known, for rexample, the Dragline bucket under the preliminary patent RK No. 17895; the bulldozer equipment under the preliminary patent RK No. 17896; the bulldozer's dump according to preliminary Patent RK No. 17897; bulldozer implement under preliminary patent RK No. 17898; working equipment of bulldozer under the preliminary patent of RK No. 17899 and Dragline Bucket by under Preliminary Patent RK No. 17900, IPC E02F3/48, 3/60, 3/76, 3/80, published in BI #10,2006, the general drawbacks of which are low reliability in operation, the inability to capture and move large rocks contained in the mud-slides, asynchronicity in the work of moving parts of the implement of the excavator and other earthmoving machines and vehicles. Very thorough research is dedicated to improvement of the design of the implement of single-bucket excavators, for example [5–10].

2 Research Method

The goal of the current work is to ensure the efficiency of the operation of the implement of the earthmoving machine while capturing large stone objects during work on transport facilities, motor and toting roads.

Methods of mathematical modeling of the interaction of the implement of the earthmoving machine with a large stone object in static and in motion were utilized in the research.

The stages of the technological process are considered: positioning of the grabbing device near the object - capturing - movement – positioning to the set location - release.

Analysis tasks. The process normally takes place in the following sequence:

- the capture process that starts with the first contact of the implements with the objects and ends with objects being correctly positioned into a fixed state
- the fixed state is registered if the object is either rigidly fixed by the start of movement or is placed horizontally on the tray (static position of the object cannot be guaranteed with expected linear and angular movements up to complete loss of fixation of the object)
- transfer process; under favourable conditions, the object remains in the same position, but movements may occur due to the forces of inertia.
- the process of removing the object from the capture device (unloading, laying to a given position).

Auxiliary tasks may be performed, such as:

- linear movements or angular reorientation of an object before or after the capture is finished;
- transfer the object to a given position with possible reorientation and its release;
- possible fragmentation (splitting, crushing or cutting) of an object into parts during or after capture due to the low strength of the material or the presence of cracks [1].

3 Research Results

For all of these, as well as some other tasks, the conditions of implementation are to be determined in the first place and only then the description of the processes themselves (taking into account the arbitrariness of the initial position, the presence and absence of obstacles to the implementation of the task).

Note that there may be failures that lead to the loss of the object from the capture device, and in some cases damage to the capture device. The possibility of such failures is highlighted further. However, the analysis of possible solutions should be carried in the following sequence: first staging and solving the problem of statics of the equilibrium of the captured object in the capture device, analysis of object's stability, and only then the task of calculating capture and release processes.

The task of capturing an object from a shapeless pile of large stones has been formulated [1].

It is wise to limit the variety of surface shapes of the objects captured to the single class of objects with only convex surfaces. The first stage of the study using mathematical models is the tasks of capturing objects of various forms by analytical or other representation of their surfaces. In principle, universal representations of closed surfaces can be used, for example, in the form of decomposition by spherical harmonics, as it is done, for example, to build accurate geometric models of the Earth's surfaces and various celestial Bodies. However, such a representation is cumbersome and its application to the current tasks cannot be justified.

For natural objects, such as boulders, the most important is the division of surface into representation components: global and aggregate local. Global representation can be seen as simplistic approximations, and local - as relatively small-scale deviations from them. Global representation sets the whole surface of the body, while local representation represents separate parts of the surface (for example, those where the implements touch the object). Global representation is sufficient for some tasks, while local representation may be sufficient for others.

The main options for how to define surfaces in three-dimensional space:

- global; generally with closed surfaces in analytical or digital forms;
- local; only with the coordinates of discrete surface points, corresponding to the possible contact points of the surfaces of the object and machine implements; the most important points in this case would be those most remote from the center;
- combined; both the coordinates of discrete points of the surfaces of objects in which contact is possible, and the representation of surface areas near these points with local approximations in, most likely, rectangular coordinate systems, specifically linear and square.

Any specific representations of surfaces can be seen as the result of an idealized view of the actual shapes of the objects being captured. This approach is utilized to ensure that preliminary stages of design may account for various possibilities of capture and release of objects of various forms and configurations. To ensure the adequate approach it is wise to introduce an array of surfaces (single or multi-class) with a relative measure. It is also appropriate to use relative models for mathematical modeling of numerous variables. But such an approach is not developed due to unavailability of statistical processing possibilities.

The diversity of both forms is presented in the form of a multifaceted classification. Global representation of the object should be considered as an idealized one, suitable for being represented with quite easy equations.

Let's analyze the global view first [1]. The equation of the surface of a given three-dimensional object can be presented as a single equation in various coordinate systems. It is common to use equations in two systems according to the formula (1)–(3):

– rectangular system $O_{x,y,z}$

$$F_1(x, y, z) = C \tag{1}$$

– spherical coordinate system

$$F_2(r, \varphi, \psi) = C \tag{2}$$

and as a special case of the second option when the equation is solved relative to the radius -

$$r = G(\varphi, \psi) \tag{3}$$

If the surfaces are supposed to be smooth, then the functions of F_1 and F_2 are uniquely defined and differentiated at all argument values. The surface of any real object should be closed but for the current tasks of interactions between object contact points and machine implements it is possible to use only those areas that directly interact. In both cases, the choice of the beginning of the coordinate system is arbitrary, but to solve the static and dynamic tasks discussed further it is convenient to choose it in the center of masses; and if symmetry is present - in the center of symmetry.

The simplest example would be a three-dimensional object, the surface of which appears to be an ellipsoid. The equation of this surface in a rectangular coordinate system, the axis of which coincides with the axis of symmetry in the rectangular coordinates is recorded in the form of

$$(x/a)^2(y/b)^2(z/c)^2 = d^2 \tag{4}$$

where a,b,c – are ellipsoid half-axes (according to the formula 4).

It is convenient to think that this is an object of "perfectly rounded symmetrical" geometry.

For a flat problem, the ellipse equation is recorded (according to the formula 5).

$$(x/a)^2(y/b)^2 = d^2 \tag{5}$$

For the real tasks of capturing of rounded boulders, the representation of the boulder surface in the form of an ellipsoid would mean idealization. However, it can be noted that the geological origin of the boulders through the process of force-rolling in the soles of ancient glaciers at low velocity has analogues to real modern technological processes of performing of spherical plastic deformation through long-term skating between two discs. There is no point in looking for a possibility to illustrate complex single-connection surfaces. However, it is useful to illustrate the possibilities of analytical representation of surfaces with some intuitive, but informal features.

In the assumption that the surface equation in the form of a function of r = G(φ, ψ) is known to be set, following auxiliary geometric tasks are solved in discreet points [1]:

1. Search of the most remote and/or closest points to the center. When the equation is set in the spherical coordinate system, these extreme points are identified, with the following simultaneously being true (according to the formula 6).

$$\partial G/\partial \varphi = 0;\ \partial G/\partial \psi = 0 \tag{6}$$

In this case, you need to separate the points of maximum and minimum distance. That information is sufficient for some capture tasks. Schematically, this can be illustrated by replacing the real surface of the body with a rectangular parallelepiped that touches the object in discrete points [1].

2. Determining the dimensions for this angular orientation. When the surfaces are smooth, these dimensions are determined by comparing the coordinates of all the minimums for each of the coordinates.

The objects captured may be in different angular orientations. Moreover, during the capture process, when the jaws are compressed, the object can move and rotate. For many tasks, the capture geometry needs to be considered as a set of different angular orientations of the object, for which you should use the known conditions of conversion of coordinates while rotating the object. This complex movement is described by the equations of transformation of parallel and angular movement.

Parallel movement is set by $\boldsymbol{u}$ vector with projections u_x, u_y, u_z. In that case, the conversion of parallel movement from system $O_1x_1y_1z_1$ to system $O_2x_2y_2z_2$ can be recorded in the form of (according to the formula 7).

$$x_2 = x_1 + u_1, y_2 = y_1 + u_2, z_2 = z_1 + u_3 \tag{7}$$

Many different possible or real angular positions need to be considered in relation to the variety of the original positions of the capture device in relation to the object, or to the reorientation of the object in the process of grabbing by the machine implements.

When presenting surfaces in three-dimensional space in a rectangular coordinate system, the transformation of the radius-vector rotation from R1 to R2 is usually recorded in a matrix form R2 = MR1, where M is a square matrix of 3 × 3 cosinus guides. The angular orientation in three-dimensional space is set consequently by three angles, but in two main variants: using Euler's or Krylov's corners.

In the classic depiction utilizing the three Euler's corners α, β, γ this matrix looks like (according to the formula 8).

$$M(\alpha,\beta,\gamma) = \begin{pmatrix} \cos\alpha\cos\gamma - \sin\alpha\cos\beta\sin\gamma & -\cos\alpha\sin\gamma - \sin\alpha\cos\beta\cos\gamma & \sin\alpha\sin\beta \\ \sin\alpha\cos\gamma + \cos\alpha\cos\beta\sin\gamma & -\sin\alpha\sin\gamma + \cos\alpha\cos\beta\cos\gamma & -\cos\alpha\sin\beta \\ \sin\beta\sin\gamma & \sin\beta\cos\gamma & \cos\beta \end{pmatrix} \tag{8}$$

With small angles of the turn, the turn matrix takes on this simple look (according to the formula 9).

$$M(\alpha,\beta,\gamma) = \begin{matrix} 1 & -\alpha-\gamma & 0 \\ +\alpha+\gamma & 1 & -\beta \\ 0 & +\beta & 1 \end{matrix} \tag{9}$$

This matrix is the sum of a single and antisymmetric matrixes. It should be noted that it is possible to use the corners of Krylov ψ, ϑ, φ which have found widespread usage currently.

At small angles, the matrix is the sum of a single and anti-symmetric matrixes [1] (10):

$$M = \begin{matrix} 1 & -\psi & +\phi \\ \psi & 1 & -\vartheta \\ -\phi & +\vartheta & 1 \end{matrix} \tag{10}$$

For the flat task of spinning around one axis, a 2 × 2-size cosinus guide matrix is used. When the surface is presented in a spherical coordinate system and the angles are set as φ and ψ, these particular angles are replaced with new values.

To set and solve capture problems you also need to know the analytical equations of the capture devices as well. They can be obtained directly from a 3D model of the capture device itself, which was most likely developed during the process of computer design of the device.

Using these matrix transformations of virtual angular movement to describe the position of the captured object through mathematical modeling is necessary for the solution of two separate tasks necessary for successful capturing: positioning of the device in order to capture the object and capturing procedure itself (the object can move under the forces of clamping).

In accordance with the general qualitative representations, further, when compiling an analysis of the conditions of static equilibrium of the object in the grip device in the neglect of contact deformations, it is considered that contact is made in discrete points. At the same time, depending on the mathematical model of the surfaces of the object and the working elements of the capture device, the geometric conditions of contact are set either by the orientation of tangents (for a three-dimensional task - tangent planes), or also by curvature radius. At the same time, of course, the shape of surfaces outside the contact zones is not significant.

As an example, let's illustrate the specifics of the task of holding an already captured object with a capture device with two parallel working elements, when the object is in contact at two points with two working elements at the smooth surfaces of the object.

First, idealized situations are analyzed. Than cases of objects of symmetrical forms follow (strictly speaking, it is not the shape of the object as a whole that is important, but exact local geometry in the supposed or realistic possible areas of contact with the working elements of the capture device that are). Only then we proceed to the impact of more complex object geometry.

Illustration 1. The capture device has two straight (flat) working elements, in presented position they are vertical, compression force R is constant (Fig. 1).

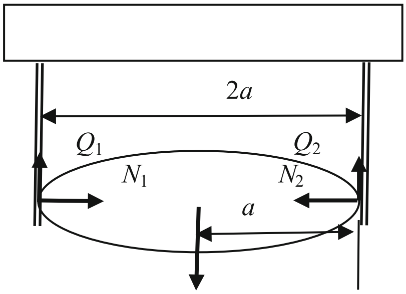

Fig. 1. Capture device

For static tasks, it doesn't matter whether these working elements move towards each other, or one of them is static while the other moves. The verticality of the working elements has the advantage of maximum isolation from environmental factors and influence.

For a flat task, a simple oblong symmetrical object with a smooth contour (as is depicted in Fig. 1 in the form of an ellipse) in horizontal orientation can be considered as one of the typical ones; the ellipticality of the contour does not specifically matter, it is important that the contour line in the contact area is smooth. Because of the symmetry we have $N_2 = N_1 = R$, $Q_2 = Q_1$.

From the single equation of static, we get that in this case the condition for maintaining balance, which makes sense in the form of absence of slippage under the influence of gravity, is expressed by (according to the formula 11).

$$fR > P \tag{11}$$

Violation of this condition results in a reduction of R or f. The increase in P causes the friction forces to no longer hold the object so it falls down. At the same time, while theoretically the object starts to slip at both contact points, it is actually a result of inevitable difference in adhesion coefficient resulting in the slip of one end only with a simultaneous rotation of the object. Depending on the conditions at the end of that process, the object will either be captured upright (if the support is somewhere close) or it will fall out of the capture device.

For the body with the center of the masses of an oblong object, displaced relative to the center (Fig. 2) the conditions of absence of slippage respectively on the left or right end for horizontal position are slightly different, so they take the form (12)

$$fRa_1(a_1 + a_2)^{-1} > P; fRa_2(a_1 + a_2)^{-1} > P \tag{12}$$

In Figs. 2, the center of the mass of the object is shifted to the left end; when the balance is lost, this left end will slip with the same possible consequences (in particular, with the fall of the object from the capture device). It is important to note that while the center of mass is shifted to the left friction forces are the same on both sides. It takes two equivalent masses on either side for the equilibrium to be lost.

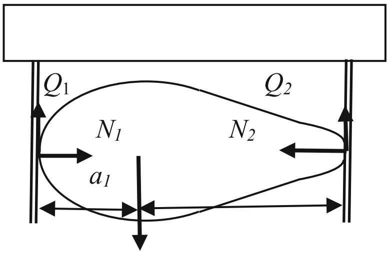

Fig. 2. Capture of a body of arbitrary shape

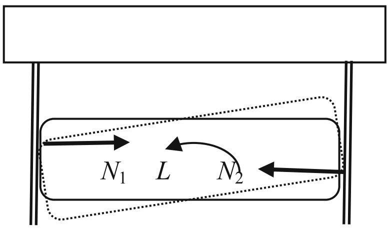

Fig. 3. Capture of a body of regular shape

Figure 3 illustrates a schematic of the same capture device grabbing an object with a cross-section in the form of a rectangle with rounded corners. With regard to the ability to hold this object in the vertical direction in relation to the current force, the specificity of this equation can be described with N1 = N2 = N [1].

When L moment is applied, the position of the contact points changes, so the moment equation for the equilibrium state is approximately described by

$$2Qa + Nb = L \tag{13}$$

where b is the thickness (or height) of an object (according to the formula 13).

Thus, resistance to the L moment is created by both tangential friction forces (for an elliptical object only they were substantial) as well as normal ones, the points of application of which are close to the angles. The prevention of angular movement than can be achieved even with very small friction forces.

The task of static equilibrium for an object that is not in an upright position, but in an skewed one is dependent on gravity forces acting not perpendicular to working elements, but at a certain angle. In this case, the reactions at the points of contact will vary, and the loss of balance due to the excess of the tangent force is more likely to occur for the higher positioned point of contact.

Example 2. The developed design refers to the implements of excavators, draglines and other special equipment for the removal of large boulders from mud-slides and their residue [9–12].

The working equipment of a hydraulic excavator with a hydraulic jaw contains a rectangular handle with a bucket and jaw attached to it and with hydraulic cylinder, lever and thrust mechanisms to control their movements, while the levers of the bucket and jaw are attached through the hinge above on the handle.

The disadvantages of that well-known technical solution include the following. There is poor coordination and asynchronous operation of extensions of hydro cylinder stocks of earthmoving equipment in the mud environment. The moment of transition to the second mode of operation of working equipment (namely, when the excavator works as a direct or reverse shovel) is not fixed, and there is no effective management of the further joint movement of the closed bucket and jaw. All these shortcomings make the work of a hydraulic excavator with a hydraulic jaw ineffective in described conditions.

A specific example of the grab design and its kinematic scheme has been developed. This technical result is achieved due to the fact that the working equipment of a hydraulic excavator with a hydraulic jaw containing a rectangular handle with a hinge attached to its handle and jaw and consisting of a hydrocylinder, levers and thrust mechanisms for control of their movements is additionally equipped with a microprocessor control system, centrally over the hinges on the handle positioned jagged wheel and in contact with moving jagged slats, together with the wheel forming a two-way flow transmission, with jagged slats located on both sides of the wheel on opposite edges of the handle. The design is capable of synchronous multi-altitude-multi-directional movement on the guide handle with fixation of the achieved level of movement, and on the front of the bucket at the place of its contact with the back of the jaw a touch sensor is placed. The sensor is connected to the entrance of the microprocessor control system of the hydraulic cylinders and the drive so the rotation of the gear of the two-way relay transmission is actuated based on the data from the sensor.

4 Discussion of the Results

The main tasks of the geometry of capture of large rock objects by the implements of earthmoving machines on transport objects, motor and toting roads have been formulated [1].

It is shown that the captured objects may be positioned in different angular orientations. During the capture process, when the jaws are compressed, the object can move and rotate. For many tasks, the capture geometry needs to be considered as a set of different angular orientations of the object, for which you should use the known conditions of conversion of coordinates of rotation. This complex movement is described by the equations of the transformation of parallel movement and turn. Mechanical capture devices (grabs) are considered, which differ a wide variety of design solutions. The provided example illustrates the specifics of the task of holding an already captured object with a capture device with two parallel working elements, when the object is grabbed at two points of smooth object surfaces with two working elements. A concrete example of the grab design and its kinematic scheme has been given.

The design of the implement is simple, handles well, is technological in manufacturing, requires few resources to produce and is energy effective.

The technical result of the proposed solution is the improvement of the efficiency of the hydraulic excavator with a hydraulic jaw through coordinated synchronous control of moving parts of working equipment (bucket and jaw), reliable fixation of the moment of transition from one mode of operation of the equipment to another and further coordinated-synchronous operation of the equipment in each of the modes.

The direction of future research is the interaction of the implement of the earthmoving machine and a large stone object in static and in motion, taking into account local and global representations of object surfaces.

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Method for Estimating Tensile Stresses and Elastic Modulus of Frozen Soil with Evolving Crack

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Abstract. Strength characteristics and Young's modulus of frozen soil are necessary for the analysis of many engineering problems. However, a number of issues in this area remain relevant. The purpose of this work: the development of a technique for indirect determination of tensile stresses and modulus of elasticity of frozen soil using three-point bending tests with evolving crack. Object of study: beams with a rectangular cross-section width of 55 mm, height 39 mm and a length of 320 mm made of artificially frozen sandy loam. The subject of research is the regularities of behavior under load of the beam with an evolving crack, and the corresponding tensile stress at the three-point bending. Methods: in this study, the methods of mathematical processing of the results of the testing, received at the SHIMADZU AGS-X test machine at three-point bending of a beam with evolving crack. The moisture content in the material for each sample was measured using SHIMADZU MOS-120H moisture analyzer. Results: it is found that the load extremum does not correspond to the extremum of the tensile stress in the cross section of the beam with crack. The tensile stress extremum is offset and corresponds to the downward branch of the curve "load – deflection". This means that the destruction of the material under the action of tensile stresses occurs not at maximum load but at the maximum value of tensile stresses at the downward branch of the curve "load – deflection". The practical significance of this result lies in the possibility of its use both in the design of new structures and in the inspection of structures in disrepair.

Keywords: Frozen sandy loam · Three-point bending · Young's modulus · Load extremum · Tensile stress extremum · "load – deflection" curve

1 Introduction

Strength characteristics and Young's modulus of frozen soil are necessary for the analysis of engineering problems in geocryology, road construction, mining and other. From all variety of frozen soils, only sandy loam is considered in this work.

The sandy loam contains no more than 10% of clay particles and is an intermediate soil between clay and sand. In the dry state, the strength of the sample sandy loam is negligible; the sample of sandy loam crumbles and collapses. However, the strength of the moistened sandy loam increases significantly after freezing, so that the frozen soil can be considered as a porous composite material consisting of soil skeleton, pore ice, unfrozen water, gas and other components [1, 2].

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As result of temperature changes, frozen soils undergo significant changes, which are visualized as deformations, and the appearance of cracks. Temperature deformation of frozen soils depend on the particle size distribution, initial moisture content, phase composition of water, pore gas saturation, temperature change rate and other factors [3, 4]. The need to take into account these factors generates a number of engineering problems, one of which is to analyze the causes of degradation and predict the service life of road surfaces [5, 6], as well as design features of geotechnical and natural objects [7, 8]. Physical and mechanical conditions of frost cracks formation are considered in the work [9].

Ice in frozen soil can be considered as an analogue of a binder in concrete, which allows us to consider in some cases frozen soils and concrete as analogues and, accordingly, to adapt the known approaches to determine their strength. For example, the homogenization theory, well known in the field of composite materials, is used in [1] to construct a model of frozen sandy soil. Based on the three-phase sphere model and Mori-Tanaka method, expressions of elastic parameters of the equivalent inclusion phase are obtained.

The tensile strength characteristics have a paramount influence on the stability of the engineering object and require further research. To verify the adequacy of mathematical models and theoretical estimates of the strength of frozen soil, appropriate experimental data are needed [10, 11]. There are two methods of experimental obtaining the tensile strength: the direct test and the indirect test. Direct test is expensive and time-consuming given the difficulty of samples preparing and conducting relevant laboratory tests.

As an alternative, the indirect methods used, such as four point bending test, the Brazilian test [10, 11], three pointers bending [2]. However, in these cases, difficulties arise, primarily associated with the mathematical description of the experimental relationships between the load on the sample and the displacement of points on its surface, as well as between stresses and strains in the sample material [11].

The main reason for the difficulties in analyzing and predicting the state of frozen soils is that the appearance of internal cracks leads to a violation of the linear relationship between the external forces and the movements of their application points. Tensile stresses cause cracks that reduce the cross-sectional area. As a result the displacement (for example, the beam deflection) increases, and the load on the test sample decreases. At the same time, however, the stresses in the section with a crack increase to a certain limit. For this reason, load extremes (external force) and tensile stresses (internal forces) can be observed in different deformations (and hence displacements). Then the extremum of tensile stresses in the section with a crack will correspond to some point on the downward branch of the load-displacement diagram. Questions relating to this circumstance are insufficiently investigated in the known literature, so the verification of the above assumption is the subject of current study.

Accordingly, the purpose of the work was to clarify insight about the tensile stress corresponding to the load extremum and the load corresponding to the tensile stress extremum in the cross section with crack (to the case of a three-point bending of beams, made from artificially frozen sandy loam). Since the issues related to external forces, displacements and stresses are discussed, to achieve this goal, it is also necessary to solve two problems simultaneously, namely, to determine the elastic modulus of the beam material and to find the maximum tensile stresses in the beam material.

2 Materials and Methods

2.1 Testing of the Beam from the Frozen Sandy Loam at Three-Point Bend

Object of study: beam with a rectangular cross-section width of 55 mm, height 39 mm and a length of 320 mm; the dimensions were determined with an accuracy of 1 mm. Beam material: artificially frozen sandy loam. Preparation of specimens was made by analogy with [2]. The beams span 280 mm. The material temperature on the fracture surface of the destroyed specimens: minus 4.6 °C. The movement speed of the loading device: 5 mm/min. The experiments were realized on the SHIMADZU AGS-X test machine, for which the allowed relative error limits are 1.0% (Fig. 1).

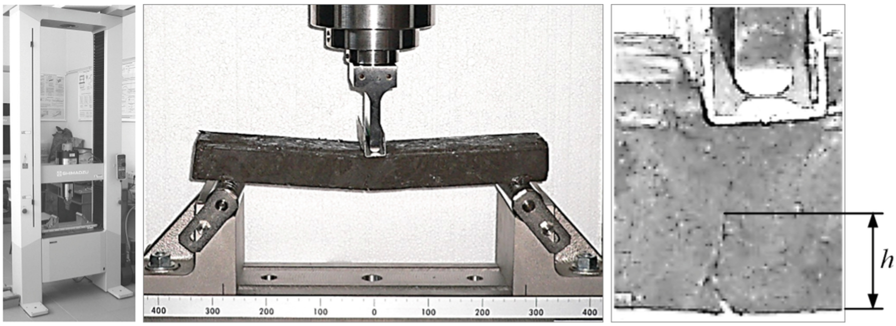

Fig. 1. Test machine, bending of the frozen sandy loam beam and localization of cracks.

After testing to failure in bending (Fig. 1), the moisture content for each specimen was measured using a moisture analyzer SHIMADZU MOC-120H. In this case under discussion, drying was carried out at a temperature of 105 °C. Reducing the moisture content in the specimen during drying was controlled automatically with a precision of 0.01% (by weight) every 30 s. In the end, the relative moisture of the specimen material was 12.53%, which corresponds to the absolute moisture 14.32%.

2.2 The Test Results Interpretation

Analysis of experimental data showed that the ratio between force and deflection can be represented by a polynomial of the fourth degree. According to the test results with a sufficiently high accuracy, the force extremum F_{extr} = 769 N and the corresponding deflection in the middle of the beam span f_{extr_F} = 0.001574 m (Fig. 2).

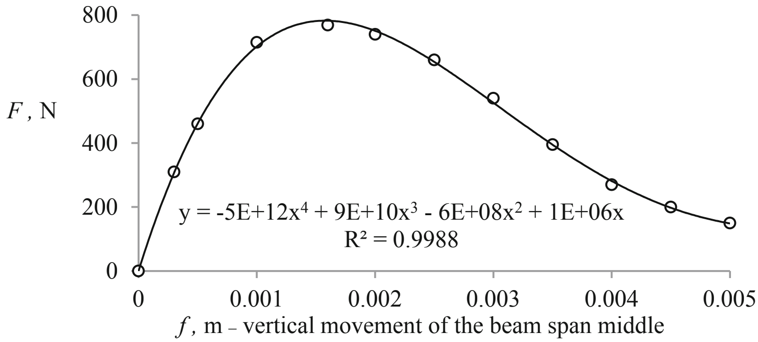

Fig. 2. Test results: changing the load (F) and vertical movement of the beam span middle (f).

However, above approximation by polynomial or other dependencies does not fully take into account the possibilities of mathematical modeling and, as an implication, often deprives the practice of an important opportunity to reveal the latent patterns of functioning of materials and mechanical systems. In current study, we try to take step to new possibilities for the analysis of experimental data in relation to the three-point bending of a beam from frozen ground. Using the test results and taking into account the crack evolution of non-constant length h (Fig. 1), let's consider an alternative approach of mathematical processing of the above experimental data (Fig. 2).

3 Results and Discussion

3.1 Mathematical Processing of a Beam Test Results with an Evolving Crack

Consider the three-point bend of a rectangular cross-section beam (Fig. 1). The study is feasible under the assumption that the properties of the beam material do not change when cracks appear, i.e. Hooke's law is performed for the material, but not for the structure (for the beam in our case). It is reasonable to assume that the crack length (Fig. 1) proportional to the value beam flexure; the validity of this assumption will be checked indirectly by comparing the results of mathematical modeling and real beam testing.

Denote L, B and H_0 – respectively, the span of the beam, the width and initial height of its cross section; h – the crack length (Fig. 1); f – flexure of the beam in the middle of the span. Then $h = H_0 \cdot K_1 \cdot f$, where K_1 – is the coefficient of proportionality (to be determined below). Denote $k = K_1 \cdot f$. Then $h = H_0 \cdot k$. As the crack length h increases, the height H of the intact cross-section part decreases (Fig. 3) and is determined by the relation:

$$H = H_0 - h = k \cdot H_0. \qquad (1)$$

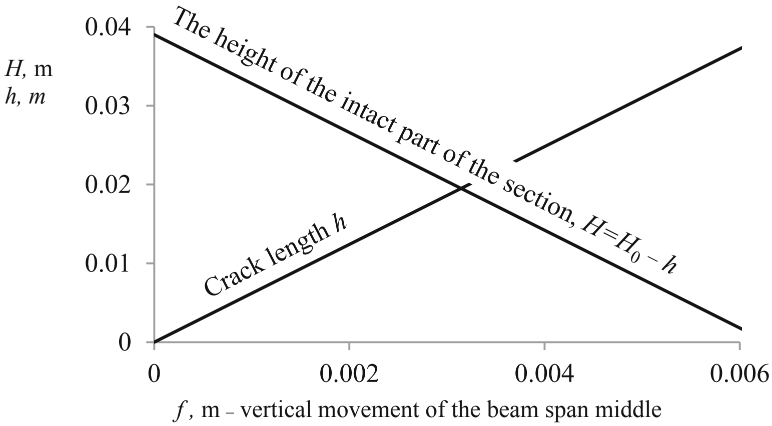

Fig. 3. Changing the height of the intact part of the section with a crack depending on the vertical movement in the middle of the beam span (this law is adopted in the initial data of the problem).

Let F and E – respectively, the external force applied in the middle of the beam span, and the elastic modulus of the beam material. As is well known, $f = F \cdot L^3/48 \cdot E \cdot I$, where $I = B \cdot H^3/12$. Then

$$F = f \cdot 48 \cdot E \cdot I/L^3. \tag{2}$$

It is clear that the formula (2) corresponds to a beam of constant cross-section and, consequently, for a beam with a crack (Fig. 1) strictly speaking not applicable. However, at three-point bending, the greatest stresses and strains of the beam material are concentrated in the vicinity of the middle of the beam span; we predict that namely these stresses, localized in the material and associated deformations, play a major role in changing the state of the beam, both without a crack and with a developing crack. Therefore, we will continue to use formula (2), in which, however, the height of the intact cross section in the middle of the beam span decreases with increasing deflection. Thus, the nonlinear nature of the dependence F (f) obtained in three-point bending tests is taken into account (Fig. 2). The validity of this assumption will be verified below by comparing the results of mathematical modeling and the real three-point bending of the beam (Fig. 1).

Let us use the experimentally established fact that the function F (f) has an extremum (Fig. 2). Having solved the equation $dF/df = 0$, we find that the extremum point corresponds to $f = f_{extr\_F} = 0.25/K_1$. To determine K_1, we use experimental data. On the above machine (Fig. 1) $f_{extr\_F} = 0.001574$ m is automatically determined. Then $K_1 = 158.823\ m^{-1}$, $k_{extr\_F} = 1 - K_1 \cdot f\mathrm{extr}_{F}$.

Knowing $k = K_1 \cdot f$ and defined above value $F_{extr} = 769$ N, can be find the modulus of elasticity E using (2), H (1) and $f = f_{extr\_F}$:

$$E = F \cdot L^3/(f \cdot 48 \cdot I). \quad (3)$$

For a beam on Fig. 1 get $E = 1948$ MPa.

The greatest tensile stress in the cross section of the beam (Fig. 1) can be determined taking into account (1) by the formula

$$\sigma = M/W, \quad (4)$$

where $M = F \cdot L/4$, $W = B \cdot H^2/6$. Having solved the equation $d\sigma/df = 0$, we find $f = f_{extr\_\sigma}$. For a beam on Fig. 1 get $f_{extr\_\sigma} = 0.003148$ m. Having defined $k_{extr\_\sigma} = 1 - K_1 \cdot f_{extr\_\sigma}$ and substituting $k = k_{extr\_\sigma}$ in (1), we find $\sigma = \sigma_{extr}$. For a beam on Fig. 1 get $\sigma_{extr} = 9.1517$ MPa.

The load $F = F_{extr\_\sigma}$ corresponding to σ_{extr} can be found using (2) at $f = f_{extr\_\sigma}$ with the above explanations. For the beam in Fig. 1 we obtain $F = F_{extr\_\sigma} = 456$ N.

Tensile stress corresponding to F_{extr}, can be find by (4) using k_{extr_F} and the above explanations. For a beam by Fig. 1 get $k_{extr\_F} = 0.75$, $\sigma_{extr\_F} = 6.8637$ MPa.

Test results and modeling of the beam by Fig. 1 with the above dimensions are shown in Fig. 4.

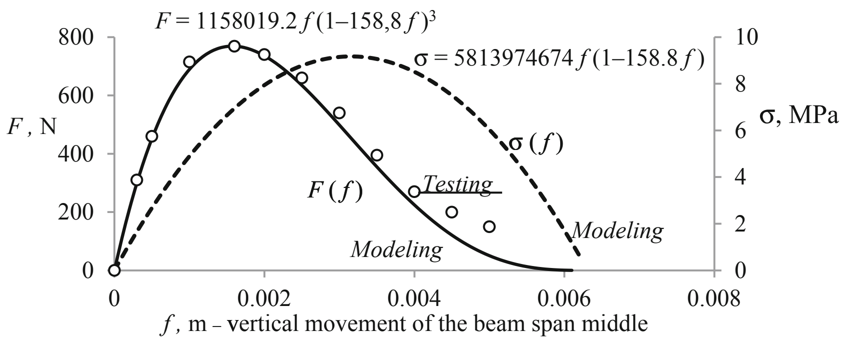

Fig. 4. Changing the load (F) and tensile stress (σ) in the cross section with crack.

3.2 Analysis of Modeling Results

An analysis of the results presented above shows that the developed method of mathematical processing of the test results for three-point bending with an evolving crack is adequate and the calculation results are consistent with the experiment for small and large cracks, including cracks whose length is commensurate with the height of the cross section of the beam (Fig. 1). For example, simulation results (Fig. 4) sufficiently accurate if the deflection does not exceed 5 mm, which corresponds to the length of the crack $h = H_0 \cdot K_1 \cdot f = 0.0390 \cdot 158.823 \cdot 0.005 = 0.0310$ м = 31 mm (or $0.7H_0$). This feature can be explained by the fact that if the crack length is greater than $0.7H_0$, the effect of the method of transferring the load to the surface of the beam according to the Saint-Venant's principle increases.

The dependence *F* (*f*) is modeled by a polynomial of the fourth degree (Fig. 4), i.e. the same degree as for the trend line in Fig. 2. However, the difference is that the polynomial for Fig. 2 obtained formally, and its coefficients are not physically justified. The polynomial is shown in Fig. 4 obtained analytically, i.e. as a solution of Eq. (2), taking into account the relations (1), (3) and the above explanations.

The dependence σ (*f*) is modeled by a polynomial of the second degree (Fig. 4), which is also was obtained analytically, namely, using the (4) relation and related explanations.

For the case under consideration, it was found that the deflection values of the beam in the middle of the span, corresponding to the load extremum and the tensile stress extremum, do not coincide and differ twice. Additional information on this issue is shown in Fig. 5.

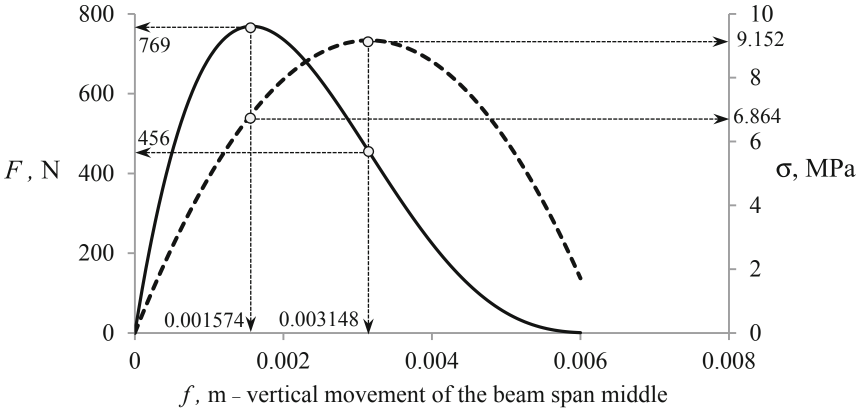

Fig. 5. The tensile stress (σ) corresponding to the load extremum (*F*) and the load corresponding to the tensile stress extremum in the cross section with crack.

As noted above, soils are extremely variable in their physical and mechanical properties. The state of the soil depends on the influence of moisture, temperature, load, as well as on the cyclicality of natural and technological influences. At the same time, the reliability of roads, bridges, mine workings and many other engineering facilities depends on the state of the soil. The works of many researchers are focused on solving the problems of analysis and prediction of strength, deformation and other physical and mechanical characteristics of soils, which is explained both by the complexity of these tasks and their the enduring relevance [10, 11].

In current paper we have considered two interrelated tasks, namely the determination of the modulus of elasticity of frozen soil and tensile strength. The interrelation between these two problems is explained by the fact that stresses are associated with deformations, and deformations, in turn, depend on the modulus of elasticity. The corresponding relations are usually nonlinear (Fig. 2), which is explained by the appearance of cracks under the action of tensile stresses (Fig. 1).

In current paper, in accordance with the theoretical elastic solution of three-point bending, an analytical approach was developed to calculate the modulus of elasticity of the beam material with an evolving crack. The approach realized under the assumption that the crack length is directly proportional to the beam deflection (Fig. 3); the coefficient of proportionality is defined as one of the results of mathematical modeling.

As the initial data for the numerical implementation of the developed approach, the usual results of the beam testing at three-point bending are required, namely, the load extremum and the deflection value corresponding to this extremum in the middle of the beam span (Fig. 2). The developed approach to the determination of the elastic modulus is simple to implementation, differences from previous studies, which used three-point bending [2], four point bending test [12], Brazilian test [11, 13] and data-mining technique [14]. We list the above-explained distinctive features of the developed approach and realized method: in parallel with the determination of the elastic modulus, the tensile stress extremum in the cross section of the beam with the evolving crack is calculated; the value of the deflection in the middle of the beam span corresponding to above extremum is determined; performed analysis of mechanical characteristics of the material on the downward branch of the curve "load – the deflection in the middle of the beam span"; the tensile stress corresponding to the load extremum is determined (Fig. 5).

The approach developed does not replace the known approaches, but only complements the possibilities of studying the mechanical state of frozen soils and similar materials (for example, concrete).

From the point of view of practice, it is important to pay attention to the following fact: tensile stresses can increase when the load decreases (Fig. 5), which is explained by the crack evolution (Fig. 1). This means that the destruction of the material under the action of tensile stresses occurs not at maximum load and at the maximum value of tensile stresses that correlation to the downward branch of the curve "load – the deflection in the middle of the beam span" (Fig. 5).

The presented data, as well as the method of determining the modulus of elasticity and tensile stresses of frozen soil can be recommended for use in studies of cracking conditions under the action of tensile stresses in road surfaces [5, 15], and in materials other engineering and natural objects [16, 17].

Taking into account the results of the work [11] and the results presented above, we note that the prospects for the development of the theme concerned relate to the study of not only stretching, but also compression of the material with cracks.

4 Conclusions

In accordance with the stated above purpose of work, a method for determining the tensile stresses and elastic modulus of a material with an evolving crack is developed and numerically implemented on the example of a three-point bending of a beam made of artificially frozen sandy loam. The reliability of the modeling results is confirmed by their consistency with the results of beam tests at three-point bending (Figs. 1 and 4).

As a result of modeling, it is found that the load extremum does not correspond to the extremum of the tensile stress in the cross section of the beam. The tensile stress extremum is offset and corresponds to the downward branch of the curve "load – the deflection in the middle of the beam span" (Fig. 5). This means that the destruction of the material under the action of tensile stresses occurs not at maximum load and at the maximum value of tensile stresses, what corresponds to the downward branch of the curve "load – deflection" (Fig. 5). The practical significance of this result lies in the possibility of its use both in the design of new structures and in the inspection of structures of emergency situations.

The prospects of this study are associated with the study of not only stretching, but also compression of the frozen soil material with cracks.

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Finishing Coatings Based on Modified Cement Colloidal Systems

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Abstract. The processes of development of finishing coatings on the basis of cement colloidal systems are determined. It is shown that the introduction of modifying additives in combination with mechanical activation allows using the optimal technological parameters of processing to give colloidal cement composites the necessary properties and increase the resistance of protective decorative coatings. The joint activation of the components of colloidal cement adhesive with a modifying additive leads to an increase in the strength of the samples at all times of hardening. Studies have shown that modifying additives and fillers have a positive effect on the thixotropic properties of the system and contributes to the formation of the hydrate with colloidal particles, which leads to hardening of the reinforcement system of a composite. It is found that the addition of metakaolin enhanced the activity of fine cement systems. The use of modifying additives in the production of colloidal cement systems and solutions based on them for decorative coatings can significantly improve a number of indicators of the quality of solutions both at the stage of preparation and use in the implementation of the application processes, and at the stage of operation. Using the functional steps of modifying additives helps to control the quality of the solutions of decorative coatings (water demand, peel ability, water-holding capacity, survivability, etc.) and cement (porosity, average density, strength, deformability, etc.). The presented studies are related to the processes of modification of colloidal cement systems in order to obtain decorative coatings with increased technical and operational characteristics.

Keywords: Colloidal and cement systems · Modifying additives · Decorative coatings · Water holding capacity · Structural characteristics

1 Introduction

Progress in building materials science, development of industrial methods of construction, as well as achievements in the field of construction chemistry and physics allowed to radically change the attitude to decorative coatings based on colloidal cement binder [1–3]. Increased and requirements for decorative coatings, they must have additional properties, which include permeability, water-holding capacity, hydrophobicity, adhesion to the base, increased strength for exterior and interior work-increased resistance to abrasion, etc. All of the above is due to the structure of the cement stone. To ensure operational reliability, the methods of processing of raw

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materials of mechanochemical activation and modification, allowing to obtain highly concentrated dispersed colloidal systems with low effective viscosity and high-performance properties, were chosen. Usual mortar mixes intended for decorative finishing of front wall panels, ceased to satisfy growing to requirements. This is due to the low crack resistance, low lexural and tensile strength and a number of other properties that do not provide the required durability. To ensure the necessary mobility of mortar mixtures based on colloidal cement systems and water-holding capacity, high rates of strength gain, low shrinkage or expansion deformation, good frost resistance, multi-component compositions were most often used, including in addition to cement, fillers and small aggregates, a complex of additives-modifiers of different nature [4–6]. Modern decorative coatings are a complex system that includes chemical and mineral additives that allow you to adjust the properties in a wide range, and above all manufacturability, density, strength and durability. One of the most important conditions for improving the quality of colloidal cement binder is physico-chemical modified surfaces in heterogeneous systems with organic or active mineral additives and the maximum possible homogenization, which will be the key to the successful use of fine cement systems for coatings [5, 6]. Modification of various complexes of chemical and mineral additives can significantly improve the physical and mechanical properties of colloidal cement adhesive and a solution based on it, including the necessary properties: mobility, plasticity, stickiness, high adhesion properties, water resistance and frost resistance [7–9]. The mechanism of action of additives of different chemical nature in cement systems (superplasticizers, polymeric, active mineral additives, etc.) is well studied [5, 6, 10].

However, the use of powder modifiers has a number of features that are due to the process of their transition from solid to liquid at low water consumption. To obtain solutions based on colloidal cement binder that meets regulatory requirements, modifiers of multifunctional purpose are widely used on modern production lines, which, when introduced into the mixture during the grinding of the initial components or mixing, contribute to a significant change in properties and structure with virtually unchanged number of basic components. Therefore, to obtain decorative coatings based on colloidal cement systems, it is necessary to investigate the influence of chemical and technological factors modifying colloidal cement systems.

2 Materials and Methods

The first paragraph after a heading is not indented (Bodytext style). During the research, materials that meet regulatory requirements were used, which determines the possibility of obtaining colloidal cement material of specified technical characteristics. To obtain colloidal mixtures Portland cement of Bukhtarma cement company, natural sand of the Nikolaev Deposit, various fillers and additives were used. As a filler instead of natural sand used screenings crushing concrete scrap. For modifying cement colloidal materials used various additives. Additives were selected with a shade that will not affect the color of the colloidal cement binder. The effectiveness of the additives used was evaluated according to the criteria of GOST 24211 according to GOST 30459. The most widely used in the technology of cement colloidal binder are plasticizing, stabilizing and structuring action modifiers, hardening regulators, additives that give the cement colloidal glue special properties, as well as complex modifiers of multifunctional action [1, 2]. Therefore, to study the basic properties of fine cement systems with fillers of different Genesis was investigated additive polymer powder (RPP). To improve the hydrophobic properties of colloidal cement systems, powder hydrophobizators of various chemical bases were used [3]. Hydrophobic powder of triple copolymer ethylene, vinyl acetate and vinyl chloride Vinnapas 8034 H was used as a hydrophobic additive. Superplasticizers were used as surfactants to obtain the greatest plasticizing effect at a lower concentration. In the technology of colloidal cement materials used active mineral admixtures (metakaolin) [4–6]. Fine-dispersed metakaolin lamellar particles provide the modified cement binder and mortar mixtures based on its high plasticity and resistance to delamination, as well as the absence of stickiness. The high content of amorphous alumina in the composition of metakaolin allows to use it as one of the components of complex non-shrink or expanding additives. The use of dispersed modifying additives in the production of colloidal cement binder allows to significantly realize the potential of cement binders, which leads to an increase in the most important properties of the modified colloidal glue. The effect of modifying additives is due to the fact that they are able to affect the process of hydration hardening of cement systems, micro-reinforce the formed artificial stone and contribute to the redistribution of mechanical stresses between the particles of modifying additives and cement stone [5–8]. It should be noted that in order to ensure high efficiency of the modifying additives are important not only its properties, but also the method of administration and the input amount.

3 Results

Production of colloidal cement binder is impossible without the use of modifying additives. Polymer dispersion additive in combination with colloidal cement binder (CCB) allows to create ready-made modified dry mixtures of stable quality [8–10]. To determine the optimal content of this additive in the solution colloidal cement mixture intended for decorative coatings, a range of quantities of 0.1–0.8% by weight of cement was used (Figs. 1 and 2). The optimal content of active and modifying additives was determined by changing the ultimate strength in bending and compression of beam samples $4 \times 4 \times 16$ cm in size at different times of hardening. Tests have shown that the investigated property is improved with increasing the input of this additive to the optimal content. As can be seen from the figures, the best is the introduction of a mixture of 0.6% of the polymer powder from the mass of the cement. Further increase in the amount of additives (more than 0.6%) has little effect on the properties of colloidal cement materials and is not economically feasible. An important property for decorative coatings based on colloidal cement mortar mixtures is their ability to retain water, as mortar mixtures are usually applied to a porous base, which intensely absorbs water. As a result, the solution is dehydrated, water becomes insufficient for hardening and normal strength. The limit of water-holding capacity is considered to be such a value of it, when not less than 15% compressive strength of standard samples made in forms without a bottom, placed on a brick, increases, compared with the strength of samples prepared in forms with a metal bottom. Limit water-holding capacity was determined by the mobility of colloid-cement mortar mixture from 3 to 6 cm water holding capacity is characterized by the property of a solution does not decompose and retain adequate humidity in a thin layer on a concrete base.

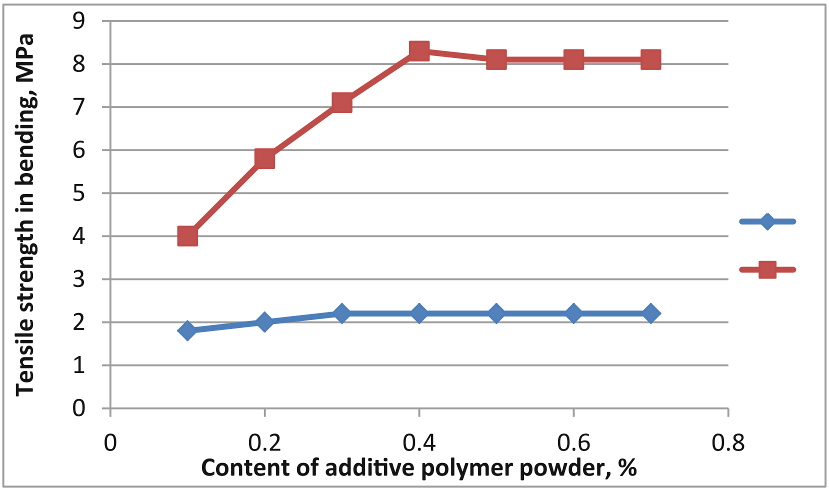

Fig. 1. Dependence of tensile strength in bending on the content of the additive

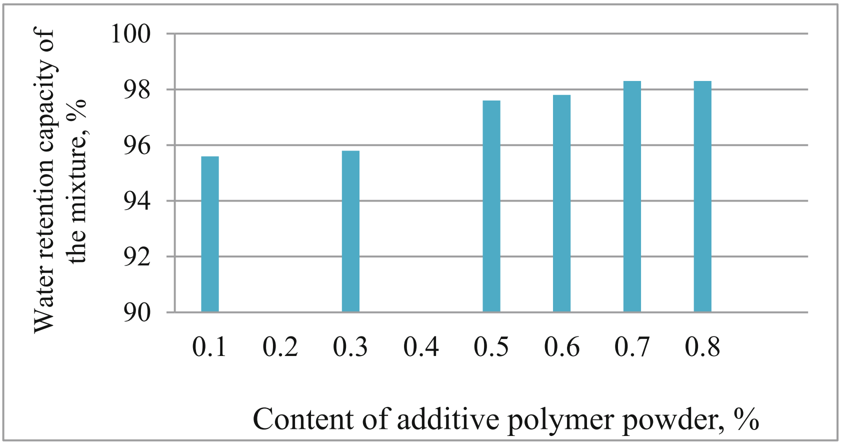

Fig. 2. The influence of polymer additives on the water retention capacity

The effect of surfactants on the properties of dispersed cement systems was studied on laboratory samples with dimensions of 4 × 4 × 16 cm after 28 days of normal hardening. Mobility of the closed cement-sand mixtures was determined at the identical water-cement ratio. The results are shown in table (Table 1).

Table 1. Properties of cement systems depending on the surfactant content.

The amount of surfactant additives, % (by weight of cement)	Normal density, %	Mobility (for Attardo), cm	Tensile strength at, MPa	
			Compression	BEND
0	27.4	15	46.1	10.4
0.1	22.1	23	51.6	12.1
0.3	21.6	25	53.2	12.2
0.4	20.7	28	61.7	14.2
0.5	20.8	29	60.9	13.6

There is a decrease in water demand and increased mobility in samples with surfactant additives (superplasticizer) in comparison with samples without additives. The obtained data show that the content of superplasticizer 0.4% by weight of cement provides optimal properties of dispersed cement systems. Studies have shown that surfactants have an impact on surface phenomena in dispersed cement systems. With an increase in the content of surfactant additives, a decrease in the viscosity of the system is observed. It is determined that the surface tension at the solid - solution boundary decreases with increasing surfactant concentration. With an increase in the content of the additive in the dispersed system, the shear stress limit practically vanishes, and the viscosity takes a low constant value. The mechanism of the plasticizing action of surfactants, apparently, is that the molecules of the additive are adsorbed on the surface of the particles, forming a monomolecular layer, formed hydrate layers around the particles due to the presence of hydrophilic groups in the molecules of the additive, there is a transition to the complete aggregate stability of the system, peptization of aggregates to primary particles, the rheological nature of the flow of the suspension with a yield point greater than zero at the yield point equal to zero. Reducing the viscosity of dispersed cement systems leads to a decrease in water demand and improve the mobility of the closed mixture, which will improve the manufacturability of solutions (pumpability), which is especially important in the factory method of obtaining materials. Surfactants contribute to the reduction of surface tension, which helps to reduce the size of crystallization nuclei and the formation of a large number of fine crystalline hydrates and, as a consequence, reduce the overall permeability of cement stone.

The pore space of colloidal cement systems is one of the main characteristics of their microstructure, a slight change in the pore space in terms of voids leads to a change in the basic properties. Porosity depends on the initial water-cement ratio, the composition of tumors of their specific volume and degree of hydration. Therefore, the influence of modification of colloidal cement systems by surfactant additives on the basic physical and technical properties of hardened cement materials, in particular on the porosity of cement stone, was studied. Among the many factors affecting the technical properties of colloidal cement systems (mineral and chemical composition of components, water-cement ratio, specific surface area), the main role is played by the characteristics of the emerging pore structure of cement stone (total number, radius, curvature, isolation), which, in turn, depends on the size and stability of the existence of hydrated cement dough formed during the hardening of hydrated phases. In order to reduce the porosity and therefore the water demand of the raw material mixture, a significant number of particles of the smallest size are required to fill the voids of the system.

A specific feature of the effect of surfactant on the microstructure of cement stone is the fact that in its presence in the cement stone formed crystalline tumors much less dispersion than without it. In the study of the structural characteristics of solidified stone from colloidal cement-sand mixtures at different hardening time, it was found that the total and open porosity of hardened cement stone based on the compositions with the addition of surfactants is lower than the porosity of samples without additives (Table 2).

Table 2. Porosity of a cement stone with addition of surfactants.

Hardening time, days	The composition without the additives		The composition with the additive surfactant	
	Porosity, %			
	General	Open	General	Open
1	13.62	10.18	12.67	9.78
3	13.41	11.54	12.31	9.08
7	15.23	12.36	9.75	6.27
28	14.89	12.19	8.48	5.24

A surfactant, changing the surface phenomena in disperse systems, colloid cement, and is influenced by the nature of crystallization of tumors on the morphology of crystals. It should be expected that the addition of surfactants to the aqueous solution that reduce the amount of surface tension, as well as the use of more soluble initial compounds, will lead to a decrease in the critical size of the crystallization nuclei, contribute to the formation of a large number of fine crystalline hydrates and reduce the permeability of cement stone. The smaller the critical size of the crystallization embryo, the higher the number and smaller the size of the crystallohydrates formed. The study of the microstructure of samples from colloidal cement systems with and without surfactant (Fig. 3) showed that the introduction of surfactants reduces the size of hydrated grain crystals.

These phenomena are undoubtedly associated with the adsorption of SP molecules on the surface of growing crystals. Adsorption increases in time and reaches a maximum of 3–5 min after the closure of the dispersion. Superplasticizer molecules, adsorbed on positively charged particles of growing crystals, complicate their growth and contribute to the emergence of many new crystals. As a result, the structure of the cement stone becomes fine-grained, less defective than that of the sample without additives.

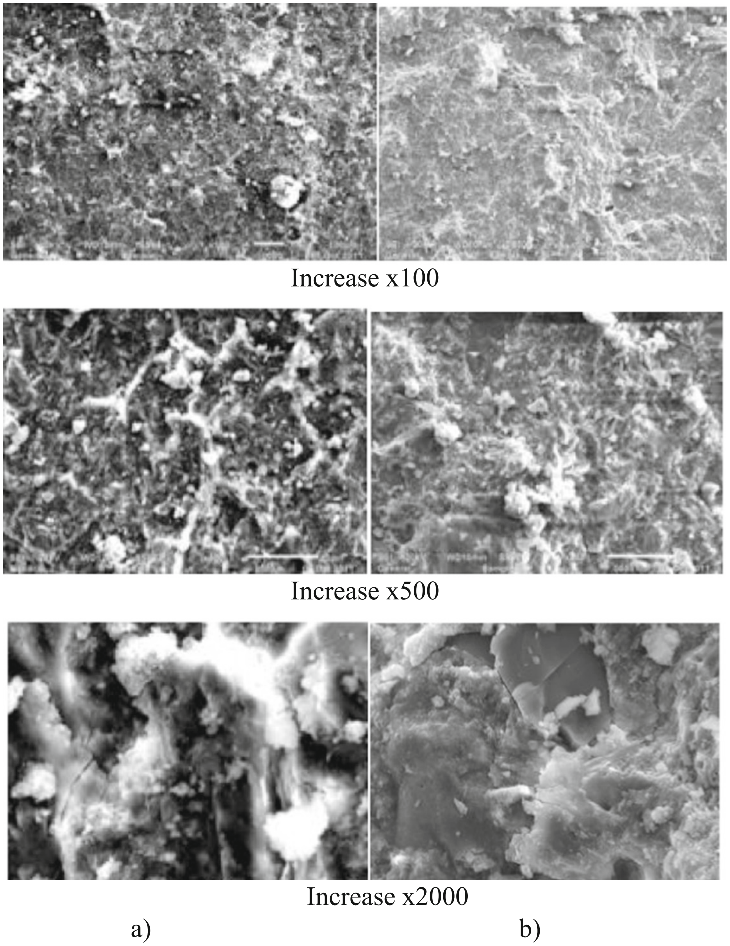

Fig. 3. The microstructure of samples of coating. a – without additives, b – with the addition of a surfactant

Mineral particles, grains and their associations, forming the structural skeleton of a composition, in the samples with the addition of a surfactant adjacent denser than in the specimen without additives, thereby eliminating the possibility of the appearance of the pore space. Individual fragments it is evident that the composition of the modified surfactants, the observed neoplasms. Formed during further hydration reactions "coagulated gel" of hydrosilicate composition fills the pores in the physical structure of the hardened stone, which increases the density of the stone.

Decorative coating based on colloidal cement systems can be attributed to the class of mineral waterproofing and is a rigid waterproof coating applied to the concrete surface. The porosity of such materials is their specific feature and mainly depends on the structure of the cement stone. Water resistance of porous materials is achieved by the introduction of sealing additives that provide clogging of the pores, or a combination of physical, chemical and mechanical (vibration) effects at the initial stages of coagulation and crystallization structure to reduce the size of the pores. Essential for facade coatings is the adhesion of the coating to the base.

The main requirements for coatings based on colloidal cement systems are water resistance, minimum water absorption, preservation of adhesion of the coating to the base and its continuity during the operation of the coating. To reduce shrinkage in the coating composition of the colloidal cement materials injected coarse aggregate – sand, combined with comprehensive modifying additive (surfactant – superplasticizer, a metakaolin, wollastonite, and polymer additives).

The finished decorative coating consists of highly dispersed cement (Sr = 5300–5500 g/cm^2) with additives, highly dispersed mineral filler and larger sand (filler) in combination with low water content and obtained by a combination of surfactant and vibration, which provides the required mobility and relatively low water content. Coating compositions were prepared on the basis of modified colloidal cement systems (binder) with different amounts of aggregate (sand or concrete scrap crushing screenings) from 30 to 70 wt. parts (a part 1 binder – 100%; the composition of the binder 2–70%; the composition of the binder is 3 to 50%, binder 4 composition of - 40%; the composition of the binder 5 to 30%).

The water-astringent ratio is 0.35 for the technological processing of mixtures with an increase in the sand content. According to the changes in linear shrinkage determined that the most optimal is a composition containing 70 wt% sand's. The introduction of sand as a filler in the coating compositions leads to a decrease in shrinkage deformation and, accordingly, to an improvement in crack resistance. Since the developed materials are waterproofing coatings, studies have been carried out on the effect of the amount of filler on the water resistance and water absorption of hardened coatings based on colloidal cement systems (Table 3).

Table 3. The effect of filler content on the properties of the waterproofing coatings.

Mixture composition	Water resistance when you are working on, MPa		Water absorption, %
	Pressing	Detachment	
Composition 1	1.9	0.9	10.9
Composition 2	1.7	0.8	10.3
Composition 3	1.4	0.7	7.6
Composition 4	1.1	0.7	4.7
Composition 5	0.8	0.3	9.1

On waterproofing properties as the most appropriate mixtures include compositions with a filler content of 50 and 60 wt%, but more optimal is the composition of 4. Studies have also shown that the main construction and technical properties and data on shrinkage properties for further research taken compositions 4 and 5.

To improve the waterproofing properties, hydrophobic additives were introduced into the developed compositions of the mixtures. The results of preliminary studies have shown that sodium stearate and oleate in comparison with other surfactants hydrophobic type to a lesser extent reduce the strength characteristics and increase hydrophysical characteristics. This makes them more suitable for the development of hydrophobized cement-filled systems. The selected water repellents were introduced in powder form in an amount of 0.25–1.00% by weight of the binder. Studies were conducted at different filler binder based on natural fine Sands, and screenings from the concrete crushing. Evaluation of waterproofing properties was carried out on water resistance, water absorption, sorption moisture (Table 4).

Table 4. The waterproofing properties of the samples.

Composition	Indicators of hardened solutions		
	Water absorption, %	Watertightness, class	Sorption moisture, %
Composition 4	4.7/4.7	W16/W16	2.1/2.5
Composition 5	5.2/5.4	W12/W12	2.3/2.5

Note – Before the slash is the filler of quartz sand after slash – screenings from the concrete crushing

The data obtained show that solidified solutions based on modified colloidal cement materials have good waterproofing properties.

4 Discussion

The introduction of modifying and active mineral additives can improve the physical and mechanical construction and technical properties and performance properties of finishing coatings based on colloidal cement systems. The influence of the modifying additive on the properties of colloidal cement systems is a consequence of the changes in the structure of cement stone. The introduction of a modifying additive in fine cement systems in the process of mechanical activation contributes to a more uniform distribution of components and uniform distribution of additives on the surface of cement particles and filler.

The use of metakaolin as active mineral additives improved the quality of neoplasm in colloidal system, provides a good plasticity of the mixtures and the lack of buildup, which is very important for the application in decorative coatings. The introduction of metakaolin in the amount of 7% by weight in the composition of fine cement systems, improves the strength and deformation properties of cement stone.

It is determined that the introduction of polymer additives allows to adjust the plastic characteristics of fine cement systems and solutions based on them, affects the kinetics of hydration of cement clinker minerals, thereby determining the rate of formation of the structure of cement stone and its parameters. It is revealed that the introduction of modifying additives leads to an increase in the amount of low-basic calcium hydrosilicates in the cement stone, which have adhesive ability and contribute to an increase in the adhesive strength of the solution for decorative coatings. It is determined that the microstructure of samples of solidified solutions based on colloidal cement materials in the presence of a complex modifier is formed more dispersed and homogeneous, which will contribute to ensuring high physical, mechanical and operational properties of the resulting coatings. Good waterproofing properties of the obtained materials in the presence of hydrophobic additives suggests a wide range of applications of coatings based on colloidal cement systems.

5 Conclusion

Thus, the studies have shown that the use of modification, mechanochemical activation can be purposefully regulate the processes of structure formation, improvement of technological properties of decorative coatings based on highly dispersed colloidal cement systems.

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Strengthening of Concrete Composites Using Polycarboxylate and Aluminosilicate Materials

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Abstract. The results of experimental studies of fine-grained concrete are presented, the formation of the structure and properties of which occurs with the participation of mineral and plasticizing additives. Metakaolin obtained by heat treatment of kaolin at a temperature of 750 °C was used as a mineral reactive aluminosilicate additive, and the water reducing component of concrete was a superplasticizer based on polycarboxylates. It is shown that one of the main factors for improving the physical and mechanical characteristics of concrete is the optimization of the particle size distribution of the fine aggregate and the finely dispersed part of concrete. It has been established that metakaolin plays the role of a multifunctional component in the composition of concrete: a microfiller, a reactive additive with a high pozzolanic effect. The features of hydration processes are shown, and the type of structure-forming phases formed with the participation of metakaolin is established. It is shown that using polycarboxylate and aluminosilicate materials, it is possible to increase the strength and durability of concrete.

Keywords: Concrete composites · Polycarboxylate · Metakaolin · Hydration · Compressive strength

1 Introduction

The intensification of construction in the Russian Federation is largely ensured by scientific achievements in the field of building materials science. A building material that is alternative to concrete in terms of quality and manufacturability is not expected in the near future. That is why issues of improving the operational and technical properties of concrete are the subject of numerous studies. For the Tyumen region, the issues of using high-strength fine-grained concrete (FGC) for monolithic construction are especially relevant, since the need of the construction industry in large aggregate is solved by supplying crushed stone from other regions. However, for the large-scale introduction of FGC, it is necessary to solve the problem of reducing cement consumption. The theoretical prerequisites for this trend are the optimization of the cement matrix.

The control methods for concrete composites are diverse, but more often they come down to an increase in the number of components in the concrete composition, mainly mineral and chemical additives, as well as complex organic-mineral modifiers. According to a number of positions of modern researchers, it is not advisable to introduce

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inert additives in concretes of a new generation. In accordance with this, additives are divided into reactive, rheology active and hydration-hardening ones [1].

Widely known reactive additives are pozzolanic mineral additives: diatomite, rotten stone (tripoli), flask, silica fume, ash, slag. The effectiveness of these additives is related to the content of active silica. The process of formation of crystalline hydrates with the participation of silica additives occurs when the liquid phase is saturated with hydroxyl ions of calcium. In this case, the pH of the system decreases, which affects the formation of the C-S-H phase [2]. At cement plants, a number of silica-containing additives are introduced only in limited dosages due to the possible increase in the water demand of cements. The introduction of silica fume and ash is implemented at concrete plants, considering them as effective additives in terms of their effect on concrete systems [3].

Significant progress in concrete production technologies is caused by the use of effective superplasticizers based on polycarboxylates with a steric (spatial) effect [4–9].

Among the methods of modifying cement stone with mineral additives, a number of researchers [10–16] recommended the introduction of metakaolin obtained by heat treatment of kaolin with a high content of kaolinite mineral. The peculiarity of kaolinite structure is that it consists of two elementary layers - a silicon-oxygen tetrahedral and an aluminum-oxygen octahedral, articulated in one layer so that the vertices of the tetrahedra are adjacent to the vertices of the octahedrons, forming the spatial structure of a layered silicate (Fig. 1).

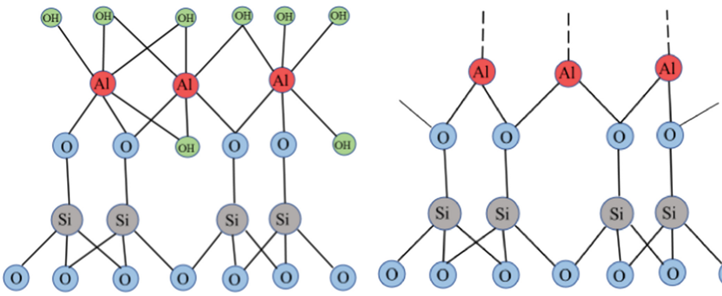

Fig. 1. The kaolin crystal lattice (a) and hypothetic structure of metakaolin cell (b)

There are different opinions on the composition of the products of kaolinite dehydration [10–16]. Due to the complexity of the study, metakaolinite is mainly represented as an amorphous structure in which the outline of the crystal structure is preserved.

Obtaining reactive metakaolinite depends on its content in the original kaolin rock, the presence of impurities, dispersion, etc. In the authors' opinion, issues on the heat treatment of metakaolinite require further development.

The control of the properties of fine-grained concrete is ensured by an integrated approach, including the selection of particle size distribution of sand and microfiller, additives combining reaction, rheological and hydration activity, dispersion-reinforcing components, and the use of effective compaction methods.

The aim of this work was to study the effect of metakaolin and a plasticizing additive on a polycarboxylate basis on the physical and mechanical properties of fine-grained concrete.

2 Materials

The following materials were used in the studies:

- Portland cement produced by the Sukholozhsky cement plant CEM I 42.5N, Russian State Standard GOST 31108-2016;
- kaolin produced by the Novokaolinovy mining plant (Chelyabinsk region) and used to obtain additive - metakaolin.

The mineral composition of kaolin: kaolinite - 84%, quartz - 8%, feldspar - 1%, hydromica - 7%.

The chemical composition of kaolin is presented in Table 1.

Table 1. Chemical composition of kaolin

Name	SiO_2	Al_2O_3	Fe_2O_3	K_2O	Na_2O	CaO	Ignition loss
Mass fraction of oxides, %	46.0–47.5	36.5–38.0	0.4–0.8	0.7–1.1	0.05–0.1	0.15	13.7

- quartz sand with a particle size modulus of 2.3 from the deposit of the Tyumen region - “Lake Andreevskoye” quarry, corresponding to Russian State Standard GOST 8736-2014;

The particle size distribution of sand is presented in Table 2.

Table 2. Particle size distribution of sand

Residue type	Residues on sieves with holes, mm						
	2.5	1.25	0.63	0.315	0.14	<0.14	Sum
Partial, g	20.0	70.0	260.0	520.0	120.0	10.0	1000
Partial, %	2.0	7.0	26.0	52.0	12.0	1.0	100
Full, %	2.0	9.0	35.0	87.0	99.0	100	–

- plasticizing additives based on aqueous compositions of modified polycarboxylate esters: MC-PowerFlow 3100, Sika Plast E2, SikaViscoCrete 20HE, Biseal POL.
- water for mixing concrete mix, corresponding to the requirements of Russian State Standard GOST 23732-2011.

3 Methods of Research

3.1 Thermal Activation of Kaolin

We used metakaolin obtained by burning kaolin in a muffle furnace for 1 h at a temperature of 750 °C. During heat treatment, the bulk of constitutional water (about 14%) is removed from the kaolinite structure, an amorphous phase (metakaolinite) is formed, the volume of which decreases by about 21% from the initial one primarily due to a reduction in the distance between the layers.

Figure 2 shows a roentgenogram of metakaolin, indicating an amorphous structure of the calcine. The crystalline phase is represented by quartz (identified by the diffraction lines d-4.2803; 3.3757; 3.3585 Aº).

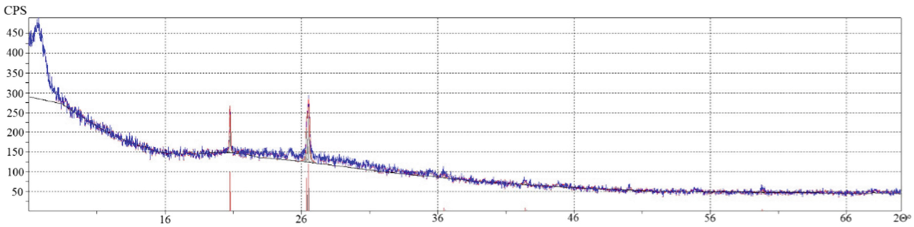

Fig. 2. Roentgenogram of metakaolin

3.2 Determination of Pozzolanic Activity of Metakaolin

The pozzolanic activity of metakaolin was determined by complexometric titration of aqueous extracts prepared on the basis of the Ca(OH)2 solution of known concentration after 7 days of interaction with metakaolin. As a result of titration, the amount of absorbed Ca+2 from the Ca(OH)2 solution was determined. To compare the pozzolanic activity of metakaolin, the authors assessed the concentration of Ca+2 in a number of aqueous extracts in which silica fume, ultrafine ash, marshalite, and finely ground slag were used as the material reacting with Ca+2.

3.3 Physicochemical Research Methods

In the process of research, the authors used a set of complementary physicochemical methods for studying the composition, structure and properties of cement stone and fine-grained concrete: scanning microscopy, X-ray phase analysis, local spectral analysis, laser particle size diffraction, and a number of other standard analyzes and techniques. To assess the microstructure and study the morphological features of cement stone tumors, the authors analyzed images (micrographs) zooming up to 7000 times.

X-ray phase analysis of metakaolin and hydration hardening products of cement stone was performed under the following conditions: Wavelength - 1.54051 (Ang.); the number of points for smoothing - 7; background polynomial degree - 3; sensitivity threshold - 3.0 sigma; peak base width - 3.0 full width at half maximum; Initial data: Full width at half maximum, deg. - 0.120; Asymmetry - 1.00; Form factor - 0.60

3.4 Particle Size Analysis

To establish the particle size distribution of sand, the sieve analysis method using the "AS300 control" horizontal sieving machine was used.

To conduct particle size analysis of cement, kaolin and metakaolin, laser analysis using a Fritsch "Analysette 22" diffraction particle analyzer was used in the study.

3.5 Determination of Rheological and Physico-Mechanical Characteristics of Concrete Mix and Concrete

An assessment of workability of fine-grained concrete mixture was carried out according to the immersion depth of the cone according to Russian State Standard GOST 5802-86.

The physical and mechanical characteristics of concrete (water absorption, average density, strength) were determined in accordance with Russian State Standard GOST 10180-2012. Concrete hardening took place at a temperature of 20 ± 2 °C and a relative humidity of more than 95%, strength control was performed at the age of 2, 7 and 28 days. Water absorption and density are set for concrete of 28-day hardening.

4 Experiment Results

4.1 Pozzolanic Activity of Metakaolin

Based on the results of complexometric titration, the residual concentration of Ca^{+2} in the aqueous extract with metakaolin was established - 4.4 mmol/l. This is two times lower than the concentration of calcium ions in the aqueous extract, where silica fume is used as an additive. Other studied materials are characterized by an even lower ability to bind calcium ions from the liquid phase.

4.2 The Study of the Particle Size Distribution of Finely Dispersed Components

The integral particle size distribution curves of kaolin and metakaolin are shown in Fig. 3.

As a result of granulometry, it was found that during heat treatment of kaolin, dispergation, a decrease in the average grain size and an increase in specific surface area are observed. This is caused by the fact that the bonds between the ions in the crystal lattice weaken, chemically bound water is removed.

Received metakaolin for 60% consists of grains up to 10 microns in size and effectively fills the cement system with ultra-sized grains (Table 3). The integral screening curves of metakaolin and cement are presented in Fig. 4.

The high dispersion of metakaolin contributes to the compaction of the cement stone structure, and as a result, the strengthening of the contact zone between the cement stone and the aggregate due to a decrease in pore volume and size, and the formation of additional calcium hydro-silicates in this zone.

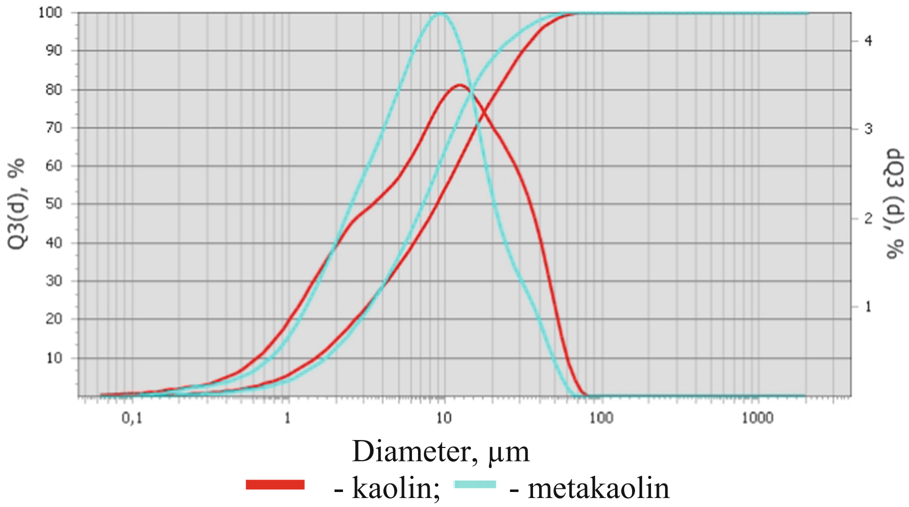

Fig. 3. Particle size distribution of kaolin and metakaolin

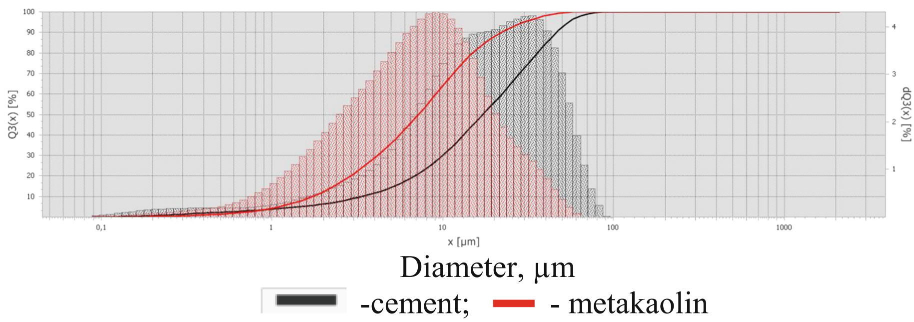

Fig. 4. Particle size distribution of cement and metakaolin

Table 3. Particle size distribution of finely dispersed components

Name of material	Full passes, %, grain size, microns											
	0.1	0.2	0.35	0.65	1.0	2.5	4.0	8.0	15.0	30.0	55.0	100.0
CEM I 42.5N	0	0.7	1.7	2.9	3.9	7.8	11.7	23.7	44.7	72.5	95.1	100.0
Metakaolin	0	0.4	1.1	2.9	5.7	18.7	28.6	47.0	68.3	88.8	99.0	100.0

4.3 The Study of Particle Size Distribution of Sand

In the formation of the structure of fine-grained concrete, the quality and particle size distribution of the aggregate are of great importance. In the scientific work, the effect of the grain composition of sand on the physical and mechanical properties of fine-grained concrete was studied. To do this, sand was dispersed into fractions, mm: 5÷2.5,

Table 4. Properties of fractionated sand

Composition number	Content of fractions, %					Density, kg/m^3		Void ratio, %		Fineness modulus. M_f	Specific surface area according to f. Ladinsky, cm^2/g
	2.5–5	1.25–2.5	0.63–1.25	0.315–0.63	0.16–0.315	Bulk	In a compacted state	In bulk	In a compacted state		
1 contr.	2	7	26	52	13	1480	1730	44.1	34.7	2.3	44.7
2	10	10	20	20	40	1590	1780	40.0	32.8	2.3	100.1
3	10	10	25	25	30	1575	1770	40.5	33.2	2.45	89.1
4	10	10	30	30	20	1555	1690	41.3	36.2	2.6	78.1
5	10	10	35	35	10	1550	1670	41.5	36.9	2.75	67.1
6	15	15	20	20	30	1590	1765	40.0	33.4	2.65	84.2
7	15	15	25	25	20	1550	1760	41.5	33.5	2.8	73.2
8	15	15	30	30	10	1525	1690	42.4	36.2	2.95	62.2
9	20	20	20	25	15	1600	1815	39.6	31.5	3.05	63.8
10	30	25	20	15	10	1555	1725	41.3	34.9	3.5	48.4

2.5÷1.25, 1.25÷0.63, 0.63÷0.315, 0.315÷0.16. By controlling the fractional composition, sand with the highest bulk density was obtained, which corresponds to the maximum packing of grains. The research results are shown in Table 4.

In obtaining fine-grained concrete, an important role, in addition to the maximum packing of sand grains, is played by the specific surface of the aggregate, which affects the W/C ratio of the concrete mixture, as well as the adhesion area of the aggregate grains with cement paste. The specific surface of sand ranged from 44.7 to 100.1 cm^2/g. Optimum for fine-grained concrete is sand with a specific surface area from 50 to 100 cm^2/g. The composition No. 9, having a particle size modulus of 3.05, has the maximum density and, consequently, the minimum void ratio.

Considering these factors, the composition of sand No. 9 with a maximum bulk density of 1600 kg/m^3 and a minimum void ratio of 39.6%, which corresponds to a packing density of grains of 68.5%, was chosen as the optimal one for obtaining high-strength concrete. Thus, by controlling the granulometry of the aggregate, it becomes possible to obtain fine-grained concrete with improved properties.

4.4 The Study of the Effect of Plasticizing Additives on the Properties of Fine-Grained Concrete

A study of the effect of polycarboxylate additives on the physical and mechanical properties of fine-grained concrete and the establishment of their optimal dosage was carried out on samples 7.07 * 7.07 * 7.07 cm with the use of sand, the particle size distribution of which corresponds to the composition No. 9 with the densest packing of grains. The rheological characteristics of the concrete mixture remained constant - the immersion depth of the cone was 5 ± 0.3 cm.

The test results are shown in Table 5.

Table 5. Physical and mechanical properties of concrete with plasticizing additives

Comp. number	Additive		W/C	Water reducing effect, %	Density of concrete, kg/m^3	Compressive strength, MPa
	Name	Dosage, wt%				
1contr.	–	–	0.67	–	2070	22.4
2.1	MC Power Flow 3100	2.0	0.55	18.0	2115	26.1
2.3		3.0	0.53	20.9	2120	30.8
2.4		3.5	0.53	20.9	2120	29.0
3.1	Sika Plast E2	1.0	0.56	16.5	2075	24.5
3.2		1.5	0.55	18.0	2090	31.8
3.3		2.0	0.56	16.5	2080	27.8
4	Sika ViscoCrete 20 HE	2.0	0.53	20.9	2085	32.6
5	Biseal POL	1.5	0.52	22.4	2120	34.9

The maximum increase in concrete strength was obtained with the following additives: MC Power Flow 3100 (at a dosage of 3.0%) and amounted to 37.5%; Sika Plast E2 (1.5%) - 42.0%; Sika ViscoCrete 20 HE (2.0%) - 45.5%; Biseal POL (1.5%) - 55.8%. For the studied fine-grained concrete, the best effect was established with the addition of Biseal POL additive, which is associated with the value of water-reducing effect - 22.4%.

4.5 The Study of the Effect of a Complex Additive Based on Metakaolin on the Physical and Mechanical Properties of Fine-Grained Concrete

To assess the effectiveness of a complex additive of metakaolin with Biseal POL (1.5%) superplasticizer, fine-grained concrete samples of 7.07 * 7.07 * 7.07 cm in size were made with the optimal particle size distribution of sand, hardening at a temperature of 20 °C and a relative humidity of more than 95%. Workability was assessed by the immersion depth of the cone and was 2 cm. The range of metakaolin introduction is from 5.0 to 10.0 wt%. The research results are shown in Table 6 and Fig. 5.

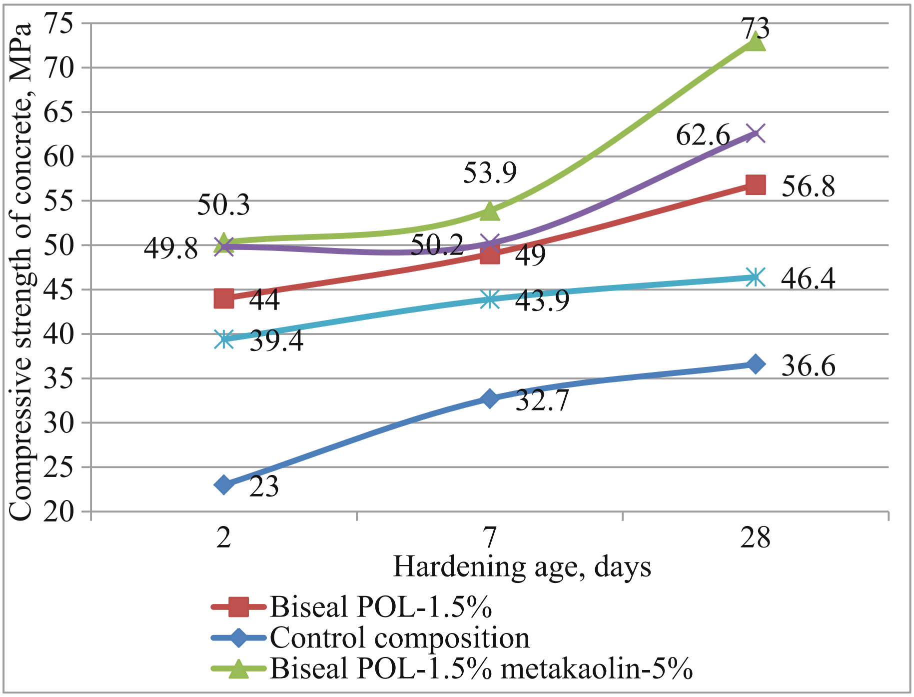

Fig. 5. Kinetics of the set of concrete compressive strength depending on the type and dosage of additives

Table 6. Effect of additives on W/C factor and concrete strengthening

Composition number	Dosage of additive, %		W/C	The increase in compressive strength, % compared with the control composition		
	Biseal POL	Metakaolin		2 days	7 days	28 days
Contr. 1	–	–	0.41	–	–	–
1.1	1.5	–	0.35	47.9	49.9	55.2
1.2		5	0.30	118.7	64.9	99.5
1.3		7.5	0.32	116.6	53.6	71.1
1.4		10	0.35	71.3	34.3	26.8

The main factor determining the characteristics of the structure and properties of hardened concrete is the water-cement ratio, which, when metakaolin is introduced, changes and reaches extremely low values at a dosage of 5 wt%. With an increase in the amount of metakaolin in excess of 7.5% wt%, the water demand of the concrete mix increases. Therefore, metakaolin as a microfiller with a certain water demand is effective at dosages of 5–7.5 wt%.

According to the results of studies, it was found that concrete with the use of a complex additive based on metakaolin has high kinetics of strength development, especially in the initial stages of hardening. At an optimal dosage of metakaolin of 5%, the increase in compressive strength after 2 days was 118.7%, and after 28 days - 99.5%. The values of water absorption are reduced by 42%, which diagnoses a decrease in the capillary porosity of concrete, contributes to the compaction and hardening of its structure.

Aluminate components of metakaolin provide high early and final strength of concrete, as well as resistance to shrinkage deformations, especially manifested in fine-grained concrete. The silicon-containing part of the additive, due to the regulation of structure formation by changing the alkaline medium, ensures the durability of the material. Due to the plate-like structure of the particles, metakaolin positively affects the workability of the concrete mix, increases its resistance to water gaining, and also reduces stickiness to the tool. But it has increased water demand, so it must be used in conjunction with water-reducing additives.

4.6 The Structure and Phase Composition of Cement Stone

The structural features of the cement stone with the introduction of metakaolin are shown in Fig. 6.

The mechanism of the formation of new hydrated phases consists of the epitaxial build-up of calcium hydro-aluminates on the surface of metakaolin grain; probably, calcium hydro-silicates are formed in parallel. The process of the formation of hydro-silicates proceeds almost to the complete binding of portlandite (Fig. 7).

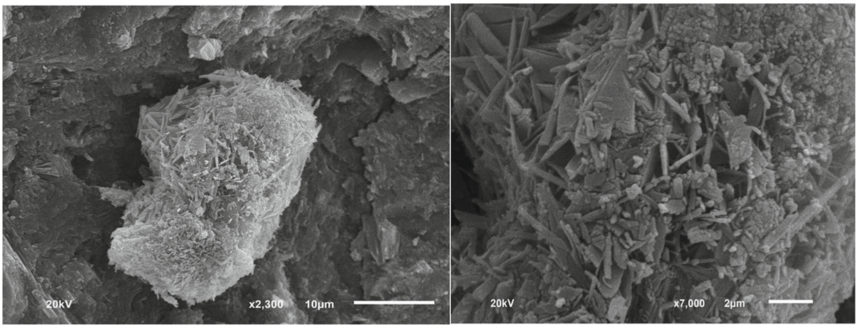

Fig. 6. Cement stone microscopy

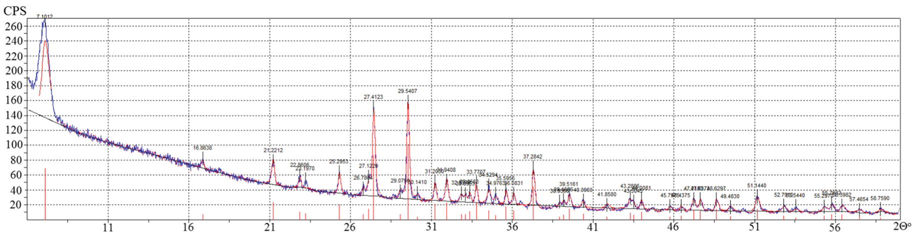

Fig. 7. X-ray phase analysis of cement stone containing metakaolin

The formation of katoite is established in the hydration products, an approximate composition of which is Ca3Al2[SiO4]1.12(OH)7.5 (identified by the diffraction lines d-2.7437; 1.6396; 2.2402; 3.0675). Also there were hydro-silicates of the xonotlite-tobermorite series, as well as calcium silicate hydroxyl of the orthorhombic syngony Ca_2[SiO3OH](OH) (identified by the diffraction lines d - 3.2660; 2.4180; 2.8789).

5 Conclusions

- It was established that metakaolin obtained by heat treatment of kaolin at a temperature of 750 °C is characterized by high dispersion and for 60% consists of grains less than 10 microns in size. This predetermines its effectiveness in fine concrete as a finely dispersed component.
- To obtain high-strength fine-grained concrete, sands of optimal particle size distribution should be used, since this leads to a decrease in void ratio up to 39.6% and an increase in the degree of compaction up to 68%.
- When comparing the quality indicators of concrete mixture and concrete, it was revealed that the Biseal POL additive (1.5%) has the best effect, which allows reducing water consumption by 22.4%, compacting the structure of concrete and providing an increase in compressive strength by 55.8%.

- The pozzolanic activity of metakaolin considerably prevails over the characteristics of a number of known reactive additives. The reactivity of metakaolin is caused by its structural features.
- Amorphous silica and aluminosilicate are involved in structural formation reactions of new hydrated phases. The mechanism of formation of new hydrates is associated with the formation of hydro-aluminosilicates, such as katoite and calcium silicate hydroxyls. The reaction activity of metakaolin allows maximum binding of $Ca(OH)_2$ into new hydrated phases.
- To obtain high-strength fine-grained concrete with a cement consumption of not more than 480 kg/m^3, it is necessary to introduce an effective superplasticizer and metakaolin into the concrete mix. Optimal dosages of metakaolin are in the range of 5–7.5%.

The composition with the addition of Biseal POL (1.5%) and metakaolin (5%) allowed obtaining a compressive strength of 73.0 MPa.

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Bending and Eccentrically Compressed Reinforced Concrete Structures at Low and Freeze-Thaw Temperatures

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Abstract. The stress-strain state of bending and eccentrically compressed reinforced concrete structures at low and freeze-thaw temperatures is considered. The effect of alternating freezing and thawing and low negative temperatures during single and multiple freezing on their bearing capacity and durability is assessed. The study was carried out according to specially developed computer programs using a nonlinear stress-strain model. The influence of the reinforcement ratio on the change in the bearing capacity of bending and compressed elements of reinforced concrete structures under the impact of freezing and thawing cycles and low negative temperatures is considered.

Keywords: Durability of reinforced concrete structures · Freezing and thawing cycles · Frost resistance of concrete · Reinforcement ratio · Nonlinear stress-strain model · Bearing capacity · Stress-strain state · Bending and eccentrically compressed reinforced concrete elements

1 Introduction

Reinforced concrete is currently the most common and demanded material in construction. But despite the many positive qualities, this material, like any other, has a finite service life. This is due to the fact that during operation, reinforced concrete structures are exposed to complex loads, natural and artificial environmental factors. The main reason for the loss of performance is a change in the initial properties and conditions of the structure material under the impact of loads, internal factors and environmental influences. This change is called material degradation. The most common causes of concrete degradation are the adverse effects of environmental factors: aggressive gases in the atmosphere, pollution of soils and groundwater, negative and freeze-thaw temperatures (especially in combination with moistening of the structure), solar radiation [1].

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In Russia, one of the most significant natural external factors causing concrete degradation is low and freeze-thaw temperatures, which is based on the geographical location of the country.

As shown in [2–11], the effect of negative and freeze-thaw temperatures leads to a change in the strength and stress-strain properties of concrete. This effect is enhanced with simultaneous moistening of the concrete with water or salt solutions. A one-time freezing of concrete increases its prismatic strength, initial elastic modulus, and compressive strains ε_{bo} and ε_{b2} compared to the values of these characteristics before freezing.

Freezing and thawing cycles (FTC) of concrete reduce its strength and the initial elastic modulus, compressive strains ε_{bo} and ε_{b2} increase during the process of FTC [11]. Moreover, changes in the stress-strain properties of concrete may exceed changes in the strength of concrete. Thus, the σ - ε diagram of concrete under the influence of low and freeze-thaw temperatures will transform. Obviously, taking into account the degradation of concrete in FTC only by introducing a reduction factor to the calculated concrete resistance, as stipulated by the applicable standards [12], cannot reflect all the features of the operation of reinforced concrete structures in FTC, since it does not take into account a significant change in stress-strain properties of concrete. In this regard, for reinforced concrete structures exposed to FTC, the importance of using a nonlinear stress-strain model to calculate their strength taking into account the transformation of σ - ε concrete diagrams under the influence of low and freeze-thaw temperatures increases [2, 10]. It should be noted that the nonlinear stress-strain model or, according to the terminology used in [2], the diagram method of calculation in accordance with the applicable standards [12] is the main method for calculating the strength of reinforced concrete structures according to normal sections.

The analysis of publications on the topic under discussion shows that, despite ongoing research and the availability of regulatory documents [11], the effect of low and freeze-thaw temperatures on the properties of concrete has not been fully studied. The issue on the impact of this factor on the strength, reliability and durability of reinforced concrete structures is even less developed. In works [9, 10], it was shown that the reinforcement ratio of bending elements affects the dynamics of changes in their bearing capacity during FTC. In connection with the foregoing, the task of assessing the effect of low and freeze-thaw temperatures on the bearing capacity of bending and eccentrically compressed reinforced concrete elements according to normal sections for various reinforcement ratios and eccentricities of longitudinal force (with eccentric compression) using a nonlinear stress-strain model is relevant.

2 Theory and Experimental Methods

Algorithms and special computer programs have been developed to assess the effect of FTC and low negative temperatures on the stress-strain state of bending and eccentrically compressed elements of reinforced concrete structures [10].

The algorithms for calculating the stress-strain state of bending and eccentrically compressed elements of reinforced concrete structures according to normal sections are based on the application of assumptions, in particular, arising from the application of the distribution of deformations and forces in the section, which is normal to the longitudinal axis of the element, according to a nonlinear stress-strain model from the equilibrium condition of external and internal forces in the element's section. The calculation of the elements of reinforced concrete structures according to the normal section is performed using the stress-strain criterion:

$$\left|\varepsilon_{b,max}\right| \leq \varepsilon_{b,ult}; \qquad \left|\varepsilon_{b,max}\right| \leq \varepsilon_{s,ult}.$$

The values of the strength and stress-strain characteristics of concrete at a positive temperature and FTC = 0 (Summer, FTC = 0), and also after exposure to FTC at a positive temperature (Summer, FTC = max) and with a single freezing (Winter, FTC = 0) are taken according to [11]. The characteristics of concrete in the frozen state after the impact of FTC were obtained by extrapolation. The change in the characteristics of concrete in the process of FTC is modeled by polynomials of the third degree. In the future, it is planned to carry out special experimental studies of the influence of FTC on the strength, elastic modulus, and ultimate strains ε_{bo} and ε_{b2} at negative temperatures, which will allow clarifying the accepted scientific hypothesis about the effect of the test temperature on the strength and stress-strain characteristics of concrete. The characteristics of concrete grade *B30* under various operating conditions used in the calculations are shown in Table 1.

Table 1. Strength and stress-strain characteristics of concrete

Operating conditions	R_b, *MPa*	E_b, *MPa*	ε_{bo}, ‰	ε_{b2}, ‰
Summer, FTC = 0	17.0 (100%)	32500 (100%)	2.0 (100%)	3.5 (100%)
Summer, FTC = max	11.9 (70%)	9850 (30%)	4.0 (200%)	6.0 (171%)
Winter, FTC = 0	32.3 (190%)	48750 (150%)	2.8 (140%)	4.7 (134%)
Winter, FTC = max	22.6 (133%)	14775 (45%)	5.6 (280%)	8.0 (229%)

The graphs of changes in R_b, E_b, ε_{bo}, ε_{b2} during operation in thawed and frozen conditions are shown in Figs. 1a, b, c, d. Figure 2 shows the stress-strain diagrams of concrete grade B30 in frozen and thawed states for different periods of operation, calculated at positive (Summer) and negative (Winter) temperatures.

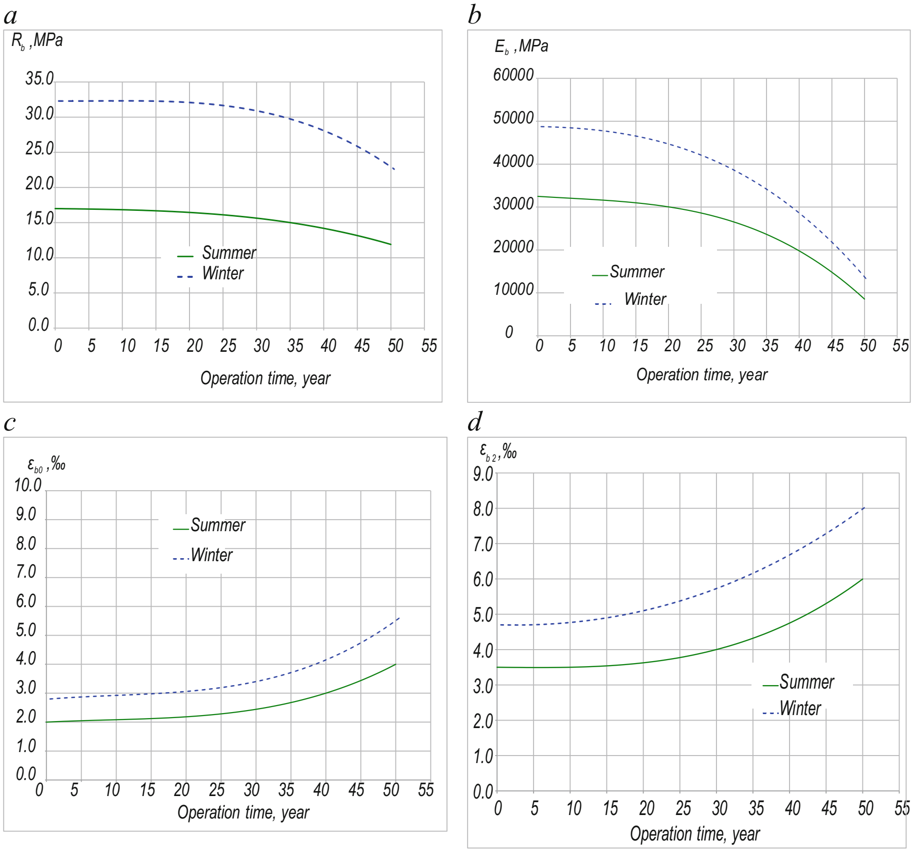

Fig. 1. Change in the strength and stress-strain characteristics of concrete grade B30 during operation in thawed and frozen states: a - prismatic strength of concrete R_b; b - elastic modulus of concrete E_b; c - ultimate strain of concrete ε_{bo}; d - ultimate strain of concrete ε_{b2}

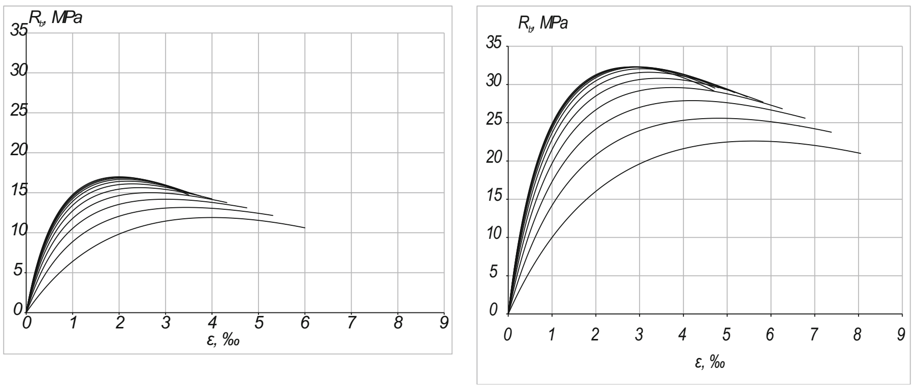

Fig. 2. Transformation of stress-strain diagrams of concrete grade B30 under the influence of FTC tested: a - at positive temperatures; b - at negative temperatures

3 Results and Discussion

The numerical analysis confirmed the expressed and generally accepted assumptions about the growth of the bearing capacity of compressed and bending elements in the winter and allowed obtaining new quantitative results.

Figure 3 shows graphs of changes in the bearing capacity of bending concrete elements in winter and summer under the influence of FTC. The change in the bearing capacity of bending reinforced concrete elements under the natural conditions of the North has a cyclical pattern, increases in winter and decreases in summer.

The quantitative parameters of the influence of reinforcement ratio on reducing the durability of bending reinforced concrete elements are determined. With a reinforcement ratio μ = 2%, the bearing capacity of a bending reinforced concrete element at a positive temperature after FTC decreased by 12.2%, and with μ = 0.5%, it decreased only by 2.5%. With a single freeze, the bearing capacity of bending elements increased by 13.0% at μ = 2%, and by 2.3% at μ = 0.5%.

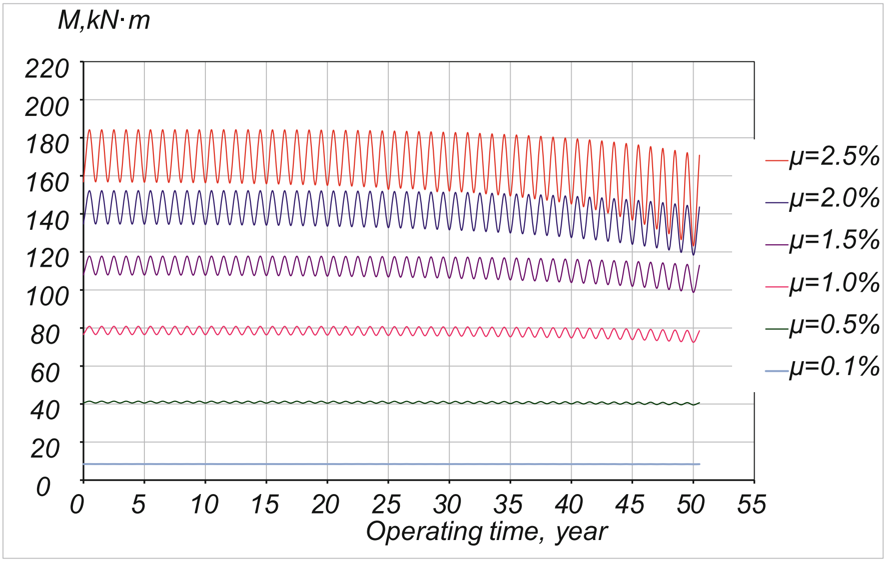

Fig. 3. The bearing capacity of a bending element at various reinforcement ratios: b = 200 mm, h_0 = 350 mm, initial concrete grade B30, reinforcement of A400 grade

The analysis of the influence of FTC and low temperatures on the limiting reinforcement ratio of bending elements of reinforced concrete structures is carried out. The maximum reinforcement ratio of longitudinal tension reinforcement $\mu_R = \frac{A_{s,R}}{bh_0}$ is taken as the limiting reinforcement ratio. Where, $A_{s,R}$ is the maximum cross-sectional area of the longitudinal tension reinforcement at which the stresses in it reach the designed resistance.

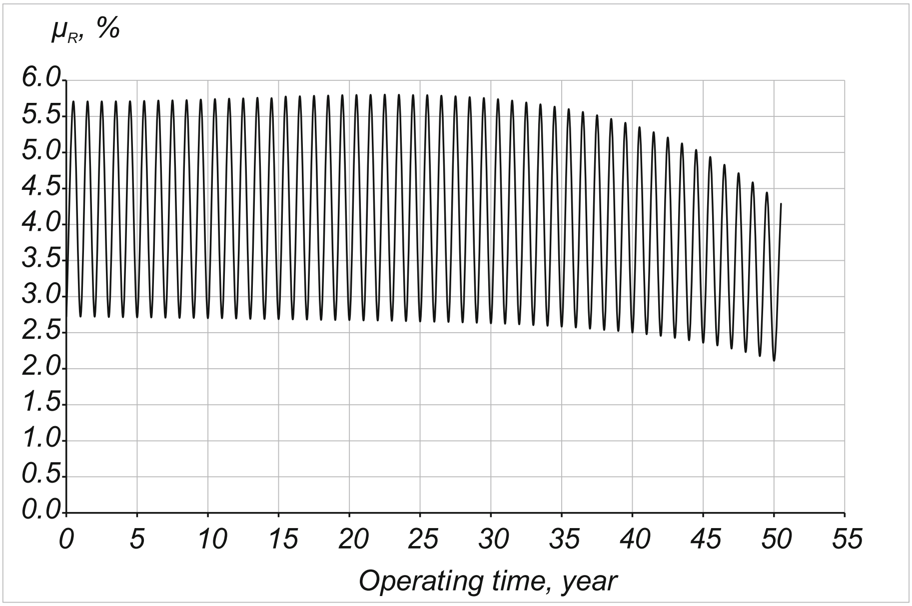

Fig. 4. The limiting reinforcement ratio of a bending reinforced concrete element: initial concrete grade B30, reinforcement of A400 grade

Figure 4 shows a graph of changes in the limiting reinforcement ratio μ_R during operation. The results are obtained numerically using a computer program developed as part of a nonlinear stress-strain model. The change in the limiting reinforcement ratio during operation will also be cyclical, see Fig. 4. At the first freezing, the limiting reinforcement ratio increased by 110%. Freezing and thawing cycles resulted in a 22% decrease in μ_R in the summer. If the actual reinforcement ratio exceeds the limiting one, brittle fracture of the bending reinforced concrete element along the normal section is possible. Placing longitudinal main reinforcement in a compressed zone of concrete will reduce the likelihood of brittle fracture of bending reinforced concrete structures in the natural conditions of the North along normal sections with a high reinforcement ratio.

It is noted that with an increase in the reinforcement ratio, the strength of reinforced concrete bending structures under the influence of FTC decreases more intensively. These circumstances indicate that the durability of reinforced concrete bending structures with a high reinforcement ratio will noticeably decrease.

It can be assumed that bending reinforced concrete elements with double reinforcement will be more durable in the North, since in this case the degradation of concrete in the compressed zone under the influence of FTC will have a lesser effect on the decrease in the normal section bearing capacity.

Compression elements with symmetrical reinforcement were calculated using a nonlinear stress-strain model for various values of the longitudinal force eccentricity and the reinforcement ratio without taking into account flexibility. The dimensions of the element's cross section $b = 400\ mm$, $h = 400\ mm$, the working height of the cross section $h_0 = 350\ mm$. The calculation results are shown in Table 2.

Table 2. Values of maximum longitudinal force $N_{мax}$ (central compression), maximum bending moment $M_{мax}$ perceived by the compressed element, and bending moment *M* at $N = 0$ (pure bending)

μ,%	0.5		1.0		1.5		2.0	
	FTC = 0	FTC = мax	FTC = 0	FTC = мax	FTC = 0	FTC = мax	FTC = 0	FTC = мax
$N_{мax}$, *kN*	Summer							
	3210 (100%)	2394 (75%)	3700 (100%)	2884 (78%)	4190 (100%)	3374 (81%)	4680 (100%)	3864 (83%)
	Winter							
	5658 (176%)	4108 (128%)	6148 (166%)	4598 (124%)	6638 (158%)	5088 (121%)	7128 (152%)	5578 (119%)
$M_{мax}$, *kN•m*	Summer							
	201.4 (100%)	163.3 (81%)	274.6 (100%)	237.1 (86%)	345.9 (100%)	310.4 (90%)	421.3 (100%)	383.7 (91%)
	Winter							
	320.0 (159%)	245.3 (122%)	395.2 (144%)	318.5 (116%)	467.8 (135%)	392.2 (113%)	540.4 (128%)	466.0 (111%)
M when N = 0, kN•m	Summer							
	82.3 (100%)	78.9 (96%)	155.1 (100%)	152.6 (98%)	228.3 (100%)	226.1 (99%)	301.4 (100%)	299.6 (99%)
	Winter							
	86.2 (105%)	81.7 (99%)	162.0 (104%)	156.4 (101%)	236.1 (104%)	230.3 (101%)	309.8 (103%)	304.0 (101%)

Change in the normal section bearing capacity of eccentrically compressed reinforced concrete elements with symmetrical reinforcement at low temperatures and with the use of FTC has a number of features. With symmetrical reinforcement, an increase in the reinforcement ratio reduces the influence of FTC and low temperatures on the bearing capacity. The value of the maximum moment perceived by the eccentrically compressed element increases during the first freezing by 59% at $\mu = 0.5\%$, and at $\mu = 2.0\%$ - by 28%. After exposure to FTC, the effect of temperature slightly decreases.

The impact of FTC on the centrally compressed element at a positive temperature (Summer) led to a decrease in the bearing capacity by 25% with a reinforcement ratio $\mu = 0.5\%$ and by 17% with $\mu = 2.0\%$. At the first freezing, N_{max} increased by 76% with a reinforcement ratio $\mu = 0.5\%$. With an increase in a reinforcement ratio up to $\mu = 2.0\%$, the increase in N_{max} was 52%.

The change in the bearing capacity during operation in the natural conditions of the North is also cyclical in dependence on temperature. At negative temperatures, the bearing capacity increases. With an increase in the reinforcement ratio, the dependence of the bearing capacity on both FTC and temperature decreases.

In the case of pure bending ($N = 0$) with symmetrical reinforcement, the bearing capacity is almost independent of the temperature and the effect of FTC. This is explained by a decrease in the contribution of concrete to the total bearing capacity of the element.

The dependences of the bearing capacity *N–M* are shown in Figs. 5 and 6.

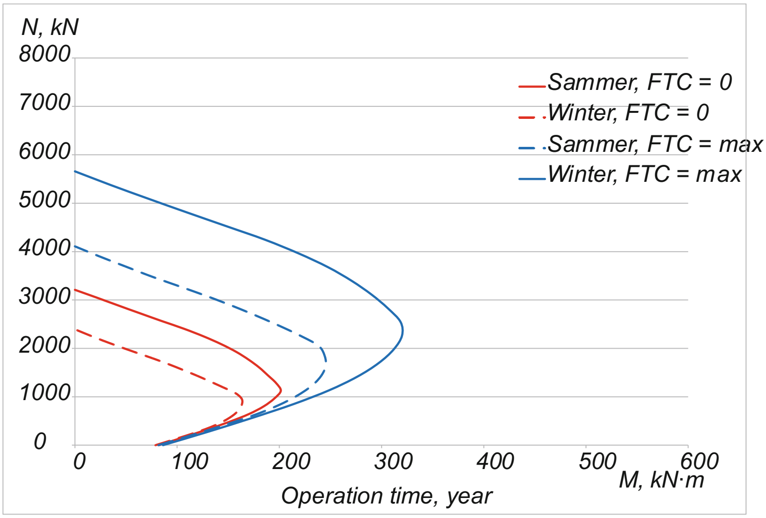

Fig. 5. Graphs of bearing capacity of eccentrically compressed square cross-section elements with symmetrical reinforcement $\mu = 0.5\%$

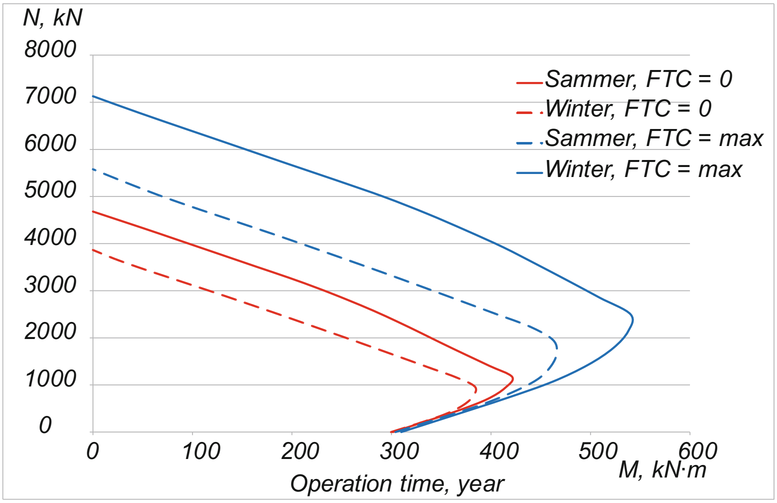

Fig. 6. Graphs of bearing capacity of eccentrically compressed square cross-section elements with symmetrical reinforcement μ = 2.0%

4 Conclusions

The reliability of reinforced concrete structures in the natural conditions of the North is cyclical and depends on the season, increasing in winter and decreasing in summer. It can be assumed that there is a hidden periodicity of failures of reinforced concrete structures in the natural conditions of the North. The probability of failure of reinforced concrete structures in the winter will decrease. When predicting the performance of reinforced concrete structures in the North, the season of operation must be taken into account.

The durability of bending reinforced concrete elements with a single reinforcement under the impact of FTC depends on the reinforcement ratio and decreases with its increase. To increase the durability of bending reinforced concrete structures operating in the natural conditions of the North, the reinforcement ratio should be reduced or structures with double reinforcement should be used.

When assuming the reinforcement ratio, it is necessary to take into account the operating conditions (the negative impact of FTC) on the limiting reinforcement ratio μ_R.

For the case of symmetrical reinforcement, the durability of compressed reinforced concrete elements increases with increasing reinforcement ratio. In the case of pure bending, the effect of low temperatures on the increase in the bearing capacity and FTC on its decrease becomes negligible. With an increase in the eccentricity of the longitudinal force, the influence of FTC and low temperatures on the bearing capacity decreases.

In this paper, only some aspects of the reinforced concrete structures operation in the conditions of FTC and low temperatures are considered, but the results obtained at this stage indicate the crucial importance of the issue.

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Information Model of Multivariate Technological Design of Earthworks

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Abstract. Earthworks are an integral part of almost any construction. Every year, the improved machines and mechanisms implement some kind of work. But in addition to modernization, an important factor is the composition of the selection of machines and mechanisms. This paper provides information on choosing the model of the most efficient set of machines from the point of view of cost and duration of work on the example of excavations. The dependence of the cost of excavator kits and transport vehicles on many factors is described.

Keywords: Technical and economic comparison of technological circle · Organization of construction processes · Set of machines · Carrying capacity

1 Introduction

Today, the variance in building design is of great importance, because the adoption of an architectural-constructive, engineering-technical, technological decision. From the point of view of technological design options, a technical and economic comparison of indicators of possible adoptions is carried out [1]. As the main criteria for assessing project cost and duration of the act [2, 3], important in the use of this method of design, is the process of formation of alternative decision, because the number of factors affecting the cost and duration of the project, taken into account during the formation, largely determine the effectiveness of this method and the project as a whole [4, 5]. In the design of earthworks, the composition of the earthmoving and transport machines is often appointed without detailed consideration of alternative variants, which affects the increase in material and workforce resources [6, 7]. In this paper, a model of multivariate design of earthworks will be presented using the example of designing a pit by an excavator with loading onto dump trucks. The factors affecting the cost and duration of the work are: the volume of the excavator bucket, the carrying capacity of the dump trucks and the distance of the ground transportation. This model is developed to determine the most effective variant for the composition of the machines necessary for the development of excavation.

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2 Technique of Alternative Design of Technological Processes of Device Pits

2.1 Raw Data to Build a Model

Formation of alternative processes of pit devices will be based on the scanning of the values of the parameters affecting the efficiency function at specified intervals. To build a multivariate model of technological design, we take a conventional pit with a volume of 1000 m^3. For difficulties in design, we accept 1 main group. The designing of a pit is carrying out by an excavator with loading onto dump trucks by Russian State Standard GESN 81-02-01-2017 «Earthworks». The factors affecting the cost and duration of the work are:

1. The volume of the excavator bucket. Taking into account the volume of pit this factor will take 3 values – 0,25; 0,4; 0,5 m^3.
2. Carrying capacity of dump trucks. The factor 7 takes values in a range 2,55–40 t.
3. Distance of the ground transportation. The range of values of this factor 1–10 km.

With a view to selecting the most effective version of letting value earthmoving and transport machines represent to relative cost units. Below are the matrixes forming the raw data with the desired characteristics (Tables 1 and 2).

Table 1. Characteristics of dump trucks

№	Carrying capacity, t	Relative replacement cost
1. GAZ-93B	2.55	1.0
2. GAZ-53B	3.5	1.76
3. ZiL-555	4.5	2.27
4. KamAZ-5510	7	2.80
5. Kraz-222b	10	3.02
6. Maz-525	25	3.92
7. BelAZ-448A	40	7.00

2.2 Model of Formation of Alternative Processes of the Device of a Pit

The model of formation of alternative processes developed in the Microsoft Excel program. The structure of the model consists of the following components: a matrix of raw data; calculating device of the model; display of results in the form of graphs. Calculating device of the model is a consistent definition of the following values:

1. Hourly capacity of the excavator. It is a quantitative measure of the amount of ground designed excavated per hour.

$$C_h = \frac{\varepsilon}{\mathrm{H}_t} \tag{1}$$

ε - volume of ground for which time is given, m^3; H_t – machine time standard, machine/hour.

Table 2. Characteristics of excavators

№	Labor costs on 1000 m^3, machine/hour	Relative cost on 1000 m^3
1. Single-bucket diesel excavators on caterpillar, bucket volume 0.5 m^3	33.63	14.52
2. 1. Single-bucket diesel excavators on caterpillar, bucket volume 0.4 m^3	41.3	9.77
3. Single-bucket diesel excavators on caterpillar, bucket volume 0.25 m^3	53.1	16.05

2. The number of excavator buckets needed to load a dump truck. Determined by dump truck carrying capacity (Q), volume of the excavator bucket (V_{kov}), coefficient of charge (K_{nap}), specific weight of ground (ρ) and coefficient of fragmentation (K_{raz}).

$$N_{kov} = \frac{Q}{\frac{V_{kov} * K_{nap}}{K_{raz} + 1} * \rho} \tag{2}$$

3. Batching time of a dump truck by an excavator.

$$T_z = \frac{N_{kov} * V_{kov} * K_{nap} * 60}{C_h} \tag{3}$$

$T_з$ – batching time, min; 60 – change to minutes.

4. Dump truck on the way. It is determined by the ratio of the distance between the building site and the place of unloading of the ground and the speed of the dump truck. Since the speed range of the movement of the accepted dump trucks under the load is different, we will take the same speed under the load equal to 30 km/h for all dump trucks. Similarly, we take the same speed of movement of dump trucks in the affected state equal to 30 km/h.

$$T_p = \frac{L}{\upsilon_z} * 60 + \frac{L}{\upsilon} * 60 \tag{4}$$

L – distance of the ground transportation, km; υ - speed of movement of dump trucks in the affected state, km/h; υz – dump truck speed under load, km/h;

5. Duration of one technological circle of a dump truck.

$$T = T_z + T_p + T_r + T_m \tag{5}$$

T_r – unloading time of dump truck, min; T_m – maneuvering time before loading and unloading the dump truck, min; T_r – 1.5 min; T_m – 2.5 min [8].

6. Number of dump trucks

$$N = \frac{T}{T_z + T_m} \quad (6)$$

In this paper, we will consider the development of the excavation with the uninterrupted operation of the excavator, so the number of dump trucks is rounded up. Thus, sets of dump trucks are formed for each excavator.

7. The cost of sets of excavators and dump trucks

$$C_{sets} = \frac{N \times C_{rel.rep.costdt} \times T_h}{8} + C_{rel.cost.exc} \quad (7)$$

$C_{rel.rep.cost.dt}$ – relative replacement cost of dump truck; T_h – labor costs, machine/hour; $C_{rel.cost.exc}$ – relative cost of excavator.

Thus, possible variants of sets of earthmoving and transport machines with the calculated values of their cost and duration of work are being compiled. On the basis of the developed model, it is possible to determine the most effective set of machines for pits of various volumes, as well as for various types of ground by introducing basic characteristics into the matrix of raw data.

3 The Research Results Obtained Using the Developed Model

3.1 The Dependence of the Cost of a Set of Dump Trucks on Their Capacity

In this paper, we will consider the design of the excavation with the uninterrupted operation of the excavator, so the number of dump trucks is rounded up. Thus, sets of dump trucks are formed for each excavator (Fig. 1).

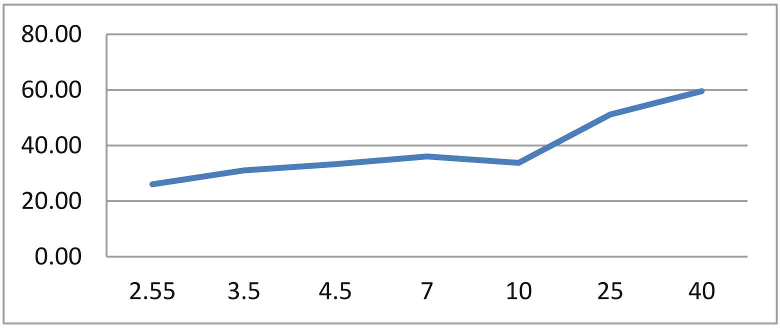

Fig. 1. The cost of sets of dump trucks, depending on their carrying capacity.

3.2 The Dependence of the Cost of a Set of Dump Trucks on the Volume of the Excavator Bucket

Based on the calculation made with the help of the developed model, it can be concluded that the most effective one in terms of cost is variant with bucket volume variant 0,4 m^3 (Fig. 2).

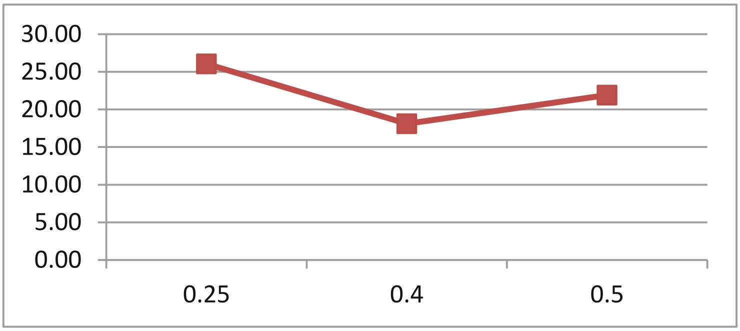

Fig. 2. The cost of a set of dump trucks, depending on the volume of the excavator bucket.

3.3 Dependence of the Cost of a Set of Dump Trucks on the Distance of the Ground Load

The values of the relative costs of sets of dump trucks, depending on the distance of ground transportation, are given in tabular form. The calculation is made for an excavator with a bucket volume 0,25 m^3 (Table 3).

Table 3. The relative cost of a set of dump trucks, depending on the distance of the ground

Car brand	Carrying capacity, t	The relative cost of a set of dump trucks, depending on the distance of the ground			
		1 km	3 km	7 km	10 km
1. GAZ-93B	2.55	13.92	25.03	47.26	63.92
2. GAZ-53B	3.5	21.00	35.29	63.86	85.29
3. ZiL-555	4.5	24.62	38.91	67.48	88.91
4. KamAZ-5510	7	29.65	42.16	67.19	85.96
5. Kraz-222b	10	27.16	35.72	52.84	65.68
6. Maz-525	25	55.43	63.36	79.22	91.12
7. BelAZ-448A	40	69.50	75.92	88.76	98.39

Let's consider the option with a range of soil sinking equal to 1 km. In this case, the cost of a complete set of machines increases with the growth of their carrying capacity. A set of dump trucks with a loading capacity of 40 tons is 2 times more expensive than sets with a loading capacity of 2.55 tons. But with an increase in the compensation range, the dependence changes its direction.

4 Conclusion

Most of the techniques for choosing the optimal set of earthmoving and transport machines are based on the dependence of the cost on the volume of the excavator bucket and the carrying capacity of the dump trucks [9–11]. The constructed model differs in that it includes the dependence of the cost on the ground transportation distance. As the results showed, this factor has a great influence on the cost of work. Thus, the model proves its effectiveness, as well as the effectiveness of the variant design method.

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Typology of Passenger Railway Stations in the Late 19th – Early 20th Centuries (Russian Experience)

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Abstract. The purpose of the study is to identify the background for the establishment of the passenger service infrastructure in the late 19th – early 20th centuries. The author considers the specifics of railway terminals and stations of a new type that appeared during that time. The period from the second half of the 19th century till the early 20th century was the time of scientific and technical development in various industries, expansion of commercial manufacturing, and development of transportation lines. A new transportation industry—the railroad—was intended to connect vast territories of the Russian state. The significance of railroad transport in the country's economy required radical changes in the Directorate of Transportation. The Ministry of Transportation established in the 1860s made it possible to create a clear structure for management of the public road system that implied its rational division into administrative and technical components. The factual basis of the study included legislative instruments and regulations issued with regard to railway track facilities, as well as regulatory documents concerning design of railway terminals and stations.

Keywords: Russia · History of architecture · Governance · Train routes · Railway stations

1 Introduction

Construction of train routes in Russia started in the late 1830s, almost simultaneously with appearance of such roads in other countries. The first road—Tsarskoe Selo Railway—was opened in 1837. In the 1850s, another two railroads were almost finished: the Warsaw-Vienna Railway (from Warsaw to the Austrian border) and the Saint Petersburg to Moscow Railway [1].

In the second half of the 19th – early 20th centuries, practical activities of the institution were mainly related to development of railroad transport that made it possible to connect vast Russian territories. Construction of railroads contributed to exploration of many lands that had been difficult to access.

The mid-1860s became the turning point in construction of train routes—that was a period of reforms, start of economy capitalization. While by the beginning of the

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1860s, the total length of railroads was a bit more than 2,000 versts (1 verst equals to 1.067 km), almost 6,500 versts were constructed by the late 1860s.

The Council on Railroads established in 1885 solved issues related to development and implementation of activities to construct and operate railroads, maintain railway facilities [2]. The Council analyzed drafts of new laws, rules and instructions related to railways. The Chief Inspectorate of Railroads was an authority regulating railroad construction and railroad facilities.

The Department of Railroads was a central body that was responsible for all issues related to railroad construction (except for state-owned railroads). The Temporary Directorate of State-Owned Railroads managed state-owned railroads. It also had the rights of a department [3]. The Department of Railroads arranged construction and operation of railroads and railroad facilities in terms of administrative and technical matters.

The creation of departments for managing the construction of railways suggests the importance of rail transport for Russia at this time. Railway construction is becoming a special branch of the Russian economy. Its development required the standardization of objects related to the track economy, as well as passenger service facilities. The purpose of the article is to study the standardization of station facilities for receiving and sending passengers.

2 Materials and Methods

The factual basis of the research included legislative instruments and regulations published during the 19th and the first early 20th centuries. Besides, sources of pre-revolutionary historiography and the 20th century historiography on railway track facilities construction were studied in detail. Development of the legal framework and the actual process design of railway terminals and stations were studied in parallel.

3 Results

In the end of the 19th century, railroad transport became a priority area of transport routes' development in Russia. The growing flow of passengers and cargo transported using railroads as well as expansion of railroad length required enhancement and enlargement of the railroad infrastructure in terms of buildings and track facilities. In the 1870–1880s, a number of governmental decrees aimed to provide legal framework for works on construction of railroads and establishment of their infrastructure were published [4–6].

At the time, railway stations had a complex organization in terms of layout and space. Railway stations included: buildings and structures for passenger handling services and transportation of cargo, track facilities (including their maintenance), residential buildings for employees, and other necessary structures and facilities [7]. A special typology of passenger buildings and railway stations in general, depending on the size of a settlement; the number of roads crossing at the same junction; the distance from one station to another, formed at the time. Passing-through, terminal, and transfer stations as well as mixed-type stations appeared [8]. Passenger stations on main railway lines were divided into classes or categories depending on the size and significance of settlements, near of through which such railway lines passed. The typology of stations was as follows: class I, II, III, IV, V stations, as well as small stations [9].

Class I stations are large terminal, intermediate and junction stations with locomotive shops and, sometimes, with a place for rolling stock repair. In that case, passenger buildings had a developed servicing unit for passengers and luggage. All trains stopped at those stations. There, cars could also be switched and made up in trains.

Class II stations were less developed in terms of locomotive shops and passenger handling services [12]. All passenger and freight trains also stopped at those stations. Locomotives were also switched there.

We can judge about the size of class I and II stations by the Moscow station, Moscow–Windau–Rybinsk Railway (Figs. 1 and 2). They included many premises of various purposes (sizes are given in square sazhens, where 1 square sazhen equals to 4.55 m2): entrance hall—92.85 sq. sazhens; waiting room for passengers, classes I and II—80.60 sq. sazhens; refreshment room for passengers, classes I and II—32.47 sq. sazhens; hall for passengers, class III—80.0 sq. sazhens; refreshment room for passengers, class III—37.98 sq. sazhens; hairdressers—4.72 sq. sazhens; ladies' room—3.61 sq. sazhen; men's room—4.17 sq. sazhens; station master's office—14.0 sq. sazhens; telegraph office—16.14 sq. sazhens; railway ticket office, classes I and II—3.75 sq. sazhens; railway ticket office, class III—3.09 sq. sazhens; on-duty gendarme office—7.37 sq. sazhens; railway section office—4.04 sq. sazhens; doctor's office—3.38 sq. sazhens; restricted areas of the refreshment room—16.20 sq. sazhens; lavatories and water closets. At those stations, rooms for passengers of different classes were located in different parts of buildings, and restricted areas were located on both sides of the entrance hall. Buildings primarily had two floors, where premises of restricted use were located on the second floor.

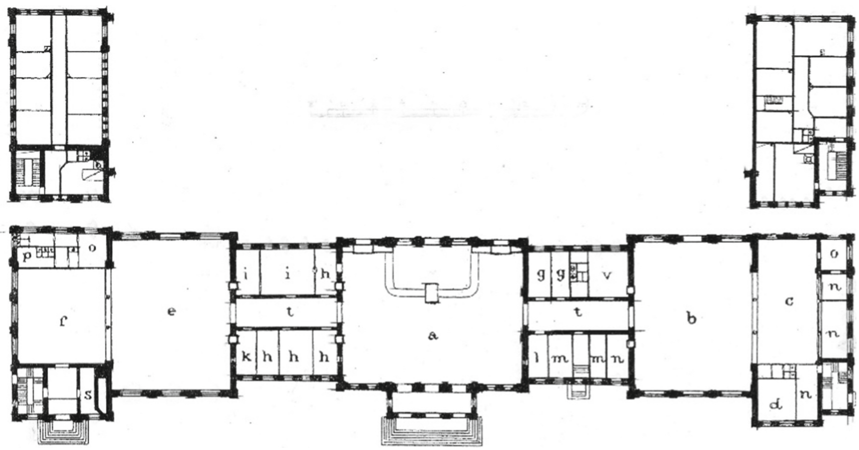

Fig. 1. Layout of a class II railway station (Moscow station, Moscow–Windau–Rybinsk Railway) Source: https://humus.livejournal.com/6514908.html [10]

Fig. 2. Moscow station, Moscow–Windau–Rybinsk Railway (currently—Rizhsky railway station). Source: https://moscowchronology.ru/vokzali.html [11]

Class III stations were average-size stations (Figs. 3 and 4) where locomotives were switched and a locomotive terminal was located. Mainly long-distance transit passengers, who change to another train, boarded at such stations. However, high-speed and express trains often did not stop there. A set of rooms in passenger buildings of this class was less diverse. Buildings included the following: entrance hall—25.82 sq. sazhens; waiting room for passengers, classes I and II—24.56 sq. sazhens; waiting room for passengers, class III—24.56 sq. sazhens; refreshment room with a food serving room—7.8 sq. sazhens; ladies' room—5.02 sq. sazhens; ladies' water closet—0.64 sq. sazhens; men's room—2.96 sq. sazhens; men's water closet—0.92 sq. sazhens; station master's office and station duty officer's office—17.4 sq. sazhens; post office—7.23 sq. sazhens; on-duty gendarme office—1.8 sq. sazhens; luggage room—4.64 sq. sazhens; railway ticket office—1.84 sq. sazhens; rooms for travelling employees—6.15 sq. sazhens; total area of wind lobbies and corridors—17.55 sq. sazhens.

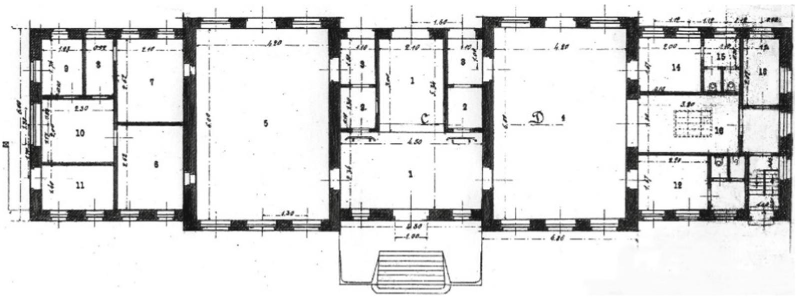

Fig. 3. Layout of a class III railway station (layout of a railway terminal on the railroad from Tiflis (Tbilisi) to the Persian border) Source: https://bestlj.ru/45799-1872-Albom-chertezhejj-sooruzhenijj-Rossijjskikh-zheleznykh-dorog-CHast-2.html [13]

Fig. 4. Class III station on the railroad from Tiflis to the Persian border. Source: https://yadi.sk/a/7MAGc6_Z3ZRk3Q [14]

Class IV stations were small stations (Figs. 5 and 6) with facilities to handle passengers and cargo. However, they had no locomotive services. Small refreshment rooms for passengers were not always present at those stations. As stations with little traffic, they were primarily located away from the city and had the following rooms: waiting room for passengers, classes I and II—12.48 sq. sazhens; waiting room for passengers, class III—16.80 sq. sazhens; refreshment room with a food serving room—7.23 sq. sazhens; kitchen—4.16 sq. sazhens; ladies' room—2.86 sq. sazhens; ladies' water closet—0.98 sq. sazhens; men's room—0.8 sq. sazhens; men's water closet—0.92 sq. sazhens; office—4.32 sq. sazhens; luggage room—2.35 sq. sazhens; telegraph office—3.06 sq. sazhens; post office—3 sq. sazhens; entryway (seni) from different sides of the station—2.16 sq. sazhens, 2.28 sq. sazhens, 4.33 sq. sazhens; stairs—2.52 sq. sazhens.

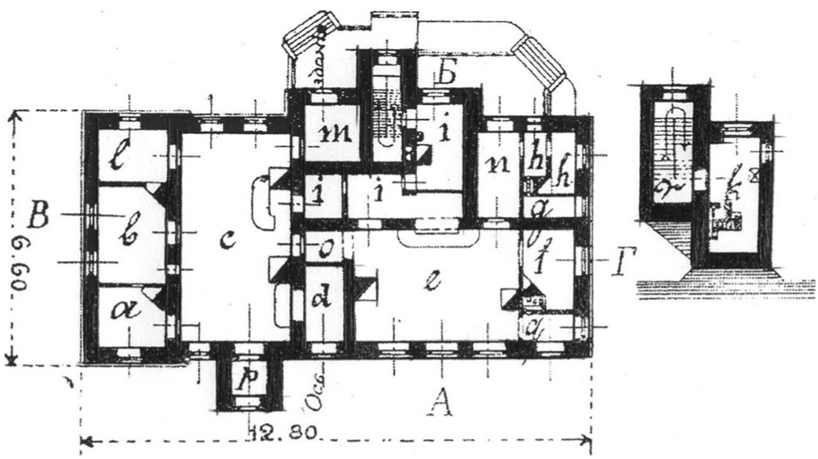

Fig. 5. Layout of a class IV railway station (layout of a railway terminal on the Altai Railway) [9]

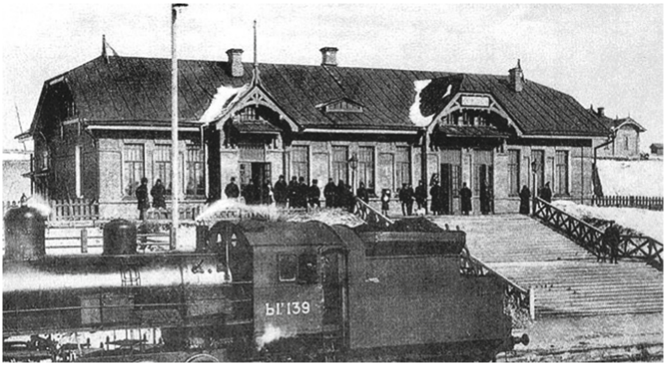

Fig. 6. Class IV railway station. Railway terminal on the Altai Railway, Source: http://www.letopisi54.ru [15]

No onboarding and deboarding of passengers or commodity operations were performed at class V stations. Such stations were built in places of tracks' intersection or train crossing. Despite that, they included the following rooms: waiting room (without dividing passengers into classes)—7.89 sq. sazhens; ladies' room—3.26 sq. sazhens; two water closets (ladies' and men's water closets)—0.89 sq. sazhens and 0.48 sq. sazhens; station master's office—4.46 sq. sazhens; telegraph office—3.26 sq. sazhens; two entryways (seni) (from the side of the yard and from the side of the platform)—1.27 sq. sazhens and 0.68 sq. sazhens.

Aside from the above listed stations, there were also passing loops, roadside and loading stations (for onboarding and deboarding of passengers, loading and unloading of freight cars) (Fig. 7).

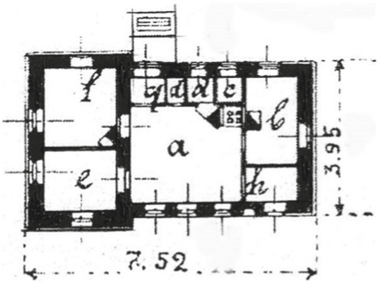

Fig. 7. Layout of a passing loop [9]

As follows from the above, depending on the class of the station, services provided to passengers varied, which meant different area standards for particular premises. The total area of stations was determined based on the rules given in the design and construction specifications for main railway lines. The rules stated: "The area of indoor premises in passenger buildings, used primarily by passengers and station's employees, without entryways, stairs and corridors, as well as post offices and residential premises (if any)… shall be as follows: for passenger buildings, category I, according to the approved design made depending on local conditions, and for passenger buildings of other categories, at least: for category II—200 sq. sazhens, for buildings of category III—150 sq. sazhens, for buildings of category IV—42 sq. sazhens, and, finally, for passenger buildings made at passing loops… 20 sq. sazhens" [16].

From the beginning of the 20th century, to standardize areas of individual premises for passenger buildings, standards established in 1900 by the Engineering Council of the Ministry of Transportation were used for new buildings of the Second Catherine Railway. Those standards described areas for entrance halls; ticket offices; luggage rooms; passenger halls with restaurants; lavatories and restricted areas.

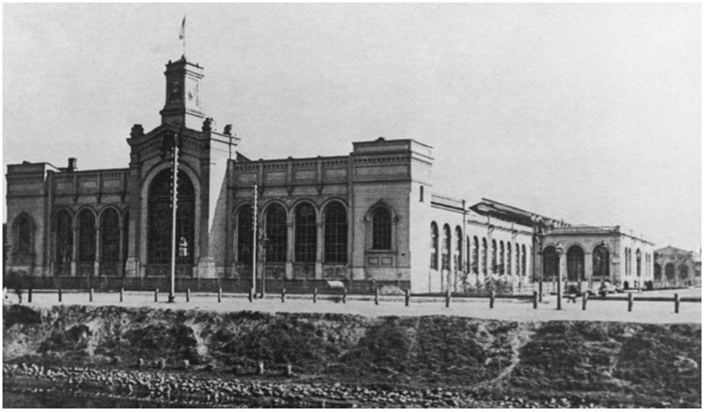

Fig. 8. Varshavsky (Warsaw) railway station, Saint Petersburg, Source: http://p3.citywalls.ru/photo_284-291215.jpg?mt=1500414786 [17]

Fig. 9. Bialystok railway station, Saint Petersburg – Warsaw Railway, Source: https://realt.onliner.by/2013/10/21/bialystok [18]

Fig. 10. Pskov railway station, Saint Petersburg – Warsaw Railway Source: https://dic.academic.ru/pictures/wiki/files/86/Vokzal_Pskov_okt2010.JPG [19]

It should be noted that, in construction of railroads, station buildings for every railroad were built in one style, and stylistic trends typical for various architectural styles of the 19th century were taken into account. Station buildings designed by architect-engineer P. Salmonovich for the Saint Petersburg – Warsaw Railway, which was finished in 1862, can serve as an example. Large arched windows of the main building at the terminal station—the Varshavsky (Warsaw) railway station in Saint Petersburg—vaguely resembled Renaissance arcades (Fig. 8). Arcade variations were also present at other stations of the railway: Gatchina, Pskov, Bialystok, Dyneburg (Figs. 9 and 10), etc.

4 Discussion

The factor of practical significance of the research is the permanent demand for any research that helps to clarify important facts of the Russian history of technology. The process of regulating the development of railway transport is associated with the factor of standardization of the constituent elements of the railway industry. One of these elements is the railway station buildings. Their standard defined the total area of the facility, the composition of the premises, their division into classes of passengers, etc. However, apart from observing the standards, the attractiveness of the architectural construction of the structure was no less important. The buildings of one railroad branch were made in the same style, as evidenced by albums of railway stations of different directions. Also, the architecture of the stations followed the general trends of stylistic trends.

5 Conclusions

Construction of railroads in Russia started simultaneously with appearance of train routes in other countries. Along with reforms of the governance structure, introduction of advanced technologies in construction of railroads, changes in equipment and rolling stock, new trends in developing the infrastructure for passenger handling gain significance. In the second half of the 19th – the early 20th centuries, a special typology of passenger stations formed: passenger stations were divided into classes and categories (depending on the size and significance of settlements, near of through which railway lines passed). As a result, by the early 20th century, a classification of railroad stations formed. Practical relevance of the study lies in continuous demand for any studies that could help clarifying important facts of the Russian history.

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Development of a Control System for the Transportation of Asphalt Mix with the Maintenance of the Required Temperature

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Abstract. The article discusses the effect of temperature on the quality of compaction of the asphalt concrete mixture, searches for possible ways to solve the problem of non-compliance with the temperature regime of the mixture during its transportation, contains, inter alia, an analysis of these solutions. In many respects, the quality of future coverage is laid down by the manufacturability of the styling process, strict compliance with the requirements of project documentation and the existing building codes and regulations (GOST, ISO, etc.). However, the technology itself of the process of making asphalt concrete pavements is constantly evolving - new complexes are emerging, changes are being introduced to existing structures of machines for building coatings. Various factors can affect the durability of the coating; among them, the low quality of compaction of the asphalt concrete mixture can be especially noted. In this article, we will experimentally determine the effect of temperature on the quality of compaction, as well as analyze possible solutions to the problem of compliance with the temperature regime of the asphalt-concrete mixture. Addition, reduction and combination of operations of the technological process, including, against the background of improving the quality and, as a result, the durability of the coating, reduce the complexity of the work performed, reduce the number of necessary personnel - all this has a positive effect on the economic component of construction, frees up additional funds.

Keywords: Asphalt concrete · Automation · Forecasting · Quality control · Heat exchange · Temperature of the mixture · Asphalt concrete mixing plant (ACMP)

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1 Introduction

Among the most important factors affecting the quality and degree of compaction is the temperature of the compacted asphalt concrete mixture. In order to determine the physical properties of the mixtures, cylindrical samples were made by mechanical compaction. In this case, the mixture is first uniformly distributed in the mold, after that the upper liner is inserted and the workpiece is placed on a special press for compaction. The pressure of the installation is smoothly adjusted to 40 MPa for 5–10 s, then after 3 min the load is removed and, using the squeeze device, the sample is removed, which is then required for testing.

Further, using special methods (according to GOST 12801-98), we make measurements and calculations, the results of which are the result of experiments.

Measurement of average density is performed by hydrostatic weighing of samples. First they are weighed at atmospheric pressure (1). After that, the compacted forms are immersed for 30 min in a vessel with water heated to (20 ± 2) °C, while the water layer covering the sample should not be thinner than 20 mm. It is important to prevent the formation of air bubbles on the samples. After that, weighing in water is performed, followed by repeated weighing in air. The average density of the sample from the mixture, g/cm, is calculated by the formula:

$$\rho_m = \frac{g\rho^B}{g_2 - g_1} \tag{1}$$

Where g is the mass of the sample suspended in air;
ρ^B - water density equal to 1 g/cm;
g_1 - mass of the sample suspended in water, g;
g_2 - mass of the sample, aged for 30 min in water and re-suspended in air.

In order to calculate the residual porosity, it is necessary to calculate the true density, g/cm, using the formula (2)

$$\rho = \frac{q_m + q_\sigma}{\frac{q_m}{\rho^m} + \frac{q_\sigma}{\rho^\sigma}} \tag{2}$$

Where q_m - mass fraction of mineral materials in the mixture, % (taken as 100%);
q_σ - mass fraction of the binder in the mixture, % (in excess of 100% of the mineral part);
ρ^m - the true density of the mineral part of the mixture, g/cm;
ρ^σ - the true density of the binder, g/cm.

The residual porosity V^o_{por}, is determined by calculation, on the basis of the previously established average and true densities with an accuracy of the first decimal, using the formula (3):

$$V_{por}^{o} = \left(1 - \frac{\rho_m}{\rho}\right)100 \tag{3}$$

Where ρ_m - the average density of the compacted mixture, g/cm;
ρ - the true density of the mixture, g/cm.

The compressive strength of the samples is determined on presses at a speed of movement of the press plate (3.0 ± 0.3) mm/min. The measurements were carried out separately for each sample of the mixture in a given temperature range. From the analysis of the graph, it follows that the absolute values of the optimum temperature for compaction are shifted to the region of large temperature values (Fig. 1). As can be seen from the graph, the temperature of the compacted asphalt concrete mixture significantly affects the strength of the coating. Similar dependences for density and residual porosity show a significant effect on them of the temperature of the compacted asphalt concrete mix (Fig. 1).

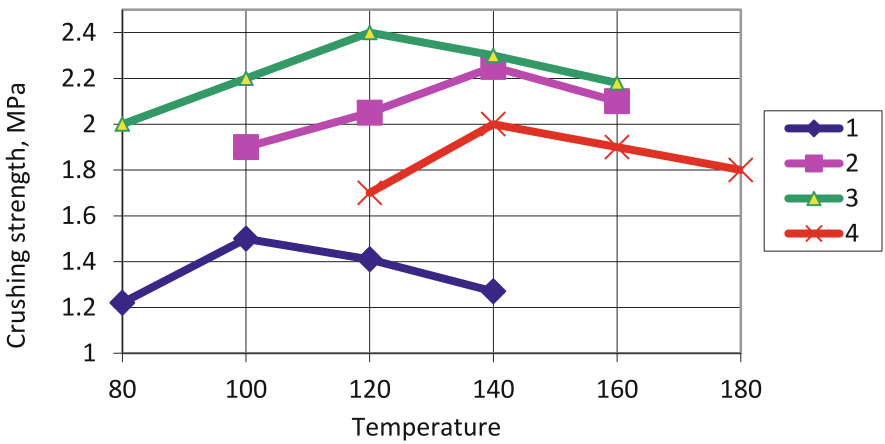

Fig. 1. Effect of compaction temperature on the compressive strength of asphalt concrete at 20 °C

A brief overview of the factors affecting the characteristics of the resulting coating. The currently existing systems for automating the production of asphalt concrete ensure stabilization of the temperature of the mixture at the outlet of the ACMP, and not at the place of its laying and compaction. Consider the factors that affect the temperature of the mixture during its packing and compaction.

- Technological factors. Depending on the type of asphalt mix, the standard defines the temperature of its laying and compaction. In addition, this group of factors can be attributed - The temperature of the mixture at the outlet of the ACMP. The loaded mass of the mixture. The uniformity of the mixture in temperature.
- Vehicle parameters (Ambient temperature. Wind speed and direction).
- Climatic factors (Ambient temperature. Wind speed and direction).

- Conditions for transporting the mixture (Distance from the ACMP to the object. Loading roads, the presence of “traffic jams” and the availability of alternative routes). Given the above factors, it was decided to conduct a study in the delivery of asphalt mix.

2 Methodology of Automated System Development

Transport operations are an integral part of the asphalt concrete paving process. However, as practice shows, this element is currently not taken into account in the process of managing the production of asphalt concrete. The process of transporting the mixture to the site affects:

- Mixture temperature
- Temperature segregation of the mixture

Based on this, a series of passive experiments were carried out, the essence of which was to photograph the asphalt-concrete mixture in the infrared range during the loading, transportation, idle stages, overloading and compaction [1]. The purpose of this study was to observe the pattern of changes in the temperature field of the asphalt concrete mixture being transported, on the basis of which, in consequence, conclusions can be drawn about the nature of the mixture cooling during transport, which allows us to estimate the segregation rate of the mixture and its suitability for laying.

The research program included:

- Fixing the temperature field when loading the asphalt mix into the dump truck at the ACMP;
- Fixation of the temperature field upon arrival of the dump truck to the construction site;
- Fixation of changes in the temperature field with a simple dump truck in the queue for unloading;
- Fixation of the temperature field of the mixture immersed in the paver bunker;
- Fixing the temperature field of the road surface after installation and compaction.

The studies were carried out in accordance with the methodology approved by the laboratory of SPETSDORSTROY LLC and in cooperation with its specialists, with their extensive assistance, great interest in the objectivity of the experiment in order to improve the quality of construction work and to achieve maximum durability, reliability and safety of the road under construction.

In short, the methodology was based on the following points:

1. Setting up the equipment, the definition of shooting points and focal length; fixing weather conditions;
2. Photographing on ACMP with fixing of time of a picture, from certain points;
3. Photographing upon arrival of the dump truck to the construction site, from the same points and angles as during the shooting at the ACMP;

4. Photographing the bodies of dump trucks, which are in the queue for unloading, with an interval of ten minutes, in order to obtain a picture of the change in the temperature field when idle;
5. Fixing the temperature field of the mixture overloaded into the asphalt paver's bunker in order to obtain a picture of the change in the temperature field of the mixture during an overload;
6. Fixing the temperature field of the compacted asphalt mixture twice with an interval of ten minutes in order to obtain a picture of temperature segregation.

3 The Research Result

At the first stage of the study, surveys were carried out in the infrared range of the bodies of seven dump trucks loaded with asphalt concrete mixture (time: 13:20; 43°18′18.6″N 45°49′32.5″ E). The picture of a small dispersion of the temperature field was characteristic [2].

At the second stage, the bodies of dump trucks caught in a traffic jam were taken 40 min later from leaving the plant, which was not originally planned (time 14:03; 42°5 7′47.1″N 45°43′08.7″ E). On the obtained images, a characteristic picture of the cooling of the mixture is observed; the most cooled zone is the crust of the bare part of the mixture massif.

Further, a series of shots of dump truck bodies was taken, arriving at the construction site with a fixed arrival time (time 14:40; 42°51′35.5″N 45°40′43.6″ E). The low temperature dispersion of the mixture surface is clearly visible, however, the crust of the mixture cooled to a critical value. In that case, if the crust is thin enough, then when the asphalt concrete mix is overloaded, the asphalt paver's bunker with its subsequent distribution to the tamping beam and the screed of the stacker, it mixes and collapses.

If lumps of the mixture are noticeable in the coating behind the smoothing plate, then it is necessary to adjust the temperature of the mixture: increase the temperature uniformity of the mixture, cover the mixture in the body with a canopy or insulate, reduce a simple dump truck before unloading the mixture (Fig. 2). It is necessary that the total duration of transport operations does not exceed the time the mixture is in a workable state, i.e. that the temperature of the mixture is at an acceptable level before the start of laying.

After that, they performed a series of infrared images of the mixture in the process of reloading into the paver bunker. At the boundaries of the fracture of the mixture, the internal mass of the mixture cooled to a lesser extent is visible, which confirms the judgment of the formation of a crust on the surface of the mixture.

The results of the shooting of the paved paving of asphalt concrete (time 15:00; 42°51′29.4″N 45°40′34.6″ E) show us a uniform temperature field of the compacted asphalt concrete mixture, however, we note that in one of the images there is an uncharacteristic heterogeneity, which, in consequence, can lead to poor seal quality (Fig. 3).

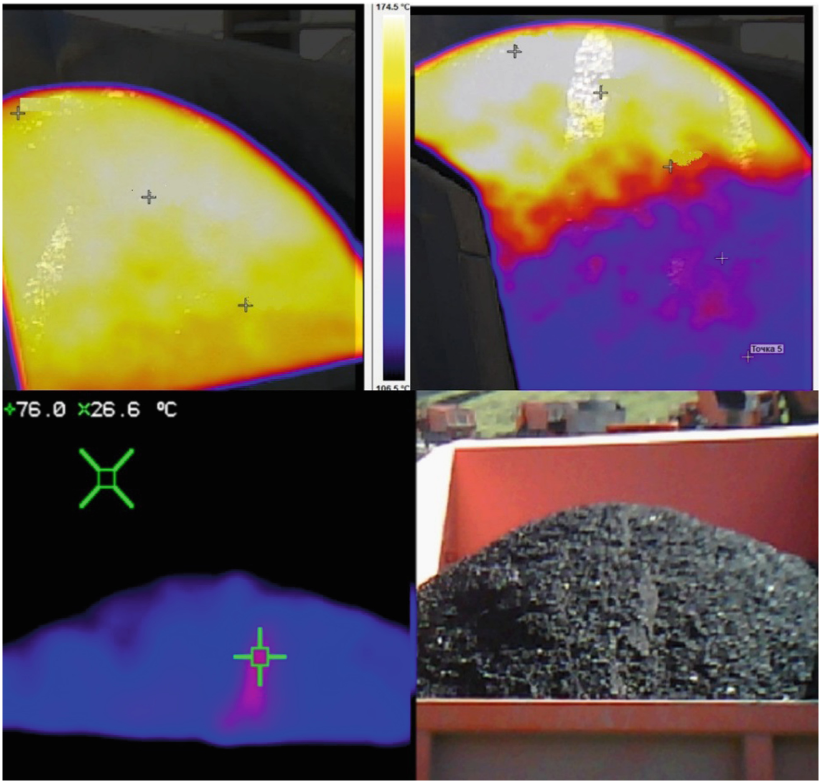

Fig. 2. Shooting in the IR range of dump bodies

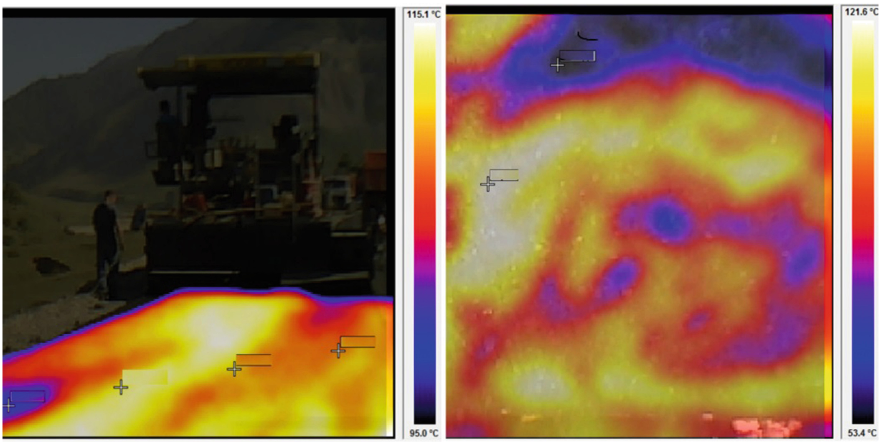

Fig. 3. Shooting in the IR range of dump bodies

Of greatest interest for the subject of research are images with significant temperature differences, the regions of which are characteristic spots [3, 4]. According to the results of the study, we can draw the following main conclusions:

- The temperature field of the mixture immediately after loading on the ACMP has a minimum dispersion;
- Failures at ACMP significantly affect the dispersion of the temperature field;
- The crust on the surface of the mixture is formed from the cooled section to the heated one;
- The formed crust has a small inhomogeneity of the temperature field;
- The mixture under the crust keeps the temperature critical;
- Stirring the mixture with augers reduces the degree of temperature segregation.

4 The Concept of the Transportation Process Control System

The most productive way is the search, creation and implementation of special technological processes and systems that allow to maintain the temperature regime of the asphalt-concrete mixture with a certain accuracy during its transportation. As possible solutions to these problems by technological means, consider the following:

- ACMP outlet temperature control. To ensure the required temperature of the mixture at the time of arrival of the dump truck to the construction site, it is possible to vary the temperature of the asphalt concrete at the time of its shipment to the ACMP, depending on the time of delivery. Among the advantages are the low cost and low resource consumption of this method, the main drawback is the low accuracy of control.
- Organizational management. It is possible to use a more rational approach to the choice of route and time of delivery, taking into account weather conditions and time of day, as well as the traffic situation. The advantage is that the arrival time is much more accurate. The disadvantage is the absence of a direct impact on the temperature of the mixture as such.
- Combined method. This method fully reveals the advantages of the methods presented above, which together represent the most optimal solution to the problem. But to further simplify its implementation, in my opinion, a special automated system is necessary. As a technological solution to the problem, we are considering the possibility of creating a method for transporting asphalt concrete mixture that takes into account temperature losses in various weather conditions, with reference to time and road conditions (Fig. 4) [5].

A special automated complex, which is a combination of software and hardware solutions for route planning and monitoring compliance with the norms of a given technological process, is presented schematically (Fig. 5) [6, 7].

The program automatically selects data:

- Machine v17
- Latitude 55.854984

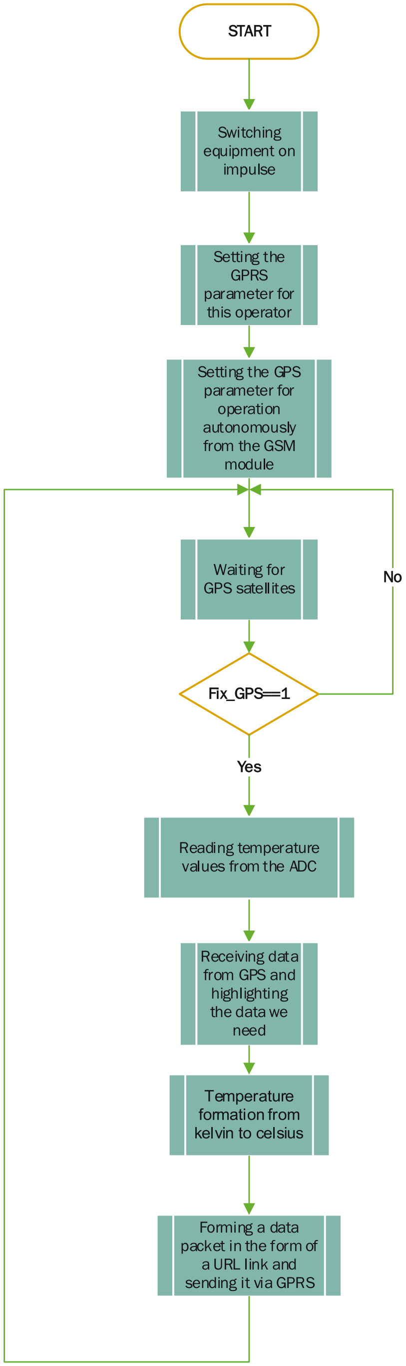

Fig. 4. The algorithm of the GPS tracker

Fig. 5. The temperature control system in the back of the truck and the coordinates of the machine

- Longitude 37.540678
- Speed 30
- Direction 0
- Temperature 139

The Arduino Mega 2560 platform was chosen for the hardware solution for implementing the device. The board provides everything needed for convenient work with the microcontroller: 54 digital inputs/outputs (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UART (hardware transceivers for implementing serial interfaces), a 16 MHz crystal oscillator, a USB connector, a power connector, an ICSP connector for in-circuit programming, and a reset button. To determine the location used GPS/GPRS/GSM module. It is designed for the Arduino platform, built on the basis of a chip from the company SIMCOM series 908 with integrated GPS navigation technology (Fig. 6) [8, 9].

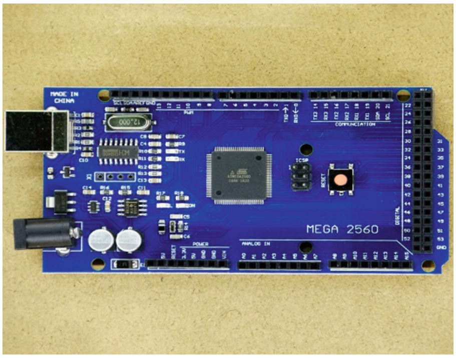

Fig. 6. Hardware solution for the temperature control system in the body of the truck and the coordinates of the machine.

On the basis of the temperature control system in the truck body and the coordinates of the machine, a WEB server with a DBMS was created. This platform allows us to work with MySQL databases and create tables inside them with the subsequent transformation in graphical form, on a geographic map and in a table form. The collected data will further allow us to analyze the values (cooling the mixture by volume, travel time, etc.) to build a mathematical model for cooling the asphalt concrete mix, taking into account various factors affecting its temperature (Fig. 7) [10].

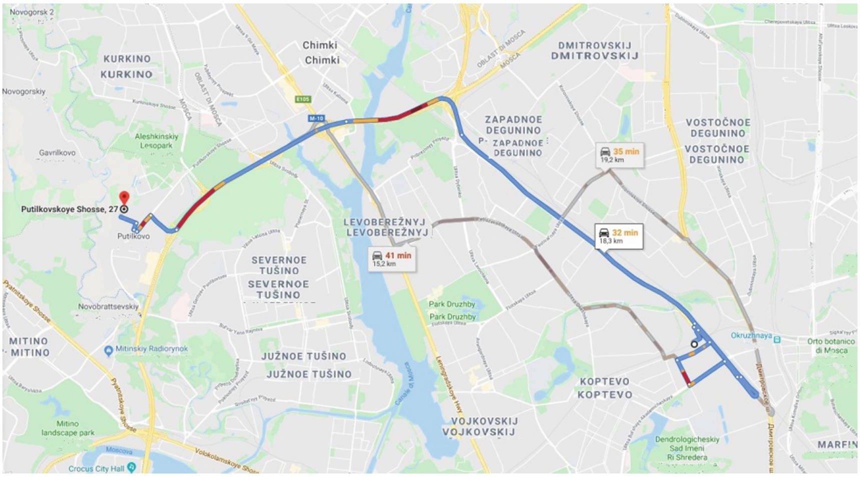

Fig. 7. Creation of databases with the subsequent transformation of object positioning information.

The introduction of a special automated complex has several advantages over technical solutions. Uniformity, the possibility of rapid implementation and development, ease of operation and the absence of the need for highly qualified service personnel do not require expensive modernization of a huge automobile fleet of road-building organizations, the possibility of application at any scale of construction and rehabilitation works, will provide a significant improvement in the quality of work. Modern automated tools allow you to create such a system in the shortest possible time, greatly simplifying the task of various satellite services, including those providing information on monitoring the situation on the roads. We consider it possible and expedient to start the development and implementation of such a complex as soon as possible.

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Fire Simulation of Bearing Structures for Natural Gas Module Plant

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Abstract. The standard (cellulose), external, slow heating and hydrocarbon modes are regulated in the majority of world standardization systems in the field of fire tests of structures. Hydrocarbon temperature mode is used to describe the combustion of flammable liquids and liquefied petroleum gas (LPG) at the enterprises of the oil refining and petrochemical industries. In this work, fire resistance degrees are calculated under standard and hydrocarbon fire modes for a model of prefabricated bearing structures of the liquefied natural gas (LNG) plant with simulated fire protection as mineral basalt wool. The calculations were performed in ANSYS software for critical temperatures of 300 °C, 500 °C and 700 °C. There are temperature-time diagrams for the standard and hydrocarbon fire mode. It is shown, that 20 mm of mineral wool are required to ensure R 120 for structure with a reduced thickness of 36.8 mm (pipe diameter 500 mm and thickness - 40 mm) and a critical temperature of 700 °C (for 500 °C - 40 mm of mineral wool respectively) for hydrocarbon fire.

Keywords: Buildings · Fire · Fire safety · Fire resistance · Computer simulation · Modeling · Hydrocarbon fire · Hydrocarbon · Liquefied natural gas

1 Introduction

Designers use different approaches to determine the required fire resistance degree of building structures and materials and focus on the calculated temperature combustion modes, which are based on averaged and idealized data on the temperatures of real fires. Standard (cellulose), external, slow heating and hydrocarbon modes are regulated in most global standardization systems for fire tests (Fig. 1) [1]. When designing plants and facilities for the petrochemical industry, facilities for production, processing, transportation of liquefied natural gas and stable gas condensate (LNG and SGK), it is necessary to take into account the possibility of spills and ignition of hydrocarbons of various nature.

Definite requirements for fire resistance of structures when they are exposed to the hydrocarbon fire are presented only for structures of drilling platforms and offshore installations. However there are differences in the regulatory documents, which should establish the appropriate test method.

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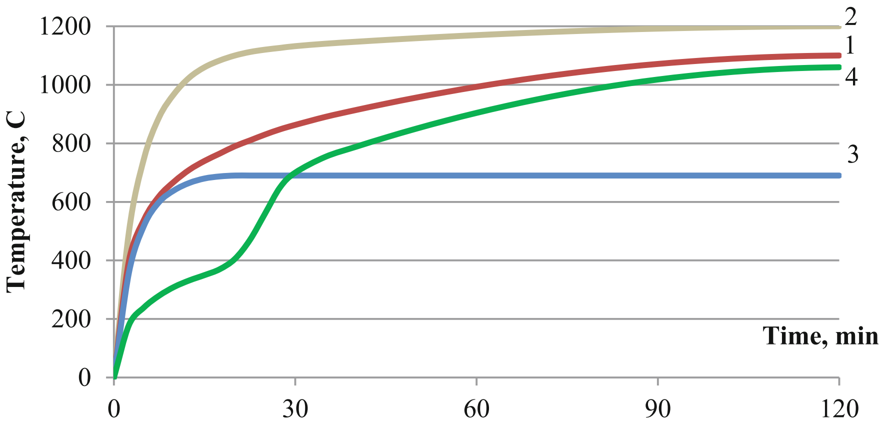

1 – standard time-temperature curve; 2 – hydrocarbon curve; 3 – external fire exposure curve; 4 – slow heating curve.

Fig. 1. Fire curves according to EN 1363-2:1999.

In Europe, the hydrocarbon fire mode is regulated by the normative document [1], in the USA [2], while the temperature in the furnace differs significantly in the first minutes of fire exposure (Fig. 2). Temperature-time curve by [2] increases more strongly. Such a difference in thermal conditions should be reflected in the calculations in the first 5 min of exposure to the structure.

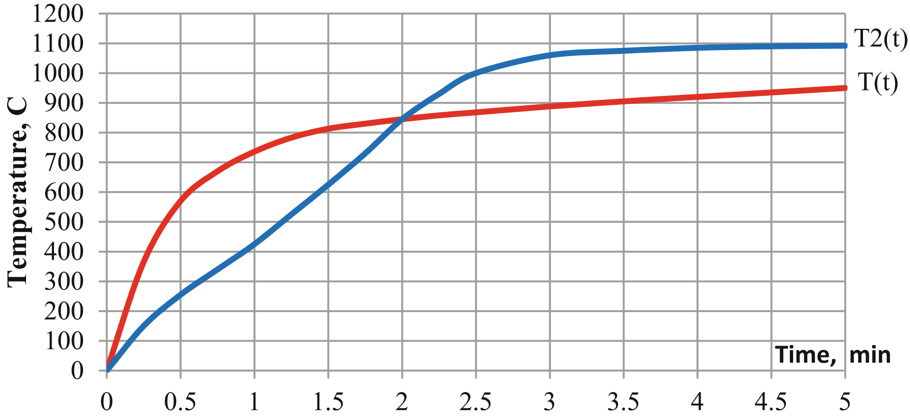

Fig. 2. Fire curves according to European standard [1]: $T(t) = 1080 \cdot (1 - 0.325e^{(-0,167t)} - 0.675e^{(-2,5t)}) + 20$ and American standard [2]: $T_2(t) = 1093.33 \cdot (1 - 0.49e^{(-1,00t)} - 0.47e^{(-0,09t\wedge 3,60)})$ (regression selection in MathCAD).

In Europe and in the USA, a large number of studies have been conducted on the behavior of materials and structures under the conditions of the hydrocarbon fire mode, and a diverse regulatory system has been developed based on this data [3–9]. For example, according to document [10], which regulates the use of hydrocarbon fire conditions according to UL 1709 [2], fire protection of bearing structures in the fire zone should be provided for a height of at least 6 m (but not less than the first tier level) up to fire resistance not less than 90 min. If the rack contains pipelines with a diameter of more than 150 mm, fire protection should be performed up to the height of the level nearest to 9 m [7].

In Russia, the fire resistance degree of technological racks supports containing pipelines for the transportation of combustible petroleum products must be at least R 60. The height of the first tier above the ground is not specified [11].

According to [12], supporting structures for separately installed at ground level devices and cistern containing flammable and combustible liquids should be made of non-combustible materials with a fire resistance not lower than R 45. Supports and racks of pipelines of combustible gases and liquefied natural gas, as well as systems of fire protection should be made of non-combustible materials with a fire resistance not lower than R 45. The used materials should be designed for the effects of cryogenic products.

A new set of rules “Refueling facilities for flammable and combustible liquids and liquefied petroleum gases on refineries and petrochemical plants. Fire safety requirements” is being discussed in Russia. According to this document, load-bearing structures of racks should be made of non-combustible materials and have a fire resistance degree at least: for columns – R 120, beams – R 60. API 2218 [10] is taken as a basis, and the fire mode is not specified, respectively, by default it should be taken as “standard”. However, it is clear that it is necessary to calculate the “real fire”, based on various scenarios of fire according to the method of calculating the “equivalent fire mode”, or to accept it in idealized form as the “hydrocarbon mode” [13].

Currently, designers use the concept of modular construction for offshore complexes of the production, storage and shipment of liquefied natural gas and stable gas condensate, as well as equipment repair and maintenance complexes that will be used to develop offshore oil and gas condensate fields.

The main parts of the LNG and SGC shipment facility located on the platform held on the seabed due to its own weight and links of the lower part of the marine gravitational platform with the ground are loading sites, mooring lines and fenders. Elements are delivered to the installation site in the form of large blocks (modules).

Figure 3 is a photo of the modules of the Yamal plant – the one of the most productive liquefied natural gas plant in Russia.

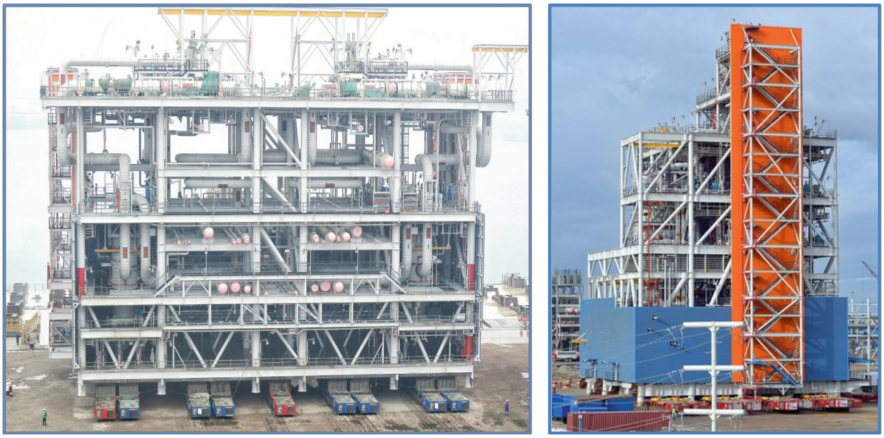

Fig. 3. Modules for the construction of the LNG plant. Photo by PJSC NOVATEK

In Fig. 4 it is shown multi-storey modules for the production and transportation of liquefied gas, the analogues of which are represented on Yamal and Sakhalin, in the Leningrad Region (Vysotsk) and other structures in world practice.

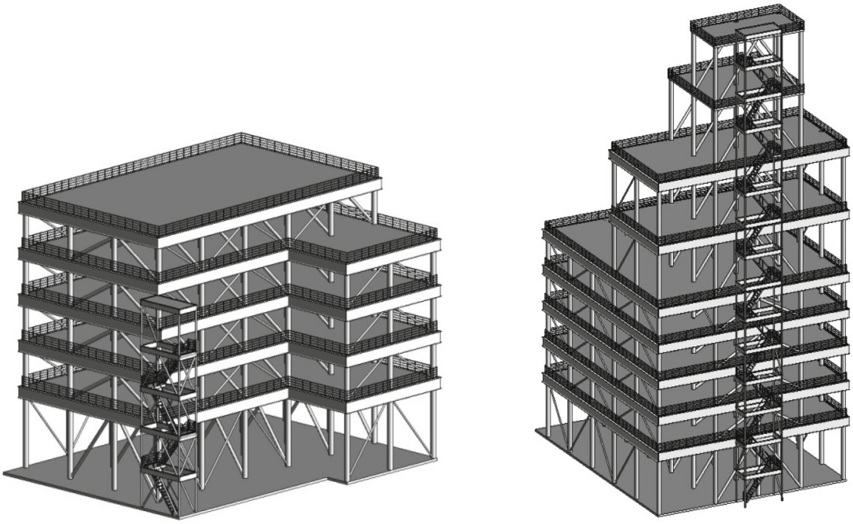

Fig. 4. Models of multi-storey modules-racks of plants for the production and processing of LNG and SGC.

In general, it is necessary to determine the estimated duration of possible fires, their characteristics (linear dimensions, intensity of thermal radiation), as well as the estimated time of impact of a real fire on the bearing structures of modules, buildings, structures, outdoor installations for all considered fire scenarios. Further, it is necessary to determine the ability of each building structure to withstand the effects of a real fire during the entire estimated time of fire that means to determine the required fire resistance degree of constructions that will ensure the stability and stability of geometrical shape of all structures for the estimated time of fire. Based on the duration of the fire, the equivalent duration of the fire is determined (the duration of a standard fire that has the same effect on the structure as a real fire). The equivalent duration of a fire depends on the type of fire load, the geometric characteristics of the units and the placement of the fire load. For outdoor installations and structures such an approach is set out in the British document PD 7974-7: 2003 "Application of fire safety engineering principles to the design of buildings. Probabilistic risk assessment" [14] and API 2218 "Fireproofing Practices in Petroleum and Petrochemical Processing Plants" [10].

Thus, the general requirement is that the fire resistance of the bearing structures of platforms and shelves that may fall into the fire impact zone must be at least R 120.

A support tube (Fig. 5) with a reduced thickness of 36.8 mm was chosen as the bearing structure of the module. It is expected that the own fire resistance limit will be quite high. Simulation of the fire resistance limits of the bearing structures allows one to predict with sufficient accuracy the required material consumption, time before the critical temperatures, etc. [15–20].

This paper presents the calculation results for the load-bearing structures of LNG modules in the standard and hydrocarbon fire mode with simulated fire protection in the form of rock wool as the most common and studied type of fire protection. Thermophysical characteristics are taken according to the data on the websites of manufacturers of this material (for example, Rockwool).

2 Methods

Fire modes are represented by the following dependencies [1]:

Hydrocarbon temperature mode:

$$T = 1080 \cdot \left(1 - 0.325e^{(-0.167t)} - 0.675e^{(-2.5t)}\right) + 20 \tag{1}$$

Standard temperature mode:

$$T - T_0 = 345 \cdot \lg(8t + 1) \tag{2}$$

where T – the temperature in the furnace, corresponding to the time t, °C;

T_0 – the temperature in the furnace prior to thermal influence (ambient temperature), °C;
t – time, calculated from the beginning of the test, min.

The calculations are performed in a complex of finite element modeling ANSYS (Workbench v.19 platform) in the module Transient Thermal, which is intended for the analysis of transient thermal field solutions based on a transient thermal conductivity equation [21, 22].

Vertical steel tube is adopted as the support member (column). Tube diameter D = 500 mm, wall thickness t = 40 mm, steel density ρ = 7850 kg/m3.

The thermophysical properties depending on the temperature of the fire exposure were set in accordance with [13, 19]:

- thermal conductivity: λ_{st} (T) = 78 – 0.048 • (T+273) (W/m • °C);
- specific heat: c_{st} (T) = 310 + 0.48 • (T+273) (J/kg • °C);

The tube is rigid fixed from both sides and it is axially-loaded. The initial temperature of the tube and ambient air: t = 20 °C; the reduced thickness of the metal is 36.8 mm. The reduced metal thickness for the flame-retardant treatment - the ratio of the cross sectional area of metal to the heated perimeter. 300 °C, 500 °C and 700 °C are taken as critical temperatures, based on the concept that:

(a) the construction designed and "overloaded" – 300 °C;
(b) construction is designed "to the limit", and the coefficients γ_t and γ_e will differ from 1.0 by generalized safety factor (average 20%), which includes the reliability coefficient of the material and the load factor of reliability. As a result, the coefficients γ_t and γ_e (at least one of them) should not exceed 0.8, which makes it possible to accept the critical temperature T_{cr} = 500 °C according to [13, 23];
(c) almost unloaded column, with a critical temperature of 700 °C.

For example, a critical temperature of 300 is obtained with a column length of 7 m and a load of 1550 tons [13, 23]:

The coefficients γ_t and γ_e for centrally compressed elements:

$$\gamma_t = N_n / \left(F \cdot R_{yn}\right) \tag{3}$$

$$\gamma_e = \left(N_n \cdot l_{ef}^2\right) / \left(\pi^2 \cdot E_n \cdot I_{min}\right) \tag{4}$$

where N_n – force from the regulatory load, kg;
F – cross-sectional area of the column, cm^2;
R_{yn} – initial normative metal resistance, kg/cm^2;
E_n – initial elastic modulus of the metal, kg/cm^2, for steel – E_n = 2100000 kg/cm^2;
l_{ef} – effective column length, cm^2;
I_{min} – the least inertia moment of the rod section, cm^4.
Effective rod length l_{ef}, if both sides are rigid fixed, will be taken 0.5 l (Table 1).

$$\gamma_t = 1550000 / (578.1 \cdot 3500) = 0.77.$$
$$\gamma_e = \left(1550000 \cdot (0.5 \cdot 700)^2\right) / \left(\pi^2 \cdot 2100000 \cdot 154051.1\right) = 0.06$$
$$T_{cr} \approx 300\,°C.$$

Table 1. Dependence of critical temperature on the coefficients γ_t, γ_e [23]

T, °C	γ_t	γ_e
100	0,99	0,96
200	0,85	0,94
300	0,77	0,90
400	0,70	0,86
500	0,58	0,80
600	0,34	0,72
700	0,11	0,59

External insulation is used as fire protection (rock wool with the thickness of 20 mm; density $\rho_w = 100\ kg/m^3$).

The thermophysical properties depending on the temperature of the fire exposure were set in accordance with [23]:

- thermal conductivity: $\lambda_w(T) = -0.107 + 0.00058 \cdot T\,(W/m \cdot K)$;
- specific heat: $c_w(T) = 582 + 0.63 \cdot T\,(J/kg \cdot K)$.

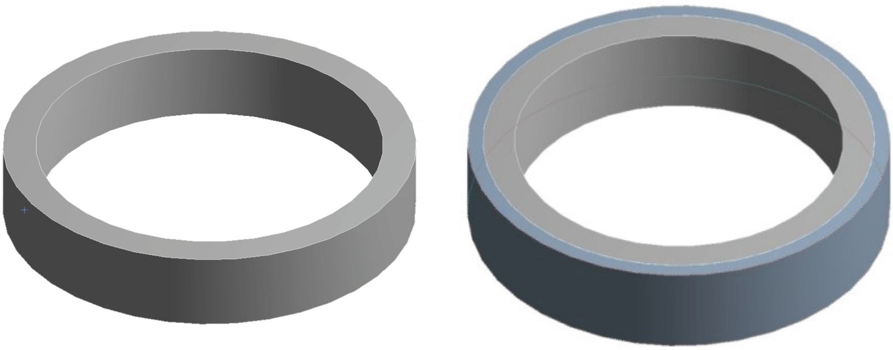

Fig. 5. Calculated tube model: (a) 500 × 40 mm without fire protection; (b) 500 × 40 mm with fire protection 20 mm.

The initial temperature of the tube and the ambient air T_0 is assumed to be 20 °C. The coefficient of heat transfer α (T) from the heating environment with temperature T to the surface of the structure with temperature T_0 was set in accordance with the formula given in [23]:

$$\alpha(T) = 29 + 5.77 \cdot S_{red} \cdot \left(((T + 273)/100)^4 - ((T_0 + 273)/100)^4\right) / (T - T_0)\,(W/(m \cdot^\circ C)) \quad (5)$$

$S_{red} = 1/(1/s + 1/s_0 - 1) = 0.79$ – reduced emissivity factor of the system "heating environment – surface design" (s = 0.85 – emissivity factor of fire chamber of the furnace, s_0 = 0.92 – emissivity factor of heated surface (rock wool)).

Further, the calculation was made of the amount of rock wool required to reach the fire resistance degree R120 for the column at various fire conditions and at critical temperatures of 300 °C, 500 °C and 700 °C.

3 Results

As a result of the calculation for the bearing structure of the module (column) with a wall thickness of 40 mm without fire protection and with fire protection 20 mm of rock wool the following dependences are obtained (Figs. 8, 9, 10 and 11). In ANSYS, for each color (for example, red) in the rendered images, its own temperature range is indicated inside the circle with the temperature distribution (Figs. 6 and 7).

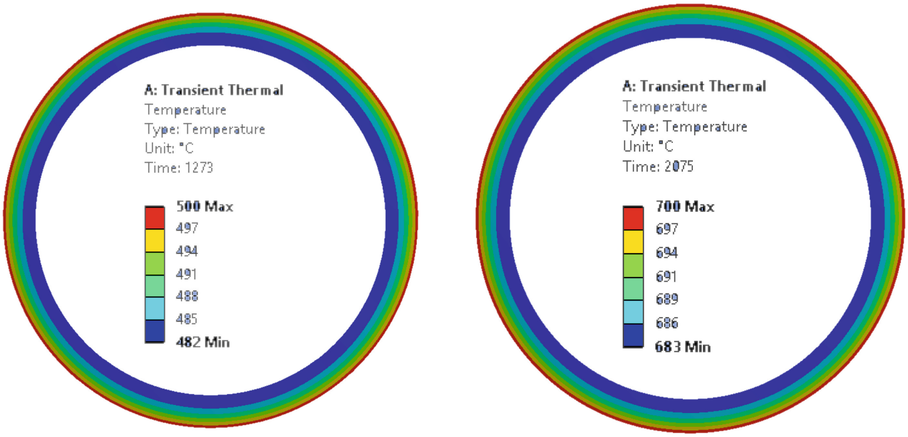

Fig. 6. Heating of the tube 500 × 40 mm without insulation (a) up to 500 °C and (b) up to 700 °C under hydrocarbon fire.

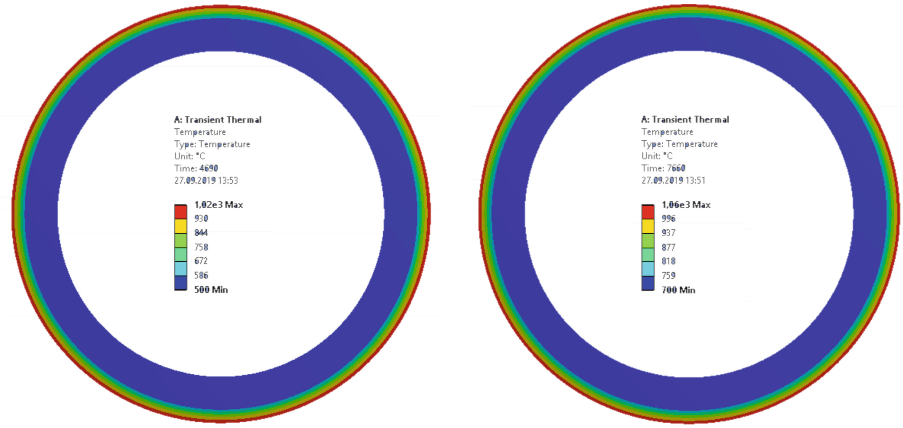

Fig. 7. Heating of the tube 500 × 40 mm with insulation 20 mm (a) up to 500 °C and (b) up to 700 °C under hydrocarbon fire.

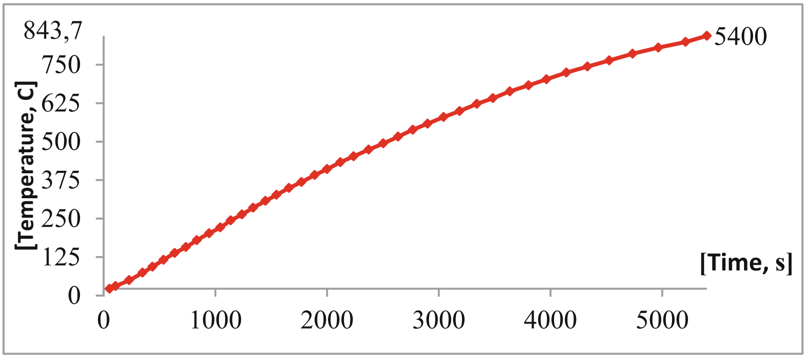

Fig. 8. Temperature-time dependence graphs of the 500 × 40 mm tube without fire protection under standard fire.

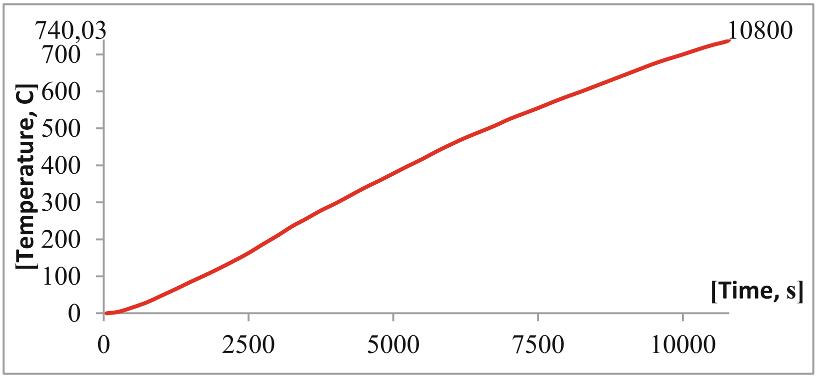

Fig. 9. Temperature-time dependence graphs of the 500 × 40 mm tube with fire protection of 20 mm under standard fire.

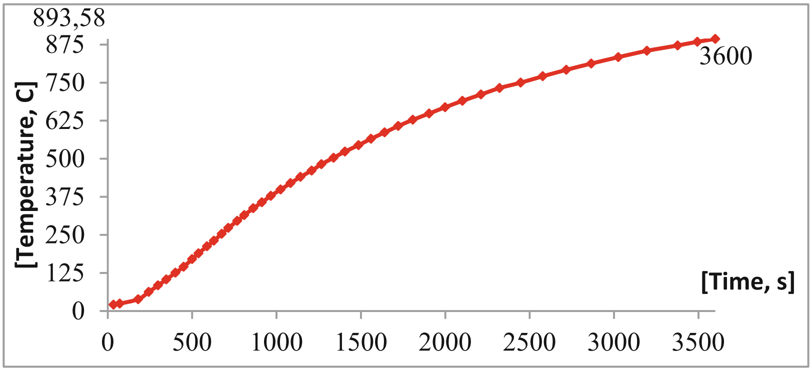

Fig. 10. Temperature-time dependence graphs of the 500 × 40 mm tube without fire protection under hydrocarbon fire.

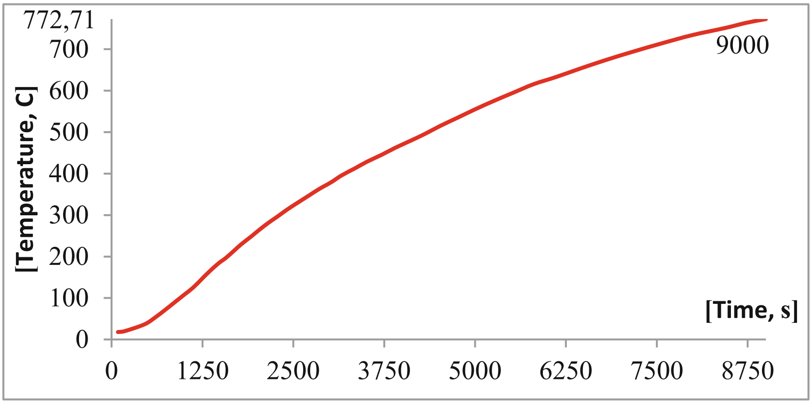

Fig. 11. Temperature-time dependence graphs of the 500 × 40 mm tube with fire protection of 20 mm under hydrocarbon fire.

Table 2. Time to reach the critical temperature of the 500 × 40 mm tube at standard fire mode and at hydrocarbon fire mode, min.

	Tcr, °C	Hydrocarbon fire mode	Standard fire mode
Without fire protection	300	13	23
	500	22	41
	700	35	64
With fire protection of 20 mm	300	43	64
	500	78	107
	700	127	165

Then, the calculation of the consumption of fire protection (rock wool) was carried out to achieve the required fire resistance degree of 120 min (Table 3).

Table 3. Time to reach the critical temperature of the 500 × 40 mm tube at standard fire mode and at hydrocarbon fire mode with the fire protection of 20 mm and 40 mm, min.

	Tcr, °C	Hydrocarbon fire mode	Standard fire mode
With fire protection of 20 mm	300	43	64
	500	78	107
	700	127	165
With fire protection of 40 mm	300	67	92
	500	124	158
	700	>180	>180

4 Conclusions

It is necessary to differentiate the objects of protection according to the possible fire conditions, substantiate by calculation and confirm with experimental data the limits of fire resistance of structures. Simulation of fire resistance of structures allows predicting their behavior under different fire conditions and selecting the required amount of fire protection.

In this paper, the fire resistance of the proposed load-bearing structure of the module for LNG production under various fire conditions was calculated in the ANSYS software. It is shown that the bearing structure with a reduced thickness of 36.8 mm has estimated fire resistance with a standard fire of 64 min, 107 min, 165 min, and with a hydrocarbon fire 43 min, 78 min, 127 min (for a critical temperature 300 °C, 500 °C and 700 °C respectively). Thus, fire protection is necessary to ensure the required fire resistance even for such massive steel structure.

For more accurate results of the simulating, it is necessary to specify the thermophysical characteristics of steel and fire protection equipment specifically in the hydrocarbon fire mode.

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Choosing Methods for Manufacture of Reinforced Concrete Frames Based on Solution of Optimisation Problems

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Abstract. A methodology has been suggested for assessing the economic efficiency of making decisions on the selection of a technology for constructing plane reinforced concrete frames manufactured without pre-stressing reinforcement. The approach is based on execution of the optimum synthesis of a structure for each of the process options in question. The optimisation is carried out using a metaheuristic scheme of evolutionary modelling. A task has been set to minimise the planned manufacturing cost of a reinforced-concrete frame while taking into consideration the peculiarities of the processes for cast-in-situ, prefabricated, and composite structures. The regulatory limitations in terms of strength, stiffness, and crack resistance of the framework are taken into consideration. Concrete and reinforcing steel classes, cross-section values of columns and cross bars, as well as the amount and diameters of reinforcement bars vary on discrete sets. The search is performed using a genetic algorithm stipulating functioning of the main and elite populations. In the main population, individuals are subjected to single-point crossover, mixed mutation execution procedures, and selection based on the criterion of minimum cost. The elite population is used for storage of efficient genetic material and replacement of inoperative individuals of the main population. When calculating the stress strain behaviour of the structure variants, the factors taken into consideration are the physically non-linear behaviour of concrete and reinforcement, and the possibility of formation of transverse cracks in concrete. The operability of the suggested methodology is illustrated via the example of selecting a method of constructing a double-span reinforced concrete frame.

Keywords: Reinforced concrete frames · Manufacturing process · Cost · Optimisation · Evolutionary modelling

1 Introduction

Reinforced concrete frames are widely used as cast-in-situ, prefabricated, or composite structures. To select a type of technology for constructing such systems, it is necessary to compare the efficiency of engineering and economical decisions to be made as applied to particular application facilities and specified construction conditions. One of the approaches in this issue is comparing alternative designs obtained by means of

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optimisation, based on various manufacturing processes. To that end, it is necessary to elaborate the problem statement and formulate an algorithm of optimum designing, while taking into account the peculiarities of different methods of construction of the facilities in question.

An up-to-date productive approach to optimisation of the system to be deformed is metaheuristic algorithms [1–16] and, in particular, evolutionary modelling [14–16]. Optimisation of reinforced concrete frames using metaheuristic schemes was considered in some research works [16–20, etc.]. Govindaraj et al. [16] suggested a methodology for evolutionary optimisation of reinforced concrete frames. The cost of concrete, formwork and reinforcing steel was an objective function. Limitations on strength, serviceability, ductility, durability were taken into account. Kaveh et al. [17] used a heuristic big bang-big crunch and a heuristic particle swarm ant colony optimization to discrete optimisation of such structures. Paya et al. [18] studied the issues of optimal design of reinforced concrete building frames using a multiobjective simulated annealing. The presented methodology was applied to a frame with two bays and four floors. Serpik et al. [19] developed an evolutionary procedure for the optimum designing of reinforced concrete beams and frames based on the condition of minimising the planned manufacturing cost of design. Mixed approaches to mutation and selection were used. They ensured an increase of the efficient design solution search convergence rate. Ulusoy et al. [20] solved the problem of optimising reinforced concrete multi-story multi-span frame structures using a metaheuristic method employing harmony search algorithm.

This paper suggests a methodology for optimising reinforced concrete frames manufactured without reinforcing steel pre-stressing, while ensuring the possibility of taking into account the peculiarities of erecting cast-in-situ, prefabricated, or composite structures. The optimisation algorithm is based on the development of computational procedures described in [15, 19, 21, 22] in the issues of reflecting the technology of construction and forming an evolutionary scheme. The limitation checking is carried out by calculating the strain stress behaviour of alternative designs in a physically non-linear statement via the finite-element method.

2 Problem Statement and Optimum Search Algorithm

Taking into consideration the possibility of using different manufacturing processes, let us generally set a problem of minimising the planned manufacturing cost C_b as

$$C_b = C_m + C_s + C_{ar} + C_{ae} + C_{pl} + C_{pm} + C_{ex} + C_{ht} \rightarrow \min \tag{1}$$

where C_m is the cost of concrete mixture, C_s is the cost of all steel grades consumed for manufacture of reinforcement bars and embedded parts, C_{ar} is add-on cost on the manufacture of reinforcement bars (they include direct labour costs and general expenses of production), C_{ae} is add-on cost of the manufacture of embedded parts, C_{pl} is the cost of positioning the reinforcing elements in the casting box, C_{pm} is the cost of product casting, C_{ex} is the cost on operation and maintenance of the casting box, and

C_{ht} is the cost of heat treatment of products taken into account during manufacture of the structural elements at the factory.

The following parameters vary: K_b, K_S are concrete and reinforcing steel grades, b is the width of the cross section of columns and cross bars (Fig. 1), h_j is the height of the cross section of the j^{th} section or the j^{th} group of sections of the truss bars $(j = 1..j_o)$, where j_o is the number of independently varying heights of cross sections, (d_i, n_i) is the pair of numbers determining the diameter and number of reinforcement bars for i^{th} independently varying layer or group of layers of reinforcement bars $(i = 1...i_o)$, where i_o is the number of independently varying pairs.

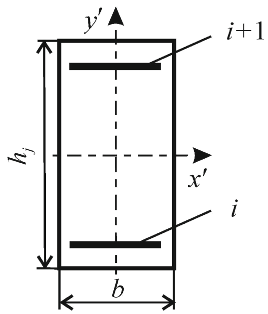

Fig. 1. Cross section of a column or cross bar: i, i + 1 are the numbers of the reinforcement layers.

The following basic limitations on the structure load-bearing capacity are taken into account in accordance with SP 16.13330.2017 SNiP II-23-81*:

(1) Strength requirements:

$$\forall \varepsilon_b < 0 : p_b = \frac{|\varepsilon_b|}{\psi_b \tilde{\varepsilon}_b} - 1 \leq 0, \ \forall \varepsilon_S > 0 : \ p_S = \frac{\varepsilon_S}{\psi_S \tilde{\varepsilon}_S} - 1 \leq 0, \ \forall \varepsilon_S < 0 : \\ p_{Sc} = \frac{|\varepsilon_S|}{|\tilde{\varepsilon}_{Sc}|} - 1 \leq 0 \tag{2}$$

where $\varepsilon_b, \varepsilon_S$ are axial strains in concrete and reinforcing steel obtained by means of finite-element analysis, p_b, p_S, p_{Sc} are parameters used for characteristic of fulfilment or non-fulfilment of strength conditions, ψ_b, ψ_S are coefficients compensating the non-uniformity of distribution of normal stresses in compressed concrete and tension reinforcing steel for cross sections located on sections with transverse cracks in tensile concrete, and $\tilde{\varepsilon}_b$, $\tilde{\varepsilon}_S$, $\tilde{\varepsilon}_{Sc}$ are strains corresponding to design compressive strength of concrete and design tensile and compressive strength of reinforcing steel.

(2) Stiffness requirement:

$$p_f = |f|/f_{ult} - 1 \leq 0 \tag{3}$$

where p_f is the parameter used for assessing the fulfilment of the frame stiffness condition, f is the displacement of a reinforced concrete element under the influence of an external load, and f_{ult} is the admissible limit value $|f|$.

(3) Transverse crack width requirement:

$$p_{acrc} = a_{crc} \big/ a_{crc,\,ult} - 1 \leq 0 \tag{4}$$

where p_{acrc} is the parameter characterising fulfilment of the crack resistance condition, a_{crc} is the transverse concrete crack width, $a_{crc,ult}$ is the admissible limit width of such cracks depending on load duration.

(4) Requirement on the absence of oblique cracks.

(5) Local strength requirement.

Let us express the weight M_{tr} of transverse reinforcement via the weight M_{lon} of longitudinal principal reinforcement using coefficient θ_{tr} ($M_{tr} = \theta_{tr} M_{lon}$), selected while taking into account the prevention of oblique cracking and assurance of local strength. We determine that only limitations 1 to 3 are active in the evolutionary scheme. We only take into account limitations 4 and 5 upon completion of evolutionary search by correcting parameter θ_{tr} with subsequent iteration of the evolutionary algorithm implementation if it is necessary to significantly change the transverse reinforcement.

Accordingly [15, 19], the groups taken into account were the main group of Π_A individuals (alternative designs) which had fixed number N of objects, an auxiliary group of Π_B improved individuals, the size of which depended on the iteration results, but did not exceed N. A single-point crossover was implemented. During mutation execution, a random change of the parameter values is stipulated with alteration of selection from the closest-number elements in a set of admissible values and from the elements which are randomly placed in such a set. The limitations are checked for individuals of group Π_A based on the iterative process of the problem solution. Group Π_A is divided into subgroups of Π_1 and Π_2 objects. If at least one of limitations 1 to 3 is not fulfilled for any individual of subgroup Π_1, then it is replaced with a individual from group Π_B which is not used in group Π_A, or a newly, randomly formed variant of the framework. If the limitations are not fulfilled for an object from group Π_2, then a penalty is introduced by multiplying the objective function value by coefficient k_p. For the problem in question it was assumed

$$\begin{aligned} k_p = & \left(1 + \alpha_{bu}\,\chi\left(p_{bu\max}\right)p_{bu\max}\right)\left(1 + \alpha_S\,\chi\left(p_{S\max}\right)p_{S\max}\right)\left(1 + \alpha_{Sc}\,\chi\left(p_{Sc\max}\right)p_{Sc\max}\right) \\ & \times \left(1 + \alpha_f\,\chi\left(p_{f\max}\right)p_{f\max}\right)\left(1 + \alpha_{acrc}\,\chi\left(p_{acrc\max}\right)p_{acrc\max}\right), \end{aligned} \tag{5}$$

where α_{bu}, α_S, α_{Sc}, α_f, α_{acrc} are preset positive numbers, $\chi(x)$ is the Heaviside function of some argument x ($\chi(x) = 0$, if $x < 0$, and $\chi(x) = 1$, if $x \geq 0$), and $p_{bu\max}$, $p_{S\max}$, $p_{Sc\max}$, $p_{f\max}$, $p_{acrc\max}$ are the maximum values of magnitudes p_{bu}, p_S, p_{Sc}, p_f, p_{acrc} for the alternative design to be checked.

3 Reinforced Concrete Frame Strain Calculation Algorithm

A physically non-linear problem is solved using the finite element method by successive approximations with consideration of the following linear algebraic equation system in each iteration $k \geq 1$:

$$\left(\left[K\left(E_{bi}^{(k-1)}, E_{Si}^{(k-1)}\right)\right]^{(k)}\right) \{\delta\}^{(k)} = \{R\} \tag{6}$$

where $[K]^{(k)}$ is the finite-element model stiffness matrix for iteration k, obtained with due allowance for secant moduli $E_{bi}^{(k-1)}$, $E_{Si}^{(k-1)}$, which are formed for each i^{th} finite element of concrete and reinforcement layers respectively based on the results of iteration $k - 1$, $\{\delta\}^{(k)}$ is a nodal displacement vector obtained in iteration k, and $\{R\}$ is a vector of external load reduced to nodes.

Each reinforced concrete bar is divided by n concrete layers and m reinforcement layers (Fig. 2a). It is assumed that for the layer stack, the flat cross-section hypothesis is true. In accordance with this hypothesis, for a single finite element (Fig. 2b) it is written as

$$u^c = u_{12} - \theta_z e_y \tag{7}$$

where u^c, u_{12} is the longitudinal displacements of points on the finite element axis and segment U_1U_2, $\theta_z = dv/dx$ is the cross-section rotation angle for a layer stack in relation to axis Oz, v is the projection of the displacement vector on axis Oy, and e_y is the projection of eccentricity vector $\bar{e}$ of finite elements to nodes on axis Oy.

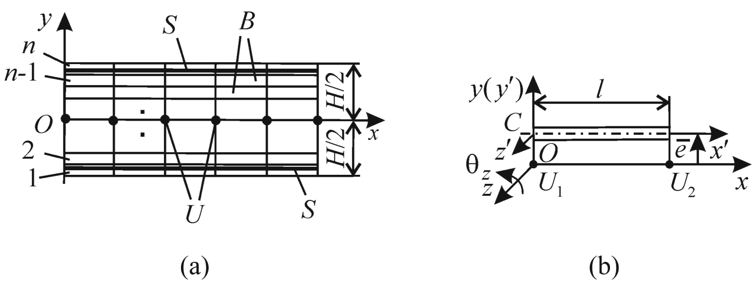

Fig. 2. Finite-element model structure at $m = 2$ (a) and finite element (b): B is concrete layers, S is reinforcement layers, U, U_1, U_2 are nodal points.

Vector of the generalised strains of the finite element is represented as follows:

$$\{\varepsilon_e\} = \left\{ \begin{array}{c} \varepsilon_x^c \\ \chi \end{array} \right\} = \left\{ \begin{array}{c} \dfrac{du^c}{dx} \\ \dfrac{d^2v}{dx^2} \end{array} \right\} = \left\{ \begin{array}{c} \frac{du_{12}}{dx} - e_y \frac{d^2v}{dx^2} \\ \frac{d^2v}{dx^2} \end{array} \right\} \tag{8}$$

where ε_x^c is the relative longitudinal strain on the finite element axis, and χ is the curvature of the bent bar axis.

The vector of generalised nodal displacements of the finite element is given by

$$\{\delta_e\} = \left\{ u_{1-2}^{(1)} \quad v^{(1)} \quad \theta_z^{(1)} \quad u_{1-2}^{(2)} \quad v^{(2)} \quad \theta_z^{(2)} \right\}^T \tag{9}$$

where $u_{1-2}^{(i)}, v^{(i)}, \theta_z^{(i)}$ are the generalised displacements for the node U_i (i = 1, 2).

It is assumed that the displacement u_{12} changes along segment U_1U_2 in linear fashion, and the displacement v is approximated using cubic law. Based on functional connections (7)–(9) a finite-element strain matrix has been obtained:

$$[B_e] = \begin{bmatrix} -\frac{1}{l} & e_y\left(\frac{6}{l^2} - \frac{12x}{l^3}\right) & e_y\left(\frac{4}{l} - \frac{6x}{l^2}\right) & \frac{1}{l} & e_y\left(-\frac{6}{l^2} + \frac{12x}{l^3}\right) & e_y\left(\frac{2}{l} - \frac{6x}{l^2}\right) \\ 0 & -\frac{6}{l^2} + \frac{12x}{l^3} & -\frac{4}{l} + \frac{6x}{l^2} & 0 & \frac{6}{l^2} - \frac{12x}{l^3} & -\frac{2}{l} + \frac{6x}{l^2} \end{bmatrix} \tag{10}$$

where l is the length of segment U_1U_2.

The generalised strain vector $\{\sigma_e\}$ and elasticity matrix $[D_e]$ of the finite element can be set down as

$$\{\sigma_e\} = \left\{ \begin{array}{c} N_e \\ M_{ez'} \end{array} \right\},\ [D_e] = \begin{bmatrix} EA & 0 \\ 0 & EI_{z'} \end{bmatrix}, \tag{11}$$

where N_e is the longitudinal force, $M_{ez'}$ is the bending moment in relation to axis Cz', E is the material elasticity modulus, A is the finite element cross-section area, and $EI_{z'}$ is the inertia moment of the finite element cross section in relation to axis Cz'.

If the stack layers are thin enough, then value $I_{z'}$ may be neglected. The stiffness matrix describing behaviour of the layer stack between neighbouring nodes will be expressed as:

$$[K_{ls}] = \sum_{t=1}^{n} [K_{eB}]_t + \sum_{t=n+1}^{n+m} [K_{eS}]_t \tag{12}$$

where $[K_{eB}]_t$, $[K_{eS}]_t$ are finite element stiffness matrices for layers of concrete and reinforcement.

4 Results of Comparison of Two Alternative Designs of the Framework

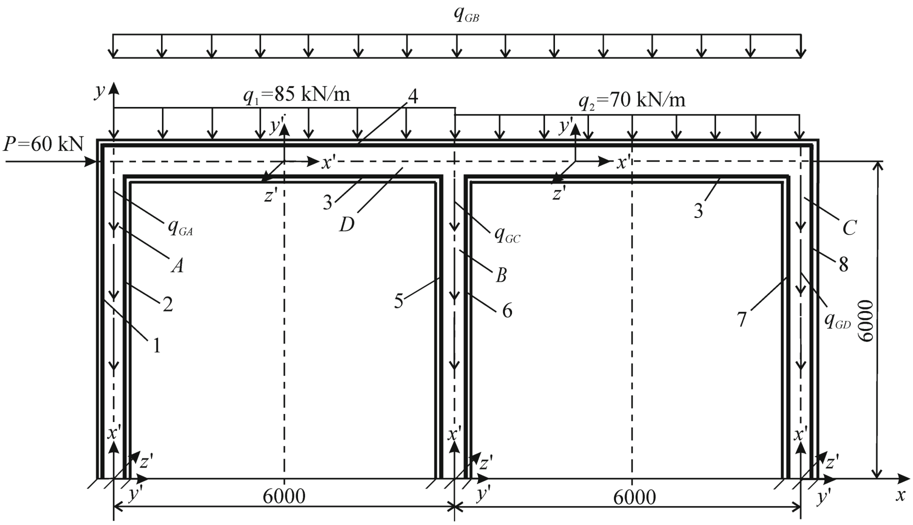

Fig. 3. Double-span reinforced concrete frame: *A*, *B*, *C* are columns, *D* is a cross bar, 1–8 are reinforcement layers.

To illustrate the effect of the presented approach, let us offer the basic results of the optimum synthesis for two alternative designs of a double-span reinforced concrete frame (Fig. 3) in which the columns and cross bar have rectangular cross sections (see Fig. 1). In the first case, optimisation was performed for a cast-in-situ structure while taking into account the welding for connection of the structural element bars. In the second case, a prefabricated structure was taken into account where columns and cross bars manufactured at the factory were used. Herewith, it was assumed that the cross bar shall be installed onto columns without match assembly welding in nodes.

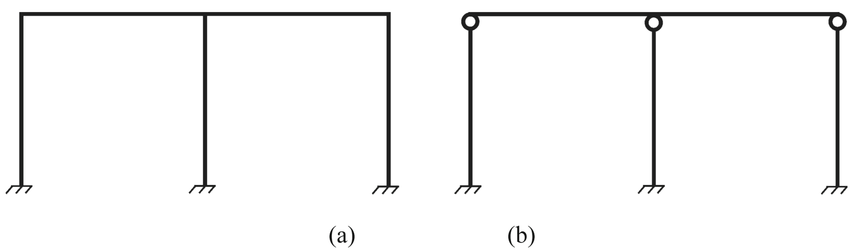

Fig. 4. Bar systems for cast-in-situ (a) and prefabricated (b) frame structures.

The frame is affected by short-term loads q_1, q_2 and loads q_{GA}, q_{GB}, q_{GC}, q_{GD} caused by the facility weight. For the first variant, a design scheme with stiff connection of the frame elements was set (Fig. 4a), for the second one, a scheme with pivot joints was used (Fig. 4b).

Table 1. The admissible values and results of optimisation of two alternative designs.

Number	Parameters, dimensions	Admissible values	Results	
			Variant 1	Variant 2
1	K_b	B15, B20, B25, B30, B35, B40, B45	B25	B20
2	K_S	A300, A400, A500, A600	A400	A400
3	b, cm	25, 30, 35, 40, 45, 50	30	30
4	H_A, cm	30, 35, 40, 45, 50, 55	30	30
5	H_B, cm	30, 35, 40, 45, 50, 55	30	45
6	H_C, cm	30, 35, 40, 45, 50, 55	30	30
7	H_D, cm	45, 50, 55, 60, 70, 80	55	60
8	(d_1, n_1), (mm, ps)	(18, 2), (16, 3), (20, 2), (18, 3), (20, 3)	(18, 2)	(18, 2)
9	(d_2, n_2), (mm, ps)	(18, 2), (16, 3), (20, 2), (18, 3), (20, 3)	(18, 2)	(18, 2)
10	(d_3, n_3), (mm, ps)	(25, 4), (25, 5), (25, 6), (28, 5)	(28, 5)	(25, 6)
11	(d_4, n_4), (mm, ps)	(25, 4), (25, 5), (28, 5), (28, 6), (32, 5)	(28, 6)	(28, 6)
12	(d_5, n_5), (mm, ps)	(18, 2), (16, 3), (20, 2), (18, 3), (20, 3)	(18, 2)	(18, 2)
13	(d_6, n_6), (mm, ps)	(18, 2), (16, 3), (20, 2), (18, 3), (20, 3)	(18, 2)	(18, 2)
14	(d_7, n_7), (mm, ps)	(18, 2), (16, 3), (20, 2), (18, 3), (20, 3)	(18, 2)	(16, 3)
15	(d_8, n_8), (mm, ps)	(18, 2), (16, 3), (20, 2), (18, 3), (20, 3)	(16, 3)	(18, 2)

The admissible design parameter values and the design parameter values obtained as a result of designing are shown in Table 1, where H_A, H_B, H_C are the heights of the column cross sections, H_D are those of the cross bar. For variant 1, the cost of the frame at current prices amounted to 188,000 RUB, variant 2 – 140,000 RUB. This means that in the case in question, the use of a prefabricated structure is more efficient in terms of reducing the planned manufacturing cost.

5 Discussion

The optimum designing of frameworks in civil construction is an efficient tool for making assessments when various engineering and organisational decisions are to be made. Such an approach may be used to select a facility manufacturing method, design type, regulatory requirements, and suppliers of component parts and materials. It is expedient to find the optimum characteristics for each solution variant in terms of reducing the cost of its installation. The use is possible in case of the optimum search for other criteria or execution of multi-purpose optimisation. In any case, it is expedient to carry out appropriate comparisons for optimised facilities.

Further developments in this field can include expanding the possibilities of the presented algorithm towards consideration of operating expenses and accidents for the facilities to be erected. It is also expedient to elaborate the issues of using the assessments of such type for reinforced concrete slabs and shells, and for metal structures.

6 Conclusions

A methodology has been developed for research into the economic feasibility of making decisions on the selection of a technology for manufacturing reinforced concrete frames while taking into account the peculiarities of a particular design and manufacturing process. The selection is based on the comparison of alternative designs obtained as a result of implementing the evolutionary optimisation procedure for various facility erection methods. A scheme for performing an optimum search for structures of such design has been formulated on the basis of a genetic algorithm and non-linear finite-element analysis. The result of comparing the economic efficiency of using cast-in-situ and prefabricated construction technology has been presented for a double-span reinforced concrete frame. The suggested approach can be recommended for use to improve the feasibility study of designed reinforced concrete systems of buildings and facilities.

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Method of Evaluation of Historical Objects of Transport Infrastructure Deformations

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Abstract. The article presents a new method for assessing the deformations of historical objects of transport infrastructure, which is based on the construction of a model in the form of a polygonal mesh of 3D triangles between deformation marks, in which the main types of deformation by distances and their changes between deformation marks are determined. The article presents new formulas for calculating the main types of deformation, such as deflection and differential settlement through distances and their variations. The comparison graphs of the derived formulas and the classical deformation definition formulas are constructed. Comparison of the limiting values of deformations described in Russian and German standards was performed. We determine a critical change in the distance at which deformation reaches the limit value established by regulatory documents. The developed methodology can be used to control the preservation of historical objects of transport infrastructure.

Keywords: Buildings · Deformation · Differential settlements · Deflection

1 Introduction

Almost all historical, architecture, urban planning and art monuments are subject to the combined effects of natural and anthropogenic factors. Preservation of historical objects of transport infrastructure is one of the most important tasks for humanity [1]. One of the most effective ways to save a heritage building is a Historic Building Information Modeling (HBIM) [2, 3], which automatically produces full engineering drawings for the conservation of historic structure and environments. This includes 3D documentation, orthographic projections, sections, details and schedules [4, 5]. Features of their structures and properties of the materials from which they are made are often unknown, which implies an individual approach to the assessment of the distribution and accumulation in them deformations [6]. In this regard, it is necessary to create a system for geodetic control of changes in deformation process in time, which will give quantitative information on the state of the object and provide an opportunity of early application of actions to ensure its safety. Currently, there are various methods for evaluating deformations [7–12], advantages and disadvantages of which are described in [13, 14], and the choice was made in favor of using polar method with a robotic

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tacheometer, since this device allowed to accurately evaluate the deformation of the building or structure.

The technique of observations using a tacheometer is described in detail in the article [15–17]. The basic idea is that observations do not fix the points of standing of the instrument. This is due to the fact that in the conditions of restoration work, it is not always possible to maintain the constancy of the observation scheme.

In addition, the remoteness of the cultural heritage monument from the starting points does not allow carrying out the transfer of coordinates from the initial points to the observed points. In addition, the loss of accuracy occurs when the coordinates are transferred. Performing observations without fixing the points of standing of the device and in a free network, the results of measurements in each cycle give approximate coordinates of the marks in the local coordinate system of the device, which for each cycle is different. In order to compare the obtained data, it is necessary to use invariant parameters. Such parameters can be, in particular, the distances and their variations. The article poses the problem of obtaining the types of deformation of interest, knowing only the distances and their variations, as well as the approximate coordinates of the marks. A review of the existing literature [6–17] showed that horizontal distances and separately vertical displacements (in particular dams) are determined separately from distances. But the definition of deformations from changes in distances in space is not presented. The task is especially important when observing deformations of monuments of cultural heritage, when deformation observations can be renewed in a few dozen years on the surviving brands.

So, in this paper we solve the following tasks:

1. To develop a methodology for detecting deformations along distances and their changes;
2. Calculate the types of deformations through distances and their variations;
3. Determine the critical change in the distance at which the deformation will reach the limit value established by regulatory documents.

It should be noted that absolute deformations (such as horizontal displacement, absolute draft) and also torsion and roll in this article are not investigated.

2 Methods

We obtain distances between deformation marks based on the results of calculations or measurements. The distances can be measured directly or can be calculated from the approximate coordinates of deformation marks.

After that we construct a model that is a polygonal mesh of 3D triangles between deformation marks. With the use of support points it is possible to determine the type of deformation. Afterwards, we derive formula for each detecting the type of deformation and than calculate a particular type of deformation through distances and their variations. Further, the derived formulas are compared with the classical ones, on the basis of which the conclusion is made about the suitability for using the derived formulas.

Determine the critical change in the distance at which the deformation will reach the limit value established by regulatory documents. The obtained results are compared with the permissible, established normative documents.

3 Results and Discussion

Consider the layout of marks. If carry out an assessment of the deformation model for changing the distance between all the marks, then get a large array of data from which it is difficult to identify a particular type of deformation. Therefore, it is necessary to build an optimal model. It is known that the triangle is the final element of the geodetic network. Since we have 3 coordinates of each of the marks, the space between marks will contain 3D triangles. A lot of triangles will be a polygon grid. It is possible to construct the triangulation in a variety of ways (for example – Delaunay Triangulation). Delaunay Triangulation - triangulation for a given set of points on the plane, in which, for any triangle all the points of the set lie outside the circle circumscribed around the triangle, except points that are its vertices. I.e. first, build triangulation for projection of points on the XY plane, and then restore the value of the Z coordinate points and get a three-dimensional model [18] (Fig. 1).

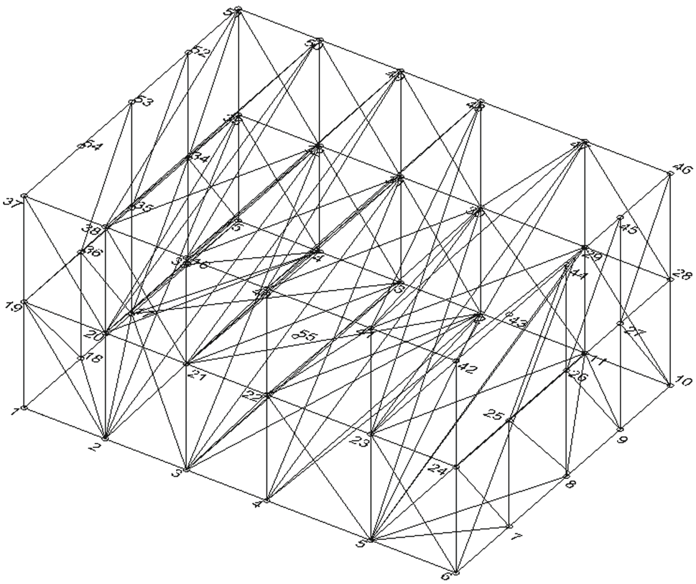

Fig. 1. Scheme of marks locations and polygon grid

The grid of triangles, built with the first observation and its numbering are for the entire period of observation.

Suppose that the coordinates of deformation marks has changed. By the results of the first cycle of observation are calculated distance between the marks obtained from a single station of the tacheometer, using the formula 1.

$$L_{ij} = \sqrt{\left(X_j - X_i\right)^2 + \left(Y_j - Y_i\right)^2 + \left(Z_j - Z_i\right)^2} \tag{1}$$

For the second cycle of observation are calculated distance L'_{ij}, then are calculated the distance difference is: $L_{ij} = L'_{ij} - L_{ij}$.

We get an array of data, consisting of the distances of the sides of the triangle to the original model (hereinafter - the “ideal” model), which will compare the model that distorted deformations (hereinafter - the “current” model).

Authors get all limit values of deformations from Russian regulations (Set of rules, Government standards) and from [19].

4 Investigation of Compression Deformation

Distort “ideal” model by compressive deformation for side 21–22 (Fig. 2). Compute the data of “ideal” and “current” model, and the difference of data of the “ideal” and “current” models (Table 1).

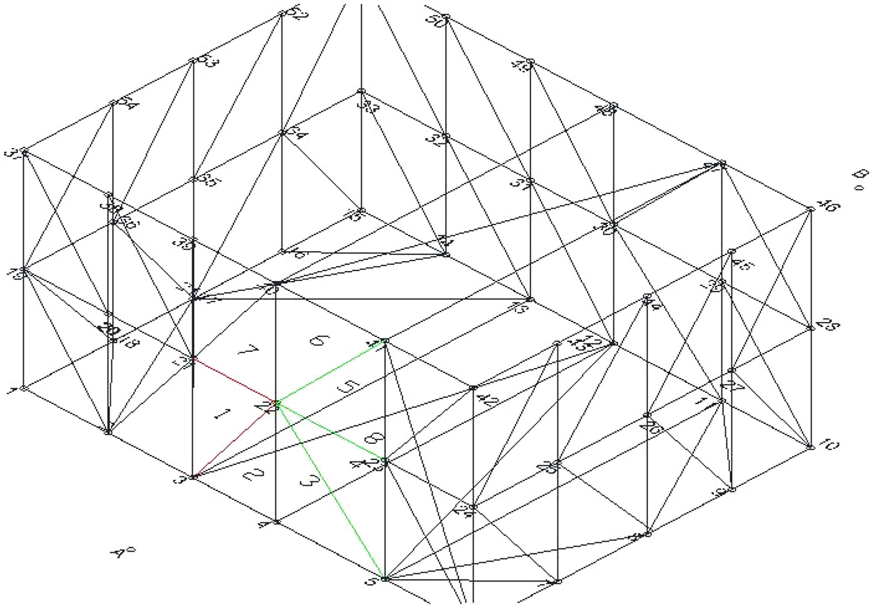

Fig. 2. Visualization of deformations in triangles

Table 1. Data of "ideal" and "current" model and difference between "ideal" and "current" models

Triangle number	The distances of the sides of the triangle of "ideal" model, m			The distances of the sides of the triangle of "current" model, m			Changing of the triangle side distances, mm		
	1	2	3	1	2	3	1	2	3
1	20,000	24,891	14,817	20,000	24,893	14,825	0,00	2,38	8,00
2	24,891	20,000	14,817	24,893	20,000	14,817	2,38	0,00	0,00
3	20,000	27,753	19,241	20,000	27,750	19,241	0,00	−2,77	0,00
4	72,181	62,892	25,463	72,179	62,890	25,463	−1,94	−1,22	0,00
5	62,892	27,753	63,128	62,890	27,750	63,128	−1,22	−2,77	0,00
6	27,753	20,000	19,241	27,750	20,000	19,241	−2,77	0,00	0,00
7	20,000	14,817	24,891	20,000	14,825	24,893	0,00	8,00	2,38
8	14,817	59,876	61,682	14,817	59,876	61,682	0,00	0,00	0,00

From Table 1 we can see that in the triangles No. 1, 2, 7 the sides 21-22, 22-3 are stretched, in the triangles Nos. 3, 4, 5, 6 the sides 22-5, 22-23, 22-41 – are compressed. Mark 21-22 can be identified by using adjacent stable triangles, as well as using support points A and B. The results are presented in Tables 2, 3 and 4:

Table 2. Matrix of distances of the "ideal" model, m:

	3	4	5	21	22	23	A	B
3	0,000							
4	14,817	0,000						
5	34,058	19,241	0,000					
21	20,000	24,891	39,496	0,000				
22	24,891	20,000	27,753	14,817	0,000			
23	39,496	27,753	20,000	34,058	19,241	0,000		
A	50,207	44,185	43,238	46,051	39,400	38,335	0,000	
B	95,026	91,349	90,056	92,898	89,133	87,807	125,398	0,000

Table 3. Matrix of distances of the "current" model, m:

	3	4	5	21	22	23
3	0,000					
4	14,817	0,000				
5	34,058	19,241	0,000			
21	20,000	24,893	39,500	0,000		
22	24,893	20,000	27,750	14,825	0,000	
23	39,496	27,753	20,000	34,062	19,237	0,000
A	46,051	39,400	38,335	50,209	44,184	43,238
B	92,898	89,133	87,807	95,028	91,348	90,056

Table 4. Matrix of distance difference, mm:

	3	4	5	21	22	23
3						
4	0,0					
5	0,0	0,0				
21	0,0	2,4	3,4			
22	2,4	0,0	−2,8	8,0		
23	0,0	0,0	0,0	4,0	−4,0	
A	0,0	0,0	0,0	**2,1**	**−1,1**	0,0
B	0,0	0,0	0,0	**1,3**	**−0,7**	0,0

Table 5. Matrix of distance difference, mm:

	3	4	5	21	22	23
3						
4	0,0					
5	0,0	0,0				
21	0,0	2,4	3,4			
22	2,4	0,0	−2,8	8,0	0,0	
23	0,0	0,0	0,0	4,0	−4,0	0,0
A	0,0	0,0	0,0	**2,3**	**−1,2**	0,0
B	0,0	0,0	0,0	**1,3**	**−0,7**	0,0

From Table 4 we see that the distances from points of reference only changed to grades 21 and 22. If A and B are positioned at the same height as grades 21 and 22, we obtain (Table 5):

From Table 5 we see that the distances from the reference points to grades 21 and 22 are the same millimetric values as when the pivot points were at different heights with grades 21 and 22. That is, grades 21 and 22 changed their position in plane XY (or in one of the planes X or Y). Based on the location of the marks on the building, we suppose that there was a deformation of the tensile/compression.

Calculate compression deformation ε (formula 2):

$$\varepsilon = \frac{\Delta l}{l_0} = 0{,}0005, \tag{2}$$

where:

$\Delta l = l - l_0$ - the absolute elongation/reduction;
l - deformed body distance;
l_0 - distance of the body in the non-deformed state

Calculate the tension/compression deformations for the other sides of the models (Table 6):

Table 6. Tensile/Compression deformations

Sides	Tension/Compression
21-3	0,0001
21-22	0,0005
22-41	−0,0001
22-5	0,0000
22-23	0,0000

The resulting value does not exceed the tolerances $\varepsilon_{tor} = 0{,}0005$.

To identify deformed marks under tension/compression strain we use adjacent triangles of the model whose sides remain unchanged, or identify these marks using the support points A and B. At the same time, the support points are at the same height and at different heights with deformable marks, to make sure that the marks have not changed their position in the Z plane. Further, by the location of the stamps on the building, it is assumed that this is a stretch/compression strain. According to the formula 1, deformation of tension/compression is calculated and its value is compared with the limiting value established by normative documents.

5 Research of Differential Settlement

In order to investigate the differential settlement, we change the marks 1 and 10 in a such way that the value of the differential settlement is the limiting value established by the regulatory documents [0.0009 in SP (Russian building rules) 126.13330.2012]. We shade the triangles located in different planes with different shading. So, triangles No 3 and 6, which are in the horizontal plane, are designated , triangles No 1, 2, 4, 5, located in the vertical plane, are indicated  (Fig. 3). Increase the length in the triangle we will call tension (stretching) and denote by red color on the model, to reduce the lengths in the triangle call compression and denote by green.

Get the difference of data (Table 7).

From Table 7 we see that in the triangles No. 1, 2, 4, 5, the sides (1–36, 1–19, 1–20, 10–29, 10–27, 10–28) under a compression. In triangle No. 6 (sides 9–10 and 10–11) under a tension of +0.4 mm and +0.3 mm.

To solve the inverse problem, i.e. identifying deformed marks, we can use other adjacent triangles, the distances in which have not changed. In addition, we can use the support points A and B. The results are presented in Table 8:

From Table 8, the distances from points of reference only changed to marks 1 and 10.

Next, we will determine in which directions our position of brands 1 and 10 has changed. We will place brands A and B at the same height as 1 and 10. The results are presented in Table 9:

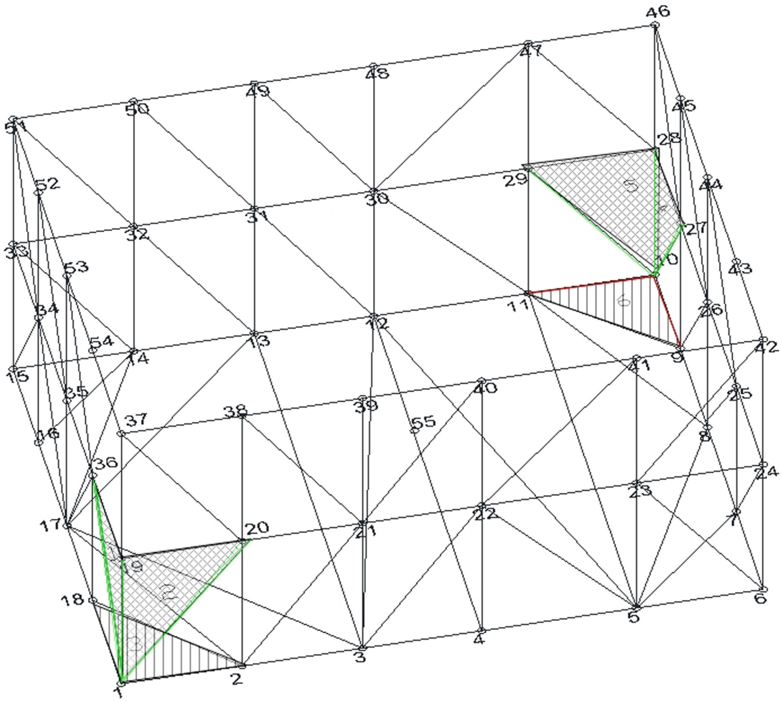

Fig. 3. Visualization of differential settlement

Table 7. Difference in data of "ideal" and "current" models

Triangle number		1	2	3	4	5	6
The distances of the sides of the triangle of "ideal" model, m	1	25,525	20,000	15,860	25,463	20,000	14,008
	2	15,860	14,999	21,829	15,759	14,008	15,759
	3	20,000	24,999	14,999	20,000	24,418	21,085
The distances of the sides of the triangle of "current" model, m	1	25,517	19,990	15,860	25,384	19,900	14,008
	2	15,860	14,999	21,829	15,759	14,008	15,759
	3	19,990	24,991	14,999	19,900	24,336	21,085
Changing of the triangle side distances, mm	1	−7,8	−10,0	0,0	−78,5	−100,0	0,4
	2	0,0	0,0	0,0	0,0	0,0	0,3
	3	−10,0	−8,0	0,0	−100,0	−81,8	0,0

Table 8. Matrix of distance difference, mm:

	1	2	9	10	11	18
2	0,0					
9	0,0	0,0				
10	0,0	0,1	0,4			
11	0,0	0,0	0,0	0,0		
18	0,0	0,0	0,0	0,0		
19	−10,0	0,0	0,0	−19,6		
20	−8,0	0,0	0,0	−22,1	0,0	
A	**−2,8**	0,0	0,0	**−19,5**	0,0	0,0
B	**−1,8**	0,0	0,0	**−50,7**	0,0	0,0

Table 9. Matrix of distance difference, mm:

	1	2	9	10	11	18
2	0,0					
9	0,0	0,0				
10	0,0	0,1	0,4			
11	0,0	0,0	0,0	0,3		
18	0,0	0,0	0,0	0,1		
19	−10,0	0,0	0,0	−19,6		
20	−8,0	0,0	0,0	−22,1		
A	0,0	0,0	0,0	0,0	0,0	0,0
B	0,0	0,0	0,0	0,0	0,0	0,0

From Table 9 we see that when the reference points are located at the same height with the deformation marks, there are no changes in the distances, which indicates that grades 1 and 10 have changed their position in the vertical plane.

Suppose that there is differential settlement, derive a formula of differential settlement by the distances and their changes. According to [20] relative differential of settlements of two points of the foundation is calculated as the difference in their vertical displacement, divided by the distance between them: $\Delta S/L$.

Consider triangles No 3 and No 6 (Fig. 4). Assume that only marks 1 and 10 have changed in these triangles.

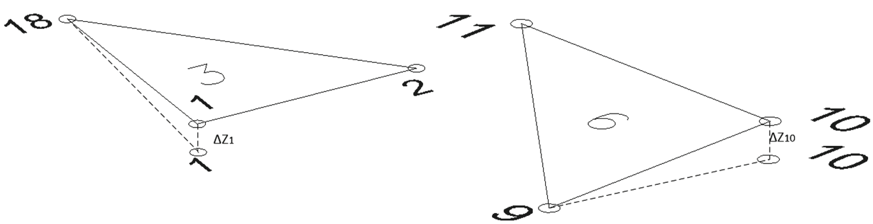

Fig. 4. Derivation of the formula for the differential settlement

Then, using the Pythagorean theorem, derive a settlement of mark 1 ΔZ_1 (formulas 3, 4):

$$\Delta Z_1^2 = L_{1'-18}^2 - L_{1-18}^2 \tag{3}$$

$$\Delta Z_1 = \sqrt{L_{1'-18}^2 - L_{1-18}^2} \tag{4}$$

We consider triangle No 6. Show the settlement of mark ΔZ_{10} 10 using the Pifagor theorem (formulas 5, 6):

$$\Delta Z_{10}^2 = L_{10'-9}^2 - L_{10-9}^2 \tag{5}$$

$$\Delta Z_{10}^2 = \sqrt{L_{10'-9}^2 - L_{10-9}^2} \tag{6}$$

So differential settlement is calculated by the classic formula (7):

$$\frac{\Delta S}{L} = \frac{\Delta Z_{10} - \Delta Z_1}{L_{1-10}} \tag{7}$$

And derived formula is equal (8).

$$\frac{\Delta S}{L} = \frac{\Delta Z_{10} - \Delta Z_1}{L_{1-10}} = \frac{\sqrt{L_{10'-9}^2 - L_{10-9}^2} - \sqrt{L_{1'-18}^2 - L_{1-18}^2}}{L_{1-10}} \tag{8}$$

$$\frac{\Delta S}{L} = 0{,}0009$$

If the marks had a similar settlement, $\varDelta \mathrm{S} = 0$. But we have $\varDelta \mathrm{S} \neq 0$, so there is an differential settlement.

We calculate differential settlement using the classical formula (7) and the derived formula (8). The results plotted in Fig. 5.

From Fig. 5, we see that the results of calculations for the derived and classical formulas coincide. The very distance 1–10 analysis is only +0.04 mm.

Limit relative differential settlement for renovated buildings (in particular, multi-storey and single-storey historical buildings or monuments of history, architecture and culture with the bearing walls of brick masonry without reinforcement) is 0,0009 for satisfactory state of construction.

We will carry out research on the model, in particular, for different distances between marks 1 and 10 (Table 10). We will distort marks 1 and 10 in such a way that the value of the differential precipitation is the limiting value established by regulatory documents, in particular, 0.0009.

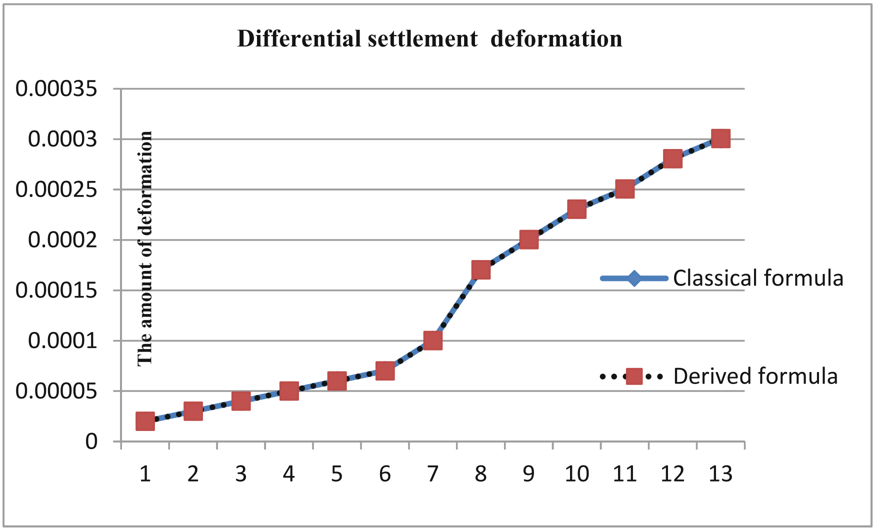

Fig. 5. Calculate differential settlement using the classical formula (7) and the derived formula (8)

We will also calculate how much the distance between brands 1 and 10 will vary. We get the following results:

Table 10. Distance 1–10 and its change

Distance between marks, m	Change of distance, mm
99,779	0,04
84,636	0,034
71,906	0,029
63,070	0,026
60,675	0,027
41,067	0,017
22,168	0,009
13,925	0,006

From Table 10 we see that as the distance decreases, its change decreases too, which indicates that the differential settlement has reached its limiting value.

Thus, it is possible to calculate the distance variation for any interval between marks at which the value of the differential settlement will reach the limit value established by regulatory documents.

To identify deformed marks in the deformation of differential settlement, we use adjacent triangles of the model, whose side lengths remain unchanged, or identify these marks using the support points A and B. At the same time, the reference points are at the same height and at different heights with deformation marks, so that make sure that the stamps have changed their position in the Z plane. Further on the location of marks on the building, it is assumed that this is an differential settlement. Estimate the distance variation depending on its length (Table 10). According to the derived formula, calculate the differential draft and compare its value with the limiting, established by regulatory documents.

6 Research Deflection Deformation

Suppose that there is a beam in the model that connects marks 25 and 36, between which we place mark 55. We form triangles in different planes of model space and denote them by different shading. Triangles No. 1–7 are indicated by hatching , triangles No. 8–14 are indicated by hatching , triangles No. 15–24 are indicated by hatching , triangles No. 25–31 are indicated by hatching  (Fig. 7). We distort the model by deformation of the deflection to the limiting value 0.0004, established by normative documents [SP (Russian building rules) 126.13330.2012]. Changes in distances of the sides in the triangle are in the Fig. 6. The data of "current" model are in the Table 11:

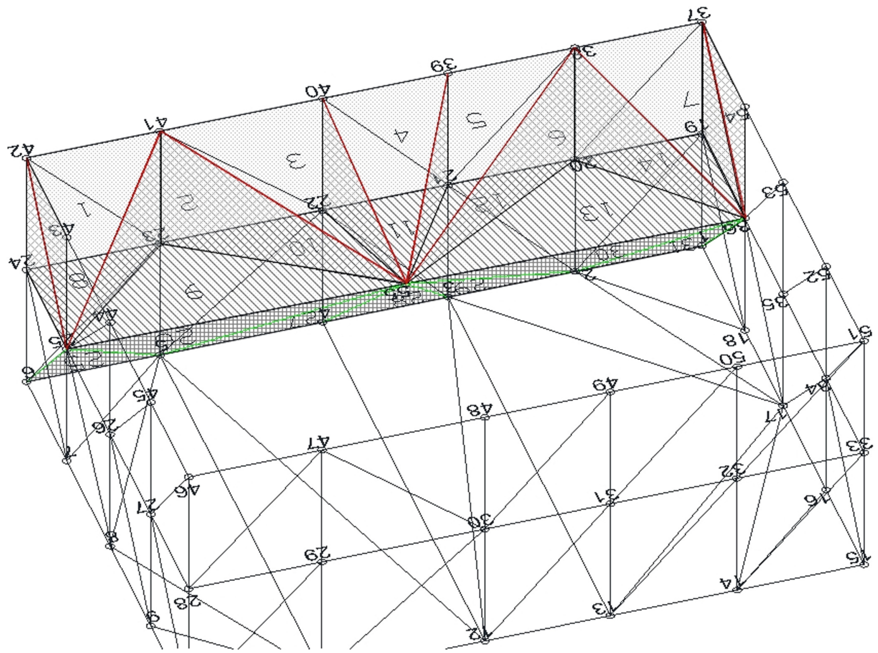

Fig. 6. Changing of the sides distances in deflection deformation

The marks, which located above the girder marks, we will call the upper ones, below the girder marks – the lower ones. From Table 11 we see that in triangles No. 1–7 and 15–24, all sides that connect the upper marks and beams were stretched, the remaining sides remained unchanged.

In triangles No. 8–15, the distances do not change. In the triangles No. 25–31, the sides connecting the lower grades of the model and the beam marks received compression, the remaining sides remained unchanged.

Thus, to identify deformation of the deflection/arch (later, any vertical deformation), triangles should be used that lie in a plane not perpendicular to the deformation itself.

Table 11. The difference between ideal and current model

Triangle number	The distances of the sides of the triangle of “ideal” model, m			The distances of the sides of the triangle of “current” model, m			Changing of the triangle side distances, mm		
	1	2	3	1	2	3	1	2	3
1	15,759	24,920	29,485	15,759	24,936	29,498	0,0	16,1	13,6
2	29,485	40,052	34,804	29,498	40,052	34,821	13,6	0,001	17,2
3	19,241	25,430	34,804	19,241	25,454	34,821	0,0	23,6	17,2
4	25,430	26,768	14,817	25,454	26,791	14,817	23,6	22,4	0,0
5	35,136	26,768	15,001	35,153	26,791	15,001	17,1	22,4	0,0
6	35,136	29,606	39,777	35,153	29,613	39,777	17,1	6,8	0,005
7	25,525	14,999	29,606	25,533	14,999	29,613	7,8	0,0	6,8
10	28,484	15,707	19,241	28,484	15,707	19,241	0,0	0,0	0,0
11	15,707	14,817	17,791	15,707	14,817	17,791	0,0	0,0	0,0
12	39,777	33,934	17,791	39,777	33,934	17,791	0,0	0,0	0,0
9	28,484	40,052	21,664	28,484	40,052	21,664	0,0	0,001	0,0
8	15,759	14,866	21,664	15,759	14,866	21,664	0,0	0,0	0,0
13	21,829	39,777	28,888	21,829	39,777	28,888	0,0	0,005	0,0
14	14,999	21,829	15,860	14,999	21,829	15,860	0,0	0,0	0,0
15	14,866	24,920	20,000	14,866	24,936	20,000	0,0	16,1	0,0
16	21,664	29,485	20,000	21,664	29,498	20,000	0,0	13,6	0,0
17	20,000	34,804	28,484	20,000	34,821	28,484	0,0	17,2	0,0
18	20,000	15,707	25,430	20,000	15,707	25,454	0,0	0,0	23,6
19	20,000	17,791	26,768	20,000	17,791	26,791	0,0	0,0	22,4
20	20,000	28,888	35,136	20,000	28,888	35,153	0,0	0,0	17,1
21	20,000	21,829	29,606	20,000	21,829	29,613	0,0	0,0	6,8
22	20,000	25,525	15,860	20,000	25,533	15,860	0,0	7,8	0,0
23	14,866	20,000	24,920	14,866	20,020	24,936	0,0	20,0	16,1
24	25,525	15,860	20,000	25,533	15,860	20,010	7,8	0,0	10,0
25	15,759	24,920	29,485	15,759	24,904	29,471	0,0	−16,0	−13,6
26	29,485	34,804	40,052	29,471	34,787	40,052	−13,6	−17,2	0,001
27	34,804	25,430	19,241	34,787	25,407	19,241	−17,2	−23,6	0,0
28	25,430	26,768	14,817	25,407	26,746	14,817	−23,6	−22,4	0,0
29	26,768	35,136	15,001	26,746	35,119	15,001	−22,4	−17,1	0,0
30	35,136	39,777	29,606	35,119	39,777	29,599	−17,1	0,005	−6,8
31	14,999	29,606	25,525	14,999	29,599	25,517	0,0	−6,8	−7,8

If the deflection is deflected: If the marks are located above the beam marks, the distances experience tension. If the marks are located below the girder marks, the distances joining them undergo compression deformation. With deflection – tension.

Using the adjacent triangles of the model, the length of the sides in which remained unchanged, we find that the marks 25, 36, 55 have changed. Also, these marks can be identified using the support points A and B (Table 12).

Table 12. Change of distances, mm:

	25	36	55	39	40	41	38	21	A	B
25	0,0									
36	0,0006									
55	0,001	0,005								
39	7,2	5,1	22,4							
40	9,3	3,9	23,6	0,0						
41	13,6	2,9	17,2	0,0	0,0					
38	5,8	6,8	17,1	0,0	0,0	0,0				
21	0,0	0,0	0,0	0,0	0,0	0,0				
A	**−6,6**	**−2,5**	**−10,2**	0,0	0,0	0,0	0,0			
B	**−5,1**	**−2,1**	**−7,7**	0,0	0,0	0,0	0,0	0,0	0,0	0,0

In order to determine in which direction the changes in marks occurred, we will place the starting points A and B at the same height as those that have changed their position of the mark. Then we get the following changes in distances (Table 13):

Table 13. Change of distances, mm

	25	36	55	39	40	41	38	21	A	B
36	0,0006									
55	0,001	0,005								
39	7,2	5,1	22,4							
40	9,3	3,9	23,6	0,0						
41	13,6	2,9	17,2	0,0	0,0					
38	5,8	6,8	17,1	0,0	0,0	0,0				
21	0,0	0,0	0,0	0,0	0,0	0,0	0,0			
A	0,003	0,0006	0,008	0,0	0,0	0,0	0,0	0,0	0,0	0,0
B	0,003	0,0005	0,006	0,0	0,0	0,0	0,0	0,0	0,0	0,0

From Table 13 we see that the distances from the reference points to the deformable marks practically did not change, in contrast to Table 12. Thus, it can be argued that marks 25, 36, 55 received a settlement, and not their change in space in two or three coordinates. We derive the calculation equation for deflection by distance between marks (Fig. 7):

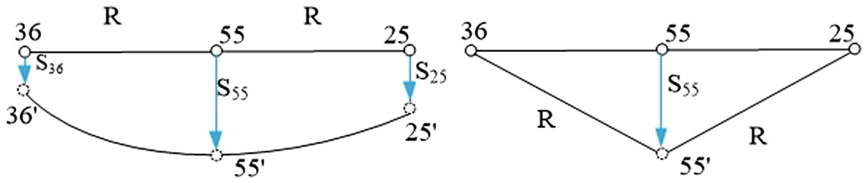

Fig. 7. Deflection side 1-8-7 (a), simplification of the deflection problem (b)

Let $L_{36-55} = L_{55-25} = R$ and $L_{36-25} = 2R$.

For simplification we consider that only distance L_{36-25} has changed (decreased) and become L'_{36-25}, but distance L_{36-55} and L_{55-25} have not changed (Fig. 7b). So, $L_{36-55} = L'_{36-55} = R$ and $L_{55-25} = L'_{55-25} = R$:

Consider triangles 36-55-55′ and 25-55-55′.

Express distance L'_{36-25} (formulas 9, 10):

$$L'^2_{36-25} = 4(R^2 - S^2_{55}) \tag{9}$$

$$L'_{36-25} = 2\sqrt{R^2 - S^2_{55}} \tag{10}$$

We apply Taylor series expansion (formula 11):

$$L'_{36-25} = 2R\sqrt{1 - \left(\frac{S_{55}}{R}\right)^2} \approx 2R\left[1 - \frac{S^2_{55}}{2R^2}\right] \text{ equation } (S_{55} << R) \tag{11}$$

$$\frac{S^2_{55}}{R} = 2R - L'_{36-25} = L_{36-55} + L_{55-25} - L'_{36-25} \tag{12}$$

The deflection is expressed by Eq. 13 [21]:

$$\frac{f}{L} = \frac{S_{55}}{L'_{36-25}} = \frac{1}{2}\sqrt{\frac{L_{36-55} + L_{55-25} - L'_{36-25}}{L_{36-55}}} = \frac{1}{2}\sqrt{\frac{L_{36-25} - L'_{36-25}}{0{,}5L_{36-25}}} = \frac{1}{2}\sqrt{\frac{\Delta L_{36-25}}{0{,}5L_{36-25}}} \tag{13}$$

$$\frac{f}{L} = +0,006$$

According to [SP (Russian building rules) 22.13330.2011] the maximum value of deflection for category II of historical objects of transport infrastructure is 0.0004.

Calculate deflection by classic formula (14).

$$\frac{f}{L} = \frac{2S_2 - (S_1 + S_3)}{2L} \tag{14}$$

where:

S_1 and S_3 - settlements of the considered construction site ends;
S_2 - max (min) settlement on the same site, L - distance between marks

Calculate the deflection according to the classic formula (14) and the derived formula (13). The results are presented in the form of a table: (Table 14):

Table 14. Deflection value of deflection according to the classical and derived formulas

Variants of mark distortions	Classic formula	Derived formula
1	0,00005	0,006
2	0,00006	0,006
3	0,00008	0,006
4	0,00009	0,006
5	0,00014	0,006
6	0,00019	0,006
7	0,00022	0,006
8	0,00024	0,006
9	0,00043	0,006
10	0,00019	0,006

As can be seen from Table 14, the derived formula gives the same results with different distortion of marks. This is obvious, since changes in the distances between the beams of the beam are practically absent in the deformation of the deflection. The sides of the beam under deformation of the deflection changed as follows: the side 25–55 changed by 0.001 mm, the side 55–36 changed by 0.005 mm and the side 25–36 by 0.0006 mm.

Then it is impossible to understand from changes in distances when the deformation of the deflection is permissible, and when critical. The value of deformation of the deflection according to the derived formula will vary depending on the distance between the marks.

Then arrange the beam marks at different distances from each other and perform distortions of grades 25, 36, 55 so that the deflection value, calculated by the classical formula, is the limiting value established by the normative documents, i.e. 0.0004. The results obtained by the derived formula are presented in Table 15:

Table 15. Study of the derived formula depending on the distance between brands

Limit deflection according to the derived formula	Distance between marks, m	Change of distances, mm		
	25–36	25–55	55–36	25–36
0,0062	79,823	0,048	0,000	0,023
0,0083	59,825	0,027	0,002	0,009
0,0124	39,829	0,016	0,003	0,004
0,0252	19,842	0,005	0,002	0,000
0,0513	9,867	0,002	0,001	0,000

Thus, it is possible to calculate the limiting relative deflection for any distance between marks, the value of which will be the limiting value established by regulatory documents.

To identify deformed marks in the deflection/bending, use adjacent triangles of the model whose sides have remained unchanged, or identify these marks using the support points A and B. At the same time, the reference points are at the same height with deformable marks and at different heights, so that make sure that the marks have changed their position in the Z plane.

Further, triangles are used to reveal deformation of the deflection/flexure, which lie in a plane not perpendicular to the deformation itself.

If the deflection is deformed: if the marks are located above the deformed marks, the distances in the triangles connecting the stable and deformed marks under the tension. If the grades are located below the deformed marks, the distances connecting the stable and deformed marks under the compression deformation. With buckling deformation - vice versa. Further, according to the derived formula, the deformation is calculated and, depending on the distance between the deformed marks, determine whether this value is limiting or admissible.

7 Conclusions

1. An algorithm for identifying such types of deformations as: differential settlement, tension/compression, deflection;
2. The new formulas for the calculation of such deformation as differential settlement and deflection from distances and their changes between deformation marks;
3. The critical change in the distance at which the deformation reaches the limit value established by regulatory documents is determined.

For a more optimal solution of the problem, the building model is represented in the form of a polygonal grid of triangles. Comparison of the calculation deformations results obtained by the derived formula and by the classical formula is performed. The results showed convergence.

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The Rock Loosening Technology in Railway Track Reconstruction

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Abstract. The object of research is the rock development in the railways reconstruction in a limited space. The difficulty is that the work must be carried out in close proximity to existing railways. Therefore, at the time of work, train traffic is impossible on the considered area. In addition, blasting operations pose a certain danger to surrounding infrastructure safety, namely: for existing paths; signaling, centralization and blocking devices; contact network, etc. The technology of rocks explosive loosening is proposed, combining the use of horizontal blast holes and special covering made of damping elements, reducing rock mass spread. The use of proposed railway tracks reconstruction technology completely eliminates the time spent on blasted rock displacement from the existing railway track to the dump. Due to horizontal borehole charges use, the blast wave seismic effect on the surrounding objects is minimized. The use of mechanization means such as railway crane and horizontal drilling machine provides productivity increase in comparison with existing technologies.

Keywords: Railway reconstruction · Horizontal borehole · Damping cover · Rocks loosening

1 Introduction

February 20, 2019 in address to the Federal Assembly president of the Russian Federation Vladimir Putin noted that capacity increase of the Baikal-Amur mainline (BAM) is an important task, solution of which promotes development of the Far East and Siberia. The expansion of BAM will better meet domestic needs of the country, as well as strengthen external economic relations with the countries of East Asia [1, 2]. BAM reconstruction work includes second track laying. Works are carried out in the mountain relief (Fig. 1) and permafrost conditions. Explosive loosening method is used for rock excavation [3]. Since the slopes are close to the existing railway tracks, train traffic on the site in question is impossible at the time of work. In addition, blasting operations pose a certain danger to the surrounding infrastructure safety, namely: for existing tracks; signaling, centralization and blocking devices; contact network, etc. In this regard, a special project is being developed to ensure the safety of railway tracks, as well as infrastructure for the reconstruction period.

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Fig. 1. Baikal-Amur mainline section in the area of Kuznetsovsky - Otkosnaya railroad line

This project provides for a set of works, including [4]:

– transportation of the contact network, alarm, centralization and blocking devices outside the dangerous zone;
– protecting objects that cannot be transferred outside the dangerous zone (e.g., existing railway track is covered with flooring consisting of sleepers).

Also the existing blasting methods have a harmful effect on the surrounding nature. Therefore blasting methods that provide good loosening quality at the least negative impact on track elements, communication, edifices and environment should be used.

Exploded rock mass transportation from the covering of existing railway track takes a significant part of time during the reconstruction. Generally, bulldozer moves rock mass to the dump for subsequent loading by an excavator into dump trucks. After work is done, the contact network and other objects must be returned to their original location. It also takes a considerable time. In general, this work organization method is very laborious and has low efficiency.

In conditions of limited working space, efficiency increase of railway tracks reconstruction works is possible by use of covering. Covering is placed along the perimeter of rock mass which is subject to explosive loosening. This will reduce the rock pieces flight range when carrying out blasting [5].

A rocks loosening method by explosion in a limited working space is known [6]. This method involves the use of an air gap in the vertical boreholes redrilling, as well as the use of gas-permeable elastic cover of large diameter pneumatic tires [7, 8]. Need to form a redrilling in the boreholes, which takes additional time, is the disadvantage of this method. In addition, vertical boreholes' redrilling amplifies blast wave seismic effect on the ledge surface located below [9].

In this study, the technology of rocks explosive loosening by horizontal borehole charges of reduced diameter under a gas-permeable shelter is proposed. Redrilling is excluded, since boreholes are located parallel to the upper surface of the exploding block. Absence of redrilling minimizes the blast wave seismic effect on the underlying ledges. Additional boreholes are drilled along the block contour to be blasted. Those form a gap between the block and surrounding rock mass (Fig. 2). It leads to ledge smooth surface formation, as well as more complete use of the blast wave energy.

The contour gap provides the blast wave reflection, which increases useful energy for rock loosening the average of 10% [9]. In this way, the maximum use of the blast wave energy is achieved.

Comparison of the existing [10, 11] and proposed technologies showed that the latter allows to increase the explosion destructive effect with a decrease in the specific consumption of the explosive.

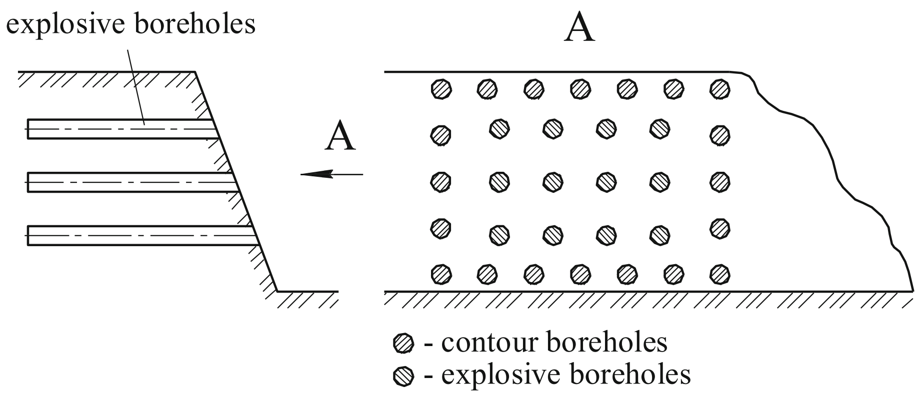


Fig. 2. The drilling scheme of the explosive block

Use of the described technology for slopes wrecking is limited by technical characteristics of existing drilling rigs, namely the drilling maximum height. Today, the leading manufacturer of drilling rigs with horizontal drilling possibility is the Epiroc group of companies. Table 1 shows the technical characteristics of the various models Epiroc drilling rigs.

Table 1. The technical characteristics of Epiroc drilling rigs

Drilling rig model	Drilling maximum height, m	Borehole diameter, mm	Maximum feed force, kN	Weight, t
AirROC D40	2.62	85–115	8	2.515
AirROC D50	3.09	105–140	21	4.8
FlexiROC D60	4.23	127–140	40	23.7
PowerROC D45	3.75	90–130	12	14
PowerROC D60	4.23	110–178	24	20.8
PowerROC T35	4.765	64–102	19,6	12.5
PowerROC T45	4.53	76–127	19,6	14.5
PowerROC T50	4.43	102–152	50	22.8
Boomer E1	9.29	38–64	20	22
Boomer XE4	13.401	38–64	22	61
Boomer L2	9.3	45–64	20	33
Boomer XL3 D	13.108	48–64	22	42

Table 1 analysis shows that AirROC series pneumatic machines and PowerROC series hydraulic machines can be used at relatively low rock height to be blasted. The Boomer series drilling rigs are characterized by a greater drilling height at similar maximum feed force values. At the same time, boreholes maximum diameter of tunneling machines is less than that of pneumatic and hydraulic machines. However, the drilling speed of tunneling machines is higher, which provides necessary productivity. The drilling rigs weight does not exceed the maximum permissible to be placed on the open-type railway platform.

The proposed blasting method implies layer-by-layer rock mass explosive loosening. The layers are located parallel to the sole of ledge to be blasted. In this case, the overlying exploded layers create a set-on weight when blasting the underlying layers.

To eliminate flight of rock pieces gas-permeable cover is used. When blasting rock top layer, the laying depth and weight of explosive affects on the cover damping capacity. The thickness of rock upper layer to be developed is found according the cover mass and its damping parameters [12]. Further, the horizontal borehole charges parameters of upper layer are determined by energy value of used explosive. The parameters are: diameter, boreholes step and location depth relative to ledge surface. Several test explosions of rock mass to be blasted are performed, after which the parameters of the charges are refined. The calculation of horizontal borehole charges parameters for the rock mass to be blasted following layers is carried out by the standard method, since upper blasted layer mass is sufficient to exclude the rock flight.

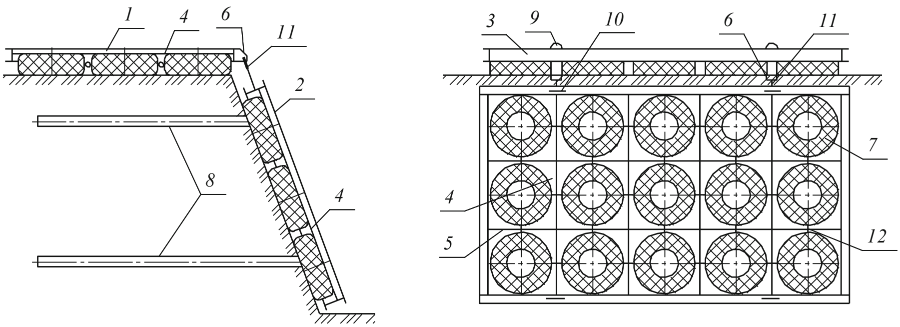
The preparation process for rock mass explosion begins with the drilling of contour boreholes at the required inclination angle. Contour boreholes should be blasted at least 100 ms ahead [13] of the boreholes for loosening. The formation of an air gap along the explosive block contour provides [14]:

- close cover contact with the slope surface during further explosions of the block;
- water penetration blocking from the surrounding mountain range into the block to be blasted;
- increasing the blast wave energy amount consumed for rock loosening due to presence of a free surface along the contour.

Loosening boreholes drilling is carried out to the upper shelter depth. Next are boreholes charging, surface network mount and cover of the rock mass with a shield. The upper layer borehole charges explosion causes rock shift upwards and partially towards the ledge slope. The blast wave energy is spent on the rock mass loosening and deformation of the cover damping components. Top layer blasting under the cover is an important step in the mountain range loosening, as the dynamic load is taken by the cover damping elements.

The loosened upper rock layer is a set-on weight in blasting the following layers. In addition, lower edge of the upper blasted layer is a surface of explosive waves reflection, which increases loosening efficiency of underlying layers [15–19]. Therefore, when loosening the underlying layers blast waves have less impact on the shelter.

The mobile cover of the block to be blasted includes lattice frames 1 for covering the block surface and lattice frames 2 for covering slope of the ledge (Fig. 3).

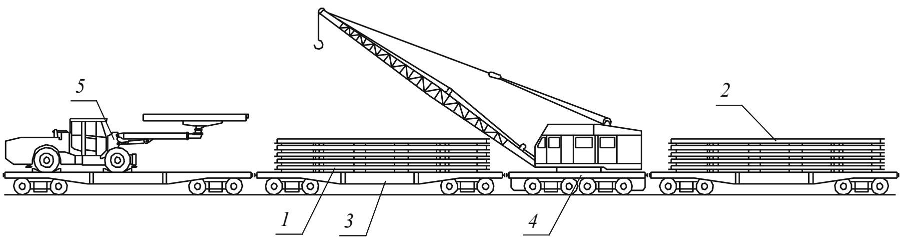


1 – lattice frame for covering the block surface; 2 – lattice frame for covering the side slope; 3 – metal frame; 4 – grid; 5 – metal rod; 6 – bracket; 7 – enclosing element; 8 – borehole; 9, 10 – slinging bracket; 11 – carbine; 12 – flexible element

Fig. 3. Scheme of the block to be blasted with installed cover

Elements 1 and 2 include frame 3, to which the grid 4 is welded, consisting of rods 5. To the grid 4 the enclosing elements 7 are suspended on the flexible elements 12 (for example, chains). Pneumatic tires of large diameter can be used as the enclosing elements.

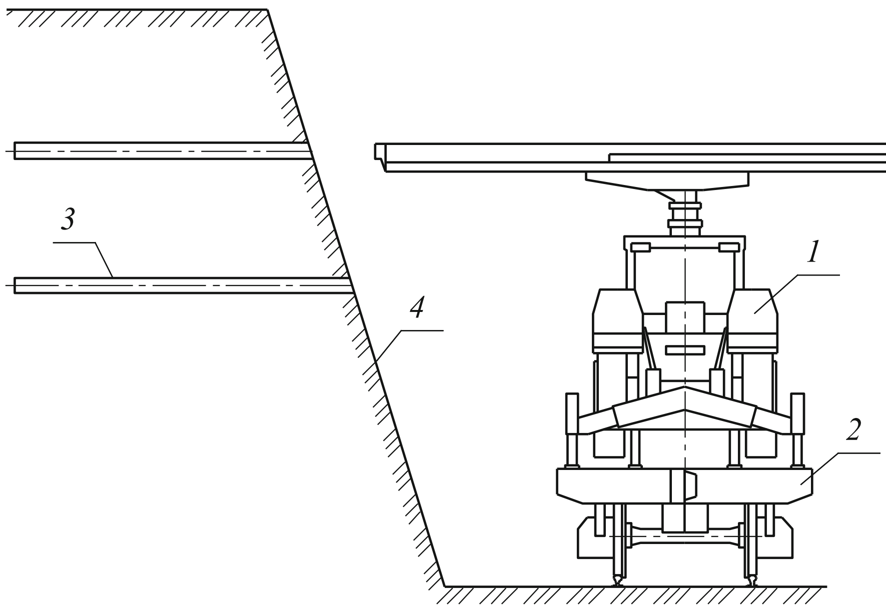
Frames 1 serving as a cover of the rock ledge upper plane are laid on one of the open-type railway platforms 3 (Fig. 4). Frames 2 serving as a cover of the rock ledge slope is placed on another railway platform 3. The railway crane 4 is in coupling with these platforms, as well as a platform with an installed drilling rig 5. Width of frames 1 and 2 doesn't exceeding the standard value.



1 – lattice frame for covering the block surface; 2 – lattice frame for covering the side slope; 3 – railway platform; 4 – railway crane; 5 – drilling rig

Fig. 4. Set of machines for blasting during the railway reconstruction

Platforms 3 in coupling with the railway crane 4 are given to the ledge section to be blasted. In the slope of ledge to be blasted, horizontal boreholes are drilling. The drilling process is schematically shown in Fig. 5. After drilling all of the boreholes produce their loading and installation of initiating charge conductors.



1 – drilling rig; 2 – railway platform; 3 – horizontal borehole; 4 – surface slope of the ledge

Fig. 5. Process scheme of drilling horizontal boreholes in the slope of ledge

Further railway crane 4 moves the frame 1 to the desired position on the block to be blasted by means of the slings threaded through brackets 9 (Fig. 3). On the upper plane of frame 1, a steel wire mesh is laid to prevent the flight of rock small pieces. Depending on the blast block width a certain number of upper frames is laid, connecting with flexible elements. On a side of the ledge slope frames 2 are setting similarly. For coupling of installed frames 1 and 2 the carbine 11 is securing in the brackets 6 (Fig. 3).

The initiating conductors are passed through the holes in the frames 1 and carry out the installation of the surface contact network. In this case, a method of short-delayed blasting is implemented. The use of reduced power charges in remote boreholes allows softening the first shock wave effect. Therefore, instead of rock mass flight there is a swelling. The cover together with the swollen rock mass provides a damping effect on the following rows boreholes explosions, which also prevents the stone fines flight.

The enclosing elements elasticity does not allow individual rock pieces to break away from lump during blasting. The inertia force of the loosened rock together with gravity force of the cover balances blast wave force. The thickness of rock layer to be blasted and loosening ratio affects the rocks flight altitude under cover.

After blasting the ledge slope frame is moved and placed on the appropriate railway platform with a railway crane. The ledge upper plane frames laying is produced similarly.

Use of the proposed railway tracks reconstruction technology completely eliminates the time spent on blasted rock displacement from the existing railway track to the dump. Due to the horizontal borehole charges use, blast wave seismic effect on the surrounding objects is minimized. Therefore, the proposed technology provides productivity increase and reduces harmful impact on the environment in comparison with existing technologies.

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Mathematical Methods for Optimizing the Technologies of Building Materials

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Abstract. The article discusses the possibilities of solving the engineering problems in the study of technological processes using the method of analytical optimization. The essence of this method is the presentation of the technological process as a cybernetic system; statistical evaluation of each element of the system with obtaining the mathematical functions; analytical study of these functions and obtaining optimization dependencies. The next step is to develop a process algorithm and compile computer programs. As an engineering interpretation, it is possible to construct optimized nomograms that allow solving both direct and inverse problems; that is, predicting the result or the choice of technological factors. The research methods described in this article are implemented in the study of the technology of cellular concrete, foam-fiber concrete, cement polymer concrete and mineral wool products. As an example, the article considers the optimization of foam concrete technology. The implementation of the developed methodology made it possible to determine the optimal value of the determining parameters, including the flow rate and length of basalt fiber, and to form a methodology for studying the properties of products.

Keywords: Foam-fiber concrete · Mathematical model · Building materials technologies

1 Introduction

One of the factors of energy saving and improving the quality of products is the optimization of technological processes, including the processes of production of building materials. Optimization solutions, on the one hand, make it possible to organize the process in such a way as to optimize the costs of the raw materials (some of which can be very energy-intensive), and on the other hand, lead to optimum heat and electricity costs for production needs [1–3].

A feature of building materials technologies is the presence of both deterministic, both statistically determined and stochastic factors affecting the result. In many cases, it is also necessary to establish the material consumption of the raw material mixture, ensuring the achievement of the standard properties of the material.

Solving the engineering problems in the field of research and optimization of the building materials technologies involve the use of several groups of processes. Firstly, it is a study of processes subjected to the physical, physicochemical or chemical laws.

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Secondly, the use of statistical methods. Thirdly, the application of methods based on the use of the laws of fluctuation laws. The descriptive models are also widely used, but the adoption of the optimization decisions with their use is practically impossible [4–6]. The methodology described in this article was used to study the technologies of the cellular concrete, the foam fiber concrete, the cement polymer concrete and the mineral wool products. In conveyor technologies, there are some differences from the described methods, due to the continuity of the production process [7–10]. As an example of implementation, the article discusses the optimization of the foam-fiber concrete technology.

2 Methods

The basis for the study of the technological processes is their presentation as a "cybernetic system". And the main research methodology is statistical methods. The object of the research in this case is the technological process. The cybernetic system called the "black box", with its own input parameters, control actions and outputs, is widely used to describe it. The "black box" can cover either the whole technology as a whole, or a separate technological redistribution, i.e. separate process: mixture preparation, molding, heat treatment.

The foam-fiber concrete is a foam concrete reinforced with a basalt fiber. The products based on it (the blocks) are used in the construction of external and internal walls and partition elements. Compared to classical foam concrete, the foam-fiber concrete has much less shrinkage and creep, and greater strength (at the equal average density). The technology of this material includes the following steps: separate preparation of the foam of the cement and the fiber mixtures; mixing them to obtain the foam-fiber-cement mixture; mold casting; heat treatment and warehousing of products. Considering that any technological process can be characterized by a large number of variable factors, the optimization methodology developed at the MGSU [3] provides for research in two stages. At the first stage, all factors describing the technology are used. Further, in the course of the experiment (active or passive), the most significant factors are established and proceed to the second stage. In the second stage, only the most significant factors are involved. As a result, the second-degree regression equations are obtained, the significance of the coefficients and the adequacy of the models are checked, and they proceed to analytical optimization [11, 12].

The concept of analytical optimization is based on two statements. First, the resulting mathematical model (in the form of a polynomial) is adequate to the real process, that is, it describes it with an established degree of accuracy. Secondly, the obtained mathematical model is an algebraic nonlinear function of several variables: with this function, all types of actions can be performed using the apparatus of mathematical analysis.

In fact, analytical optimization consists in determining the points of extremum of the function of several variables with respect to each variable (for which they find the partial derivatives for each of the variables and equate them to zero); solving polynomials taking into account the found extreme functions and obtaining regression equations optimized for one or more variables. Mathematically, this can be represented by the following sequence of equations:

$$Y = f(X_1, X_2, \ldots, X_k) \tag{1}$$

$$\frac{dY}{dX_1} = f(X_1, X_2, \ldots, X_k) = 0 \rightarrow X_1 = f_1(X_2, X_3, \ldots, X_k) \tag{2}$$

$$Y[X_1 = f_1(X_2, X_3, \ldots, X_k)] = f_{opt}(X_1, X_2, \ldots, X_k) \tag{3}$$

The next steps are the interpretation of the obtained optimized polynomials (analytical, physical and graphical) and additional experiments in the field of calculated optima in order to verify and confirm the results obtained by calculation.

The next, the process algorithm is formed using optimized functions and compiling computer programs.

3 Results

The analysis of the technology of foam concrete reinforced with basalt fiber revealed 19 process characteristics that influence the results (functions Y_1 and Y_2) with varying degrees of intensity. As the resulting functions are taken: Y_1 - the average density of the foam-fiber concrete, kg/m^3; Y_2 - compressive strength of the foam-fiber concrete, MPa. To evaluate the effect (calculation of bi coefficients for single X_i), an experiment was planned for 19 factors. The experimental conditions are presented in the Table 1 (columns 1–4). As a result of an active experiment and observations of the production of foam-fiber concrete products, the coefficients of the regression equations were determined for single values of the factors (Table 1, columns 5 and 6).

The matrix was constructed in such a way that it was not possible to calculate pair wise and quadratic interactions, but this was not required at the first stage of the experiment. The coefficients in bold are smaller (in absolute value) of the confidence interval Δb, therefore, they are insignificant and equal to 0 (bi = 0).

As a result of the analysis of the significance of the coefficients (the degree of their influence on the result), 4 factors were identified that have the greatest impact on the result. To study this influence in detail and develop practical recommendations, an experiment was carried out and analytical optimization was carried out.

As a result of assessing the significance of factors, the greatest influence on the result was exerted by:

- the consumption of the basalt fiber, kg/m^3: coefficients at X_1 are 4 in Y_1 and 0.27 in Y_2;
- the length of basalt fibers, mm: the coefficients at X_2 are −20 in Y_1 and 0.14 in Y_2;
- the consumption of the Portland cement, kg/m^3: the coefficients at X_3 are 3 for Y_1 and 0.34 for Y_2;
- the foaming agent consumption, kg/m^3: coefficients at X_4 are −60 in Y_1 and −0.23 in Y_2.

These factors were used at the second stage of the experiment - the construction of quadratic regression equations and their analytical optimization.

Table 1. Experimental conditions for ranking and determining the significance of factors

Name of factor	Symbol X_i	The average value of the factor, $\overline{X}_i$	Interval of variation, ΔX_i	Coefficient value at X_i	
				Y_1	Y_2
Consumption of basalt fiber, kg/m^3	X_1	0,75	0,25	**4**	0,27
The length of basalt fibers, mm	X_2	5	1	−20	0,14
Portland cement consumption, kg/m^3	X_3	265	25	**3**	0,34
Foaming agent consumption, kg/m^3	X_4	10	2	−60	−0,23
Diameter of basalt fibers, microns	X_5	5	1	**−6**	0,09
Sand consumption, kg/m^3	X_6	120	40	**7**	−0,08
Water consumption, dm^3/m^3	X_7	110	20	**3**	−0,07
Duration of grinding sand, min	X_8	40	10	**6**	**0,05**
Mill load factor	X_9	0,5	0,2	**5**	0,07
Foam preparation time, min	X_{10}	12	4	10	**−0,04**
The frequency of the foam mixer shaft rotation, min^{-1}	X_{11}	40	10	9	**−0,05**
The duration of mixing, min	X_{12}	10	4	8	0,09
The mixer shafts rotation frequency, min^{-1}	X_{13}	25	5	10	0,10
Exposure before heat treatment, h	X_{14}	3	1	**4**	0,09
Exposure temperature, °C	X_{15}	30	10	**5**	0,08
The temperature rise in the heat treatment chamber, h	X_{16}	4	1	**5**	0,07
Exposure at constant temperature, h	X_{17}	6	1	**6**	0,09
Heat treatment temperature, °C	X_{18}	80	15	**7**	0,11
Temperature reduction up to 30 °C, h	X_{19}	4	1	**6**	0,08
Confidence interval Δb				8	0,06

The experiment, the matrix of which is presented in Table 2, was aimed at optimizing the properties of the raw materials and optimizing the composition of the foam-fiber concrete.

The technology of the two-stage foam concrete has been studied quite well and its formulations have passed wide testing. The novelty lies in the use of the basalt fiber (fiber). Therefore, in the experiment, this aspect of the technology was given the special attention. The following functions were taken as optimization functions: Y_1 — an average density of the foam-fiber concrete, kg/m^3; Y_2 – a compressive strength of the foam-fiber concrete, MPa.

Table 2. Experiment conditions

Name of factor	Symbol X_i	The average value of the factor, $\overline{X}_i$	Interval of variation, ΔX_i	Factor values at levels	
				−1	+1
Consumption of the basalt fiber, kg/m^3	X_1	0,75	0,25	0,5	1,0
The length of basalt fibers, mm	X_2	5	1	4	6
Consumption of the Portland cement, kg/m^3	X_3	265	25	240	290
The foaming agent consumption, kg/m^3	X_4	10	2	8	12

The statistical processing of the experimental results allowed us to obtain the following dependencies:

1. The average density of the foam concrete reinforced with basalt fiber:

$$Y_1 = 560 - 20X_2 - 60X_4 + 12X_2^2 \tag{4}$$

The confidence interval calculated through the Student criterion and the variance of parallel experiments was Δb = 8. All coefficients of the equation smaller than Δb are considered insignificant and equal to 0. The analysis of the polynomial shows that the density of the foam concrete is most affected by the foaming agent consumption and by the increase in the length of basalt fibers. It was determined that the use of short fibers helps to reduce the average density (−20 coefficient at X_2) – the foam is stabilized. At large lengths, the density increases (factor 12 at X_2^2) - the destruction of the foam structure by long fibers is possible.

2. The optimal fiber length is determined using the analytical optimization method:

$$\partial Y_1/\partial X_2 = -20 + 24X_2 = 0 \tag{5}$$

respectively X_2 = 20/24 = 0,83.
In physical terms, the optimal length of basalt fiber is:

$$\widetilde{X_2} = \overline{X_2} + \Delta X_2 \cdot (0{,}83) = 5 + 1 \cdot 0{,}83 = 5{,}83 \tag{6}$$

Taking account of the accepted probability of predicting a reliable result of 98%, the optimal length of the basalt fiber is 5.8 ± 0,1 mm

3. We solve the equation Y_1 (X_2X_4) with X_2 = 0.83:

$$Y_1[X_2 = 0{,}83] = 560 - 20 \times 0{,}83 - 60X_4 + 12 \times (0{,}83)^2 = 552 - 60X_4 \tag{7}$$

4. The strength of the foam-fiber concrete is determined by the following polynomial

$$Y_2 = 2{,}81 + 0{,}25X_1 + 0{,}12X_2 + 0{,}32X_3 - 0{,}22X_4 - 0{,}11X_1X_2 + 0{,}13X_2X_3 - 0{,}09X_1X_3 \tag{8}$$

The calculated confidence interval is Δb = 0.06. To the greatest extent, the strength depends on the consumption of Portland cement (coefficient at X_3 equal to 0.32), to a slightly lesser extent on the consumption and length of basalt fibers and the consumption of foaming agent (coefficients at X_1, X_2, X_4). With an increase in the consumption of the foaming agent, the strength decreases (coefficient at X_4 equal to −22). Of the pair interactions, the most significant in X_2X_3 is the combined effect of the fiber length and the consumption of Portland cement.

5. Taking into account the results of analytical optimization, we solve the equation $Y_2 = f_1(X_1X_2X_3X_4)$ with $X_2 = 0{,}83$

$$Y_2[X_2 = 0{,}83] = 2{,}88 + 0{,}38X_3 + 0{,}18X_1 - 0{,}22X_4 - 0{,}09X_1X_3 \quad (9)$$

6. The foaming agent consumption (X_4) is determined by calculation. In the model, we equate it to the average value (in encoded form $X_4 = 0$).

Accordingly, Y_1 becomes equal to 552 kg/m^3, which, taking into account the accuracy of the experiment (98% probability), will be 552 ± 11 kg/m^3, and the equation for the strength of foam concrete takes on the final form:

$$Y_2 = 2{,}88 + 0{,}38X_3 + 0{,}18X_1 - 0{,}09X_1X_3 \quad (10)$$

The next step in the methodology was the construction of a process algorithm. The structure of the algorithm is as follows: input block of input data (factors in natural value), coding block of factors in natural value, function block, decoding block, data output block. The functional (calculated) block of the algorithm has included all the linear dependencies obtained from the results of the first stage of the experiment, as well as the optimized functions obtained from the results of the second stage of the experiment. Based on the algorithm, a computer program was developed, all numerical calculations were carried out, and a graphical interpretation was carried out. A fragment of a graphical interpretation of the dependence Y2 = f2 (X1X3) is presented in Fig. 1.

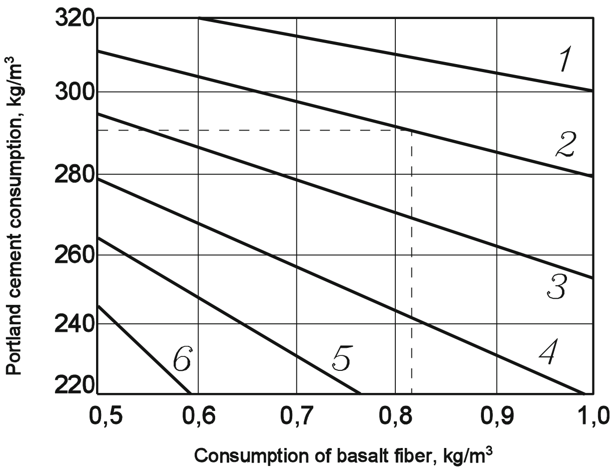

Fig. 1. Determination of the consumption of the Portland cement and the basalt fiber depending on the required strength of the products (with a design average density of 550 kg/m^3), MPa: 1 – 3,2; 2 – 3,0; 3 – 2,8; 4 – 2,6; 5 – 2,4; 6 – 2,2.

Taking into account the data of analytical optimization and Fig. 1, the consumption of the basic components are determined (Table 3).

Table 3. The consumption of the basic components

Average density, kg/m^3	Consumption of the components, kg/m^3			
	Portland cement	Silica filler	Water	Basalt fiber
400	240	73	95	0,8
500	270	117	110	0,7
600	313	159	126	0,6

The parameter for optimizing the manufacturing process of the foam-fiber concrete is the strength-density ratio of the material. For its value determination, we use the optimization function:

$$K_k = \frac{Y_2}{Y_1^2} = \frac{2.88 + 0.38X_3 + 0.18X_1 - 0.09X_1X_3}{(550)^2} \quad (11)$$

The graph of the function $K_\kappa = f_3(X_1, X_3)$ for the region of optimal values is presented in Fig. 2

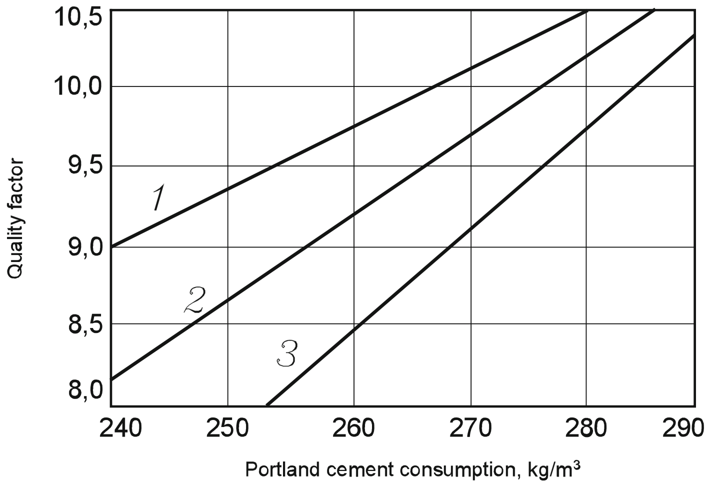

Fig. 2. The correspondence of the strength-density coefficient (quality factor) of the foam-fiber concrete on the consumption of the Portland cement and the basalt fiber, kg/m^3: 1 – 1,00; 2 – 0,75; 3 – 0,50

As a result of the experiment, it was found that the consumption of the basalt fiber affects both the strength and the density of the cellular concrete products. The length of the basalt fiber only affects the strength of the products. The nomogram has been constructed that allows one to determine the consumption of the basalt fiber depending on the required strength of the products and the consumption of the Portland cement. The effect of the consumption of the Portland cement and the basalt fiber on the strength-density coefficient of the foam-fiber concrete was studied.

4 Conclusions

The use of the mathematical methods in the study of technological processes is an effective tool in solving practical problems. In the field of building materials technologies, these methods can be used in optimizing the technology parameters and in optimizing the consumption of the raw materials that ensure the optimal results.

The proposed concept of the analytical optimization is based on two statements. (1) The resulting mathematical model (in the form of a polynomial) is adequate to the real process, that is, it is described with an established degree of accuracy. (2) The resulting mathematical model is an algebraic nonlinear function of several variables: with this function, all types of actions can be performed using the apparatus of mathematical analysis. The methodology for optimizing the foam-fiber concrete technology, presented as an example, is in many respects common to other bench production technologies. In conveyor technologies, there are some differences from the methods described, due to the continuity of the production process.

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Current State of Intellectual Property Management and Innovational Development of the Russia

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Abstract. The present research is aimed at studying the current state of intellectual property management and the level of innovational development of Russia. The objective of the study is to substantiate theoretical and methodological provisions of current condition of innovational development level of the government and its control, which are closely connected to modernization of economic system of Russia. It will enable working out theoretical provisions and research and practical recommendations on intellectual property management intended to improve the rate of innovative activities of economic entities. When the set objective was under realization, the following tasks reflecting the logic of the present research were fulfilled: regulatory legal basis of intellectual property management was investigated; aspects influencing the level of innovational development of economy of Russia were studied; problems of intellectual property control and future innovational development of Russian economy were determined; recommendations on improving the system of intellectual property management in modern economy were substantiated. The research substantiated that the current development stage of intellectual property management demands the using the model of complete innovational modernization of economic sectors for raising the level of innovational development of Russia.

Keywords: Intellectual property · Innovational economy · Innovative modernization · Advanced production technologies · Patents

1 Introduction

The authors assume that specific aspects of intellectual property management in the Russian economic system and the innovative development level of the Russian Federation largely depend on the strategic development model being implemented by the government. Thus, the state can implement the first model of complete innovational modernization of economy sectors or the second model of orientation to export of

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hydrocarbons [1]. Innovational modernization involves understanding intellectual property as the main factor of economic development and implementing programs on its stimulation in practice. The second model implies the absence or declaration of support for the development of intellectual property.

By this day, sufficient amount of programmatic documents have been adopted in Russia [2–4] that confirm the priority of the model of innovative modernization of the country's economic system. However, it is worth mentioning that the problem of supporting innovative modernization of the economy is solved extremely inertly and unsystematically in practice. The authors agree with the statement that tasks set by programmatic documents are implemented inefficiently [5]. The scientific literature reflects a judgmental opinion on the problem regarding the management of intellectual property in modern Russia [6–11].

2 Materials and Methods

The research was methodologically based on the fundamental provisions of modern economic theory, theory of state control in the field of intellectual property, comparative analysis of indicators characterizing the level of innovational development of Russia and several foreign countries. Statutory and regulatory enactments of the Russian Federation on intellectual property issues, statistical data of Russia and foreign countries regarding issues of intellectual property management and innovational development, proceedings of national programs became the informational basis of the research.

3 Results

The study on indicators regarding intellectual property management and innovational economy has revealed the close interrelation between the use of results of intellectual property and of advanced production technologies, the innovative activities and long-term competitive performance of organizing various forms of ownership and types of economic activities. The further research will demand finding new levers over improvement of competitive performance of Russian organizations selling goods, works or services.

One of the researchers in the field of innovation management believes that the main goal of the vast majority of innovative development programs adopted in Russia is the corruption, not a comprehensive innovative modernization of the economic system [9]. The authors do not agree with position of the researcher. Corporation «RUSNANO» is one of the most significant organizations providing assistance in the implementation of the state policy for the development of the nanoindustry, investments in high-tech projects and creation of new industries in our country (Table 1).

Table 1. Key indicators of the financial accounts of RUSNANO Group according to IFRS for 2015–2018, million rubles.

Indicator	2015	2016	2017	2018
A. Consolidated statement of profit or loss				
Profit for the year:	**7321**	**4498**	**(5308)**	**5636**
Net income from financial assets	12533	5636	8045	14854
(Loss) Foreign exchange gain	758	(2036)	(625)	1283
Reclassification of exchange differences on translation into presentation currency	–	17581	–	–
Income (including interest income and other operating income)	6679	3557	1855	1015
Operating expenses	(4979)	(5982)	(5189)	(5409)
Financial expenses	(13981)	(14305)	(8782)	(6025)
Income tax expense/income	6311	47	(612)	(82)
B. Consolidated statement of financial position (balance sheet)				
Total liabilities and equity (book value of assets)	**226304**	**194040**	**168395**	**185530**

According to the consolidated financial statements for 2016, the profit of «Rusnano» Group amounted to 4.5 billion rubles. In 2015 «Rusnano» Group demonstrated profit of 7.3 billion rubles. A number of authors note in the scientific literature that this result indicates a steady trend that allows getting profit by increasing the value of the portfolio due to increased asset management and improved development indicators of portfolio companies [12, 13]. In 2017, the loss of «Rusnano» Group amounted to −5.3 billion rubles, in 2018 profit was again observed and amounted to 5.6 billion rubles. The analysis of the financial statements of «Rusnano» Group indicates the presence of ineffective means of state support of innovation in the Russian Federation.

Current global development trends also demonstrate the direct impact of scientific and technological progress on economic growth and improving the welfare of the population, which determines the competitiveness of economic entities and their products in the national and world market. The comparative study of indicators characterizing science and technology, the effectiveness of innovation in certain countries is presented further (Table 2) [14].

The comparison of absolute and relative indicators characterizing the costs of research and development in Russia and other countries showed that the costs of innovative modernization of the Russian economic system are much lower. For instance, the costs in 2016 in relation to the gross domestic product of Russia were 1.10%, while in Germany it was 2.94%, in the UK - 1.69%, in Japan - 3.14%, in the Republic of Korea 4.24%, in the USA - 2.9%.

Table 2. Internal research and development costs for 2014–2016.

Country	2014		2015		2016	
	Million dollars	As a percentage of gross domestic product	Million dollars	As a percentage of gross domestic product	Million dollars	As a percentage of gross domestic product
Russia	40339.2	1.07	39733.7	1.10	39873.9	1.10
Germany	109562.7	2.87	113921.8	2.92	118473.4	2.94
UK	43811.1	1.67	45345.0	1.67	47244.5	1.69
France	60585.6	2.28	61239.8	2.27	62162.7	2.25
Republic of Korea	73099.8	4.29	75734.1	4.22	79354.3	4.24
China	370589.8	2.02	407415.1	2.07	451201.4	2.12
Japan	169554.1	3.40	169673.1	3.28	168644.9	3.14
USA	476460.0	2.73	496585.0	2.74	511089.0	2.74

Table 3. Distribution of internal research and development costs by science sector in 2016, as a percentage.

Country	Public sector	Business sector	Higher education sector	Non-profit organization sector
Russia	32.0	58.7	9.1	0.2
Germany	13.7	68.0	18.3	–
UK	6.3	67.0	24.6	2.1
France	12.9	63.6	22.0	1.6
Republic of Korea	11.5	77.7	9.1	1.6
China	15.7	77.5	6.8	–
Japan	7.5	78.8	12.3	1.4
USA	11.5	71.2	13.2	4.1

The distribution of internal research and development costs by science sectors also characterizes the level of innovative modernization of the state economy (Table 3) [14].

Statistics show the predominance of internal costs for research and development in the public sector of science, while in other countries the costs are distributed more in the business sector, represented by organizations the main activity of which is the production of goods or services for sale.

4 Discussion

Thus, the development and improvement of intellectual property management has unsystematic, declarative nature, and effective innovative activity, which positively affects the Russian economy, is very limited. The number of Russian organizations performing research and development in 2017 amounted to 3944 [15], including research organizations - 1577, design organizations - 273, design and planning-and-surveying organizations - 23, pilot plants - 63, institutions of higher education - 970, industry organizations with research and design divisions - 380, others - 658 (Fig. 1).

The number of Russian organizations performing research and development in 2017 by sector of activity is presented in Fig. 2 [16].

The indicators correspond to the data presented in Table 3 on the distribution of internal costs for research and development by sector of science. The situation is observed that the number of public sector organizations (1493) exceeds the number of organizations in other sectors: business - 1292, higher education - 1038, non-profit organizations - 121.

Patenting intensity factor stiffly affects the proportion of advanced manufacturing technologies used. There is a decrease in the number of patents granted for the period 2015–2018 by 2.8–5.1%, while the share of applied advanced production technologies increases averagely by 6.3% per year (with the exception of 2017 - 3.3%). Thus, a significant part of patents granted in Russia is used insufficiently in the real sector of the economy, thereby not significantly affecting the implementation of innovative modernization (Table 4) [16].

Table 4. Applied advanced production technologies, units.

	Totally	Growth, %	Number of patented advanced technologies being applied	Growth, %
Advanced production technologies, totally				
2014	204546		9519	
2015	218018	6.5	9249	−2.8
2016	232388	6.6	9617	4.0
2017	240054	3.3	9127	−5.1
2018	254827	6.1	8802	−3.6

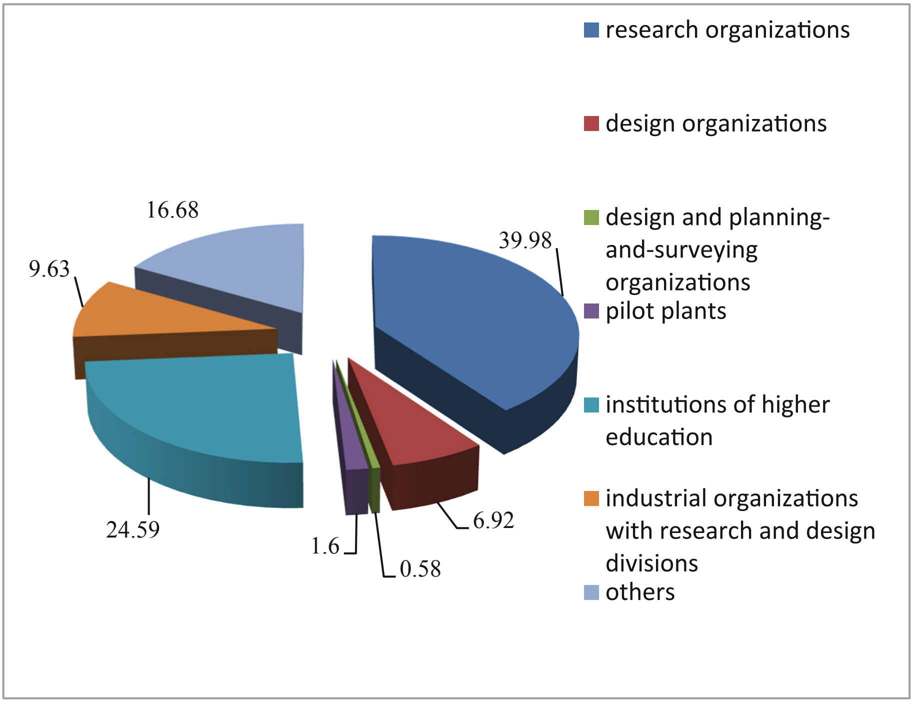

Fig. 1. Types of Russian organizations performing research and development, %.

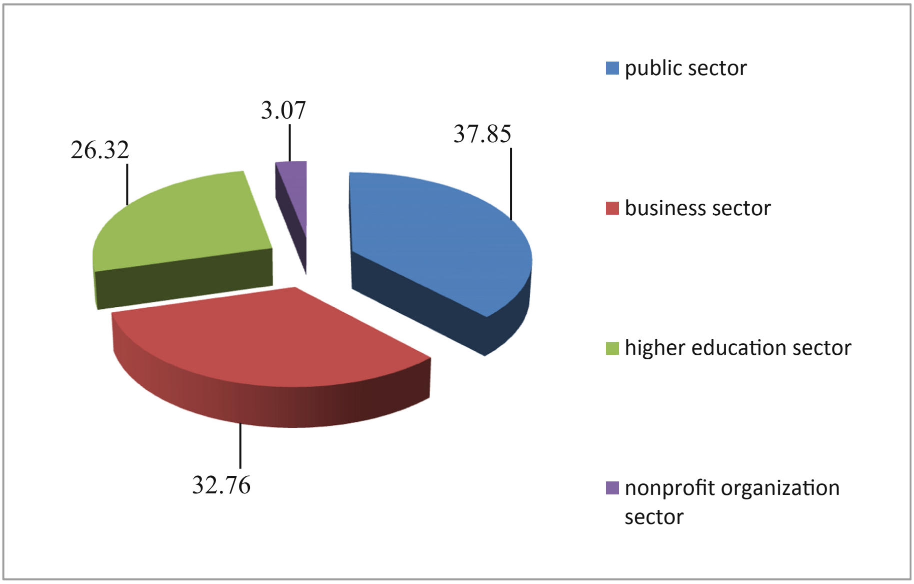

Fig. 2. Number of Russian organizations performing research and development, by sector of activity, %.

5 Conclusions

The authors declare that there is a close interrelation between the management of intellectual property, level of innovative activity and long-term competitiveness level of business entities of various types of economic activity, regardless of ownership forms. Comprehensive innovative modernization of economic sectors that is based on the effective management of intellectual property creates new levers for enhancing the competitiveness of Russian organizations selling goods, works and services.

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Boundary Layer of the Wall Temperature Field

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Abstract. The paper proposes a method for determining the temperature of small and large dimensional areas of enclosing structures. The purpose of the article is to determine the thickness of the temperature boundary layer at non-stationary modes of heat transfer for areas of random dimension. These areas are filled with scalar heat-conducting medium. It is necessary to solve the tasks related to the calculation of heat transfer in walls for one-dimensional and multidimensional models. It is proved that the thermal resistance of a one-dimensional wall is not less than the thermal resistance of a multidimensional wall in both steady-state and unsteady temperature regimes. It is explained that the temperature fluctuations do not pass inside the body of the wall and are localized on the wall surface. The maximum increase in the temperature flow in the steady-state regime for a multidimensional wall is approximately 41% compared to a one-dimensional wall. The effect of inclusions (thermal bridges) is related to the disseminate of heat flow along a multidimensional wall. This is the meaning of geometric inclusion, that is, increasing the dimension of the area filled with a scalar medium. Geometric inclusions must be taken into account when calculating walls other than one-dimensional walls.

Keywords: Energy efficiency · Thermal resistance · Enclosing structure · Heat transfer · Geometric inclusions

1 Introduction

Any enclosing structure performs the function of a thermal barrier (curtain) blocking the transfer of heat. The influence of heat flux unevenness is taken into account by introducing correction coefficients [1–3].

Performance of measures to increase the thermal resistance of the enclosing structures requires assessment of the thermal stability of the wall. It is shown that the increased thermal resistance of the wall does not always ensure the stationary temperature of the wall faces [4]. Increasing the thermal resistance of the wall leads to a rise in the cost of construction.

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The article [5] discusses the increase of heat-protective properties of external enclosing structures. The method of estimation of the coefficient of thermal homogeneity from the analysis of thermograms of external enclosing walls of buildings is stated. Two methods of estimation of the coefficient of thermal homogeneity are proposed. One method is based on obtaining averaged temperature values by numerical processing of thermograms, the other – on numerical integration along the contours of the lines of temperature curves.

Also a large number of works devoted to the microclimate of the spaces [6–8]. In the works of Korniyenko [9, 10] it is concluded that increasing the requirements for moisture protection of enclosing structures when using the calculated values of temperature and relative humidity of the internal air, according to Russian standards, is not always advisable. Taking into account changes in the microclimate parameters in the premises allows to more accurately assess the moisture-proof properties of enclosing structures in the process of their design. Also, according to the results of calculations, it can be seen that the reduction of air permeability of enclosing structures can improve the class of energy efficiency of buildings.

In the works of the Moscow school of construction heat engineering the influence of foreign inclusions on the value of thermal resistance is considered. Inclusion is an area occupied by a foreign heat-conducting medium, different from the medium of the enclosing structures. The influence of inclusions is taken into account by a system of coefficients, taking into account the distortion of the temperature field of the enclosing structures in the stationary mode [11–13]. The influence of foreign (metal) inclusions, their shape and location inside the wall, on the value of heat flow through the wall is specially studied. Obviously, any foreign inclusion leads to a deviation of the current lines near the inclusion, distorting the one-dimensional character of the heat propagation.

The inhomogeneity of the area filled with a heat-conducting medium causes the "spreading" of the heat flow not only across the wall (y-axis), but also along the wall (x-axis, z-axis). The inhomogeneity of an area is when the transverse and longitudinal dimensions of the wall are of the same (close) order. On another, this wall is a two-dimensional or multidimensional wall. This leads to a geometric inclusion effect that distorts the one-dimensional model of heat flow distributions. It is proved that the spreading of the heat flow does not increase the thermal resistance of a homogeneous enclosing structures. That is, the thermal resistance decreases.

The effect of inclusion is taken into account by introducing a correction multiplier into the original form of the Fourier formula for the one-dimensional heat flux. Thus, inclusion is explained as a factor that distorts the one-dimensional propagation of the heat flux. Similarly, the increase in the dimension of the area of the enclosing structures occupied by the heat-conducting medium can be interpreted as a geometric inclusion.

Unsteady modes of heat transfer are considered in the field of classical limit problems of thermal conductivity [14–17]. The reaction of the enclosing structures to changes in temperature limits is manifested in the thermal inertia of the wall and in the regeneration of heat by the wall. Therefore, along with the active thermal resistance, the wall has a reactive thermal resistance. Reactive thermal resistance must be taken into account in non-stationary thermal conditions of the medium.

The purpose of the article is to determine the thickness of the temperature boundary layer in non-stationary modes of heat transfer.

To achieve this goal, it is necessary to solve the problems associated with the calculation of heat transfer in enclosing structures for one-dimensional (thin) and multidimensional (thick) models:

1. The effect of inclusion on the inhomogeneity of the temperature field and heat flow
2. Determination of heat flow in one-dimensional and multidimensional walls

It will be proved that under constant limit (boundary) conditions the thermal resistance does not increase with increasing dimension of the domain.

2 Methods

It is necessary to determine the question of the existence of a one-dimensional temperature field in the strip $-\infty < x < \infty$, $0 < y < h$. It is assumed that the x, y coordinates are already normalized, h: = H/L, L, H – longitudinal and transverse dimensions of the wall, (values are either of the same order or incommensurable). Figure 1 shows a diagram of a one-dimensional wall, stylized unlimited strip (the change in surface temperature occurs at the x coordinate), but the temperature inside the strip also depends on the y coordinate.

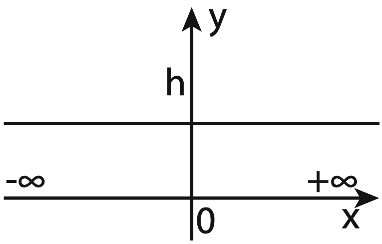

Fig. 1. Scheme wall

It is necessary to reverse the Laplace operator (∇^2) in the strip, if the limiting conditions of the first kind (Dirichlet): $T(x,0) - \varphi_0(x) = T(x,h) - \varphi_1(x) = 0, \varphi_{0,1} \in L_1(E^1)$:

$$T(x,y) = \frac{1}{2\pi}\left(\begin{array}{l} \int\limits_{-\infty}^{\infty} d\xi\varphi_0(\xi) \int\limits_{-\infty}^{\infty} d\omega \frac{sh\omega(h-y)}{sh\omega h}\exp(-i\omega(x-\xi)) \\ + \int\limits_{-\infty}^{\infty} d\xi\varphi_1(\xi) \int\limits_{-\infty}^{\infty} d\omega\frac{sh\omega y}{sh\omega h}\exp(-i\omega(x-\xi)) \end{array}\right) \quad (1)$$

where:

ξ—the variable of integration;
$\varphi_{0,1}$—the temperature on the wall surface faces;
x, *y*—coordinates, m
h—wall thickness, m
ω—spectral number
i—imaginary unit

Consider the case if **h** $\ll$ **1,** then the formula (1) takes the form:

$$T(x,y) = \varphi_0(x)(1 - y/h) + \varphi_1(x)y/h,$$

Conclusion: for a narrow strip (thin wall), the temperature distribution in section x = const is determined by the limit temperatures $\varphi_{0,1}(x)$ in this section. Heat flow in this section is determined by the local temperature difference $\varphi_0(x) - \varphi_1(x)$. This is the "the Saint-Venant principle". The heat flux in the direction of the X axis is less than the heat flux in the direction of the Y axis in h- times at all points of the distribution density (functions) $\varphi_{0,1}(x)$.

In this case, we can use a one-dimensional model and assume that the temperature distribution in the section x = const does not depend on the temperature distribution in adjacent sections. In this case, the heat flow in the section x = const is determined by the wall thickness and the temperature difference only in this section.

Consider the case if **h** $\gg$ **1** (wall of large thickness). Then a Dirichlet core handling formula is formed for the temperature distribution in the upper half-plane y > 0, where t = the variable of integration:

$$T(x,y) = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{\varphi_0(x - ty)dt}{1 + t^2}.$$

The second dimension by x (length or width of the building on the wall) is included. The Dirichlet formula can be written as follows:

$$T(x,y) = \frac{1}{\pi} \int_{0}^{\infty} \frac{\exp(-ty\partial_x)dt}{1 + t^2} \varphi_0(x) = \exp(-iy\partial_x)\varphi_0(x).$$

It can be verified that this formula really depicts the solution of the first limit problem for the Laplace equation, where $i^2 = -1$.

3 Results and Discussion

Any effect that bends the heat flow current line is an inclusion. There are three types of inclusions: foreign inclusion, geometric inclusions (change of domain dimension), boundary inclusions (inhomogeneity of boundary temperatures). By definition, the transverse component of the heat flux density is determined by:

$$\dot{q}_y(x,y) := -\frac{\partial T}{\partial y} = \frac{2}{\pi}\int_0^{\infty} \frac{t\varphi_0'(x-yt)}{1+t^2}dt = i\partial_x \exp(-iy\partial_x)\varphi_0(x) = i\exp(-iy\partial_x)\varphi_0'(x),$$

it follows from this expression that:

- the heat flux density on the line $x = 0$ is $\partial_x\varphi_0(x)$;
- it is necessary to implementation the conditions of thermal equilibrium in a stationary temperature regime:

$$\int_{-\infty}^{\infty} \dot{q}_y(x,0)dx = 0 \rightarrow \varphi_0(\infty) - \varphi_0(-\infty) = 0.$$

The heat flux density on the ordinate $y = 0$ is determined by the standard:

$$\dot{q}_y(x,0) := -\left(\frac{\partial T}{\partial y}\right)_{y=0} = -\frac{1}{\pi}\lim_{y\rightarrow+0}\int_{-\infty}^{\infty} \frac{\partial_y\varphi_0(x-ty)tdt}{1+t^2} = \frac{1}{\pi}\int_{-\infty}^{\infty} \frac{t\partial_x\varphi_0(x)}{1+t^2}dt.$$

In symbolic notation: $\dot{q}_y(x,0) = i\varphi_0'(x)$.

As can be seen, in the case of a half-plane, the heat flux distributing in the direction of the y axis clearly depends on the x coordinate. In this case, the one-dimensional model of thermal conductivity does not work.

Conclusion: there is a nonzero x-component of the temperature gradient commensurate with the y-component of the gradient. The inhomogeneity of the boundary temperature distribution $\varphi_0(x)$ on the ordinate $y = 0$ plays the role of inclusion, distorting the one-dimensional model of heat distribution:

$$\dot{q}_x(x,y) := -\frac{\partial T}{\partial x} = -\frac{1}{\pi}\int_{-\infty}^{\infty} \frac{\varphi_0'(x-yt)dt}{1+t^2} = \exp(-iy\partial_x)\varphi_0'(x),$$

It turns out that the components of the heat flux density vector are equal (almost) at all points of the upper half-plane. The modulus of the heat flux vector is 1.41 times greater than its x, y components.

If h = O(1) (the order of unity"moderate" width), the wall of finite thickness (parameters are set by x, y coordinates), the temperature distribution in the strip, approximately has the form:

$$T(x,y) = \frac{1}{\pi}\left(\int_{-\infty}^{\infty} \frac{\varphi_0(x-ty)dt}{1+t^2} + \int_{-\infty}^{\infty} \frac{\varphi_1(x-t(h-y))dt}{1+t^2}\right).$$

The value of the heat flux density along the y axis is calculated as follows:

$$\dot{q}_y(x,y) = -\frac{\partial T}{\partial y} = \frac{1}{\pi}\int_{-\infty}^{\infty} \frac{\varphi_0'(x-ty) - \varphi_1'(x-t(h-y))}{1+t^2} t dt,$$

where: $\varphi_0' \varphi_1'$ - derivative over the entire argument (x − ty)

Using the commutativity of the operator ∂x, this can be written:

$$\dot{q}_y(x,y) = i\big(\exp(-iy\partial_x)\varphi_0'(x) - \exp(-i(h-y)\partial_x)\varphi_1'(x)\big).$$

It turns out that the heat flow across the wall of bounded thickness (two-dimensional wall) is determined by non-local difference of boundary temperatures on ordinates y = 0, y = h. The heat flow is determined by the difference of the boundary temperature derivatives, as opposed to the one-dimensional wall.

The idealized model of heat transfer is a stationary mode. At the time-varying temperature of the external source (the air in the room and/or in the surrounding area) or the abundance of the heat source, there is a reactivity of the wall. The reactive component is manifested in the damping of the source temperature change by the solid medium (wall construction material). Also in existence of "delay" of reaction of a enclosing structures on change of temperature and/ or power of a source.

Both effects influence on the thermal resistance of the enclosing structures. For example, in the conditions of stationary heat transfer no heat accumulation in the wall can not be. By virtue of the condition of continuity $div\mathbf{q} = 0$. The temperature distribution in the wall is uniquely determined by the limiting temperatures. In case of unsteady heat transfer, the inertia of the temperature distribution and the accumulation of heat are determined by the value of the local temperature derivative $\partial(T,x)/\partial(t,x) = \partial T/\partial x$.

The traditional mathematical apparatus used to calculate the temperature state of enclosing structures is based on Fourier analysis of the point spectrum of the external source temperature. The application of the continuous spectrum allows us to obtain simple expressions for solving the first and second limit problems in the one-dimensional case.

$$T(t,y) = \exp\left(-y\partial_t^{1/2}\right)T_w(t),$$
$$T(t,y) = \exp\left(-y\partial_t^{1/2}\right)\partial_t^{-1/2}\dot{q}_w(t),$$

Figure 2 shows a graph of temperature attenuation along the wall thickness. Where T_w – boundary temperature.

That is, the temperature fluctuations do not pass inside the solid and are localized near the surface of the heat supply. Figure 3 shows the speed of attenuation of temperature fluctuations. Experimental data on temperature attenuation in the body of a full-bodied clay brick are given. The speed of temperature change are plotted along the vertical axis ∂T/∂t, for various cavities of the thermocouple, x-axis-time in minutes. A "rectangular" temperature pulse was created on the surface of the heat supply

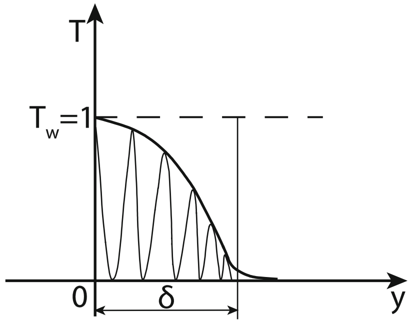

Fig. 2. Attenuation of temperature fluctuations along the wall thickness

(removal) and the speed of temperature fluctuations at different depths of thermocouple sealing were measured.

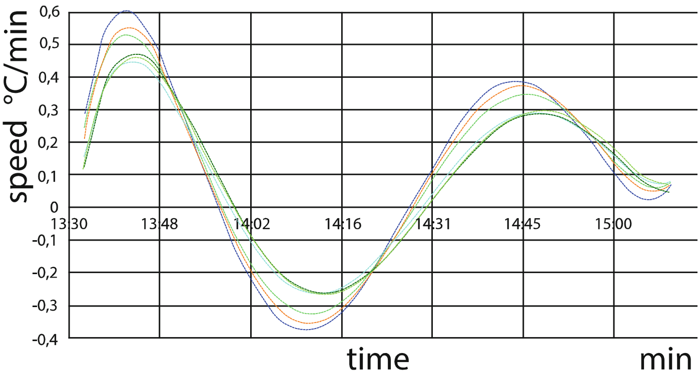

Fig. 3. Speed of temperature change over time

For a two-dimensional domain, the solution of the limiting first and second Fourier problems has the form. Where ^ the Fourier transform in X with a continuous spectrum is denoted:

$$\hat{T}(t,y) = \exp\left(-y/\sqrt{\omega^2 + \partial_t}\right)\hat{T}_w(t),$$
$$\hat{T}(t,y) = \exp\left(-y/\sqrt{\omega^2 + \partial_t}\right)\sqrt{\omega^2 + \partial_t}\hat{q}_w(t).$$

From the given dependences it follows that the heat flux in the one-dimensional problem is not less than in the two-dimensional:

$$q_w(t) = \partial_t^{1/2} T_w(t),$$
$$\hat{q}_w(t) = \sqrt{\omega^2 + \partial_t} \hat{T}_w(t),$$

If the boundary temperature $T_w(t, x)$ does not depend on x, then the thickness of the temperature boundary layer of the one-dimensional and two-dimensional walls is determined by:

$$\delta(t) = \partial_t^{-1/2} T_w(t)/T_w(t),$$

$$\delta \hat{T}_w = \left(\partial_t^{(\omega)}\right)^{-1} (\partial_t^{(\omega)})^{1/2} \hat{T}_w,$$
$$\delta = \left(\partial_t^{(\omega)}\right)^{-1/2} \hat{T}_w(t)/\hat{T}_w(t).$$

The results are agreed with the existing literature [18–20]. It is proved that high thermal mass (thermal resistance) often leads to higher energy consumption in cold climates. Enclosing structure with high thermal mass, will be effective in hot climates. This result has implications for the design of buildings in cold climates and contradicts the generally accepted assumption that high heat mass correlates with low energy consumption. Passive heat storage in the room is a promising solution to improve the energy efficiency of the building.

4 Conclusions

1. The effect of inclusions that cause the inhomogeneity of the temperature field of the heat flow is due not only to the heterogeneity of the material of the enclosing structure, but also its size. In a one-dimensional wall, the temperature distribution is linear, the heat flow is one-dimensional and distribution across the wall. In this model, the longitudinal components of the wall heat flow are small. In a two-dimensional wall, there is another degree of freedom for heat flow: along the wall (changing the length or width of the building on the wall).
2. In a two-dimensional wall, the heat flux is 41% greater than in a one-dimensional wall with the same temperature difference. In a two-dimensional wall, the heat flux modulus is generally greater than in a one-dimensional wall.

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Calculation and Strengthening of Reinforced Concrete Floor Slab by Composite Materials

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Abstract. The research and comparison of traditional and composite method of reinforced concrete slab reinforcement is carried out in the article. The administrative office building was considered. By means of the software forces in an overlapping plate were defined. Taking into account the complexity of the pretension of composite elements, the calculation was made taking into account the initial stress-strain state in the cross section. All calculations of the stress-strain state of the section are performed using a nonlinear deformation model. Graphic images of the results calculation are shown. Show the diagrams of strains and stresses in the cross selection of the element under the action of the initial and calculated moment, as well as the characteristic parameters of the stress-strain state. MBRACE LAMINATE lamellas produced by BASF were used as reinforcement materials. The influence of the reinforcement method using a composite material on the load-bearing capacity of the slab is assessed. The estimation of economic efficiency of the use of two methods of reinforcement is made.

Keywords: Concrete structure · Strengthening · Composite · Materials

1 Introduction

Strengthening of bearing reinforced concrete structures and ensuring their required characteristics using composite materials is a hot topic, especially when it is required to strengthen structures in places where it is impossible to perform reinforcement in the form of steel or reinforced concrete elements. To perform structural reinforcement with composite materials, it is necessary to take into account not only the design parameters and calibration calculations of load-bearing structures, but also the results of field surveys with the analysis of the possibility of performing structural reinforcement with composite materials.

2 Materials and Methods

The administrative office building was considered. In terms of the complex shape of the building with the dimensions of the building area 44 × 36 m, with a maximum height of 25 m above ground. The building has 5 floors. The height of the floors is different;

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there are numerous differences on the floor slabs. There is a basement under the entire area of the building. The structural system of the building is a monolithic reinforced concrete frame. The spatial rigidity of the building is provided by the joint work of columns, walls, floor discs and coatings, as well as rigid sealing of columns and walls in the Foundation.

According to the results of technical inspection of floor slabs, it was decided to strengthen them. The analysis of possible variants of amplification is carried out. According to the results of the analysis, it is concluded that it is impossible to strengthen this structure of floors using standard methods of strengthening. Thus, it was decided to strengthen the composite materials.

By means of the software forces in an overlapping plate were defined. Taking into account the complexity of the pre-tension of composite elements, the calculation was made taking into account the initial stress-strain state in the cross section. All calculations of the stress-strain state of the section are performed using a nonlinear deformation model.

The selection of reinforcement elements by external composite reinforcement on the example of basement floor slabs was considered. Figure 1 shows a fragment of the results of the calibration calculation with the selected areas of the deficit of the lower reinforcement in the slab.

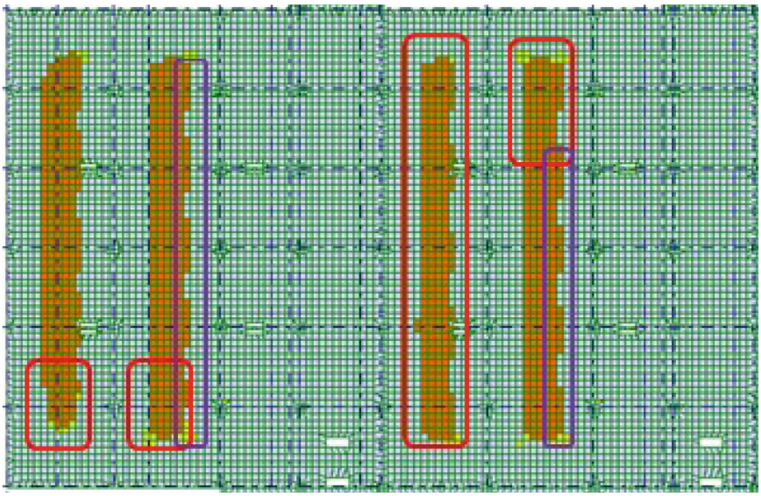

Fig. 1. Lower reinforcement of floor slabs of the basement along the x-axis. Red frames highlight areas with a deficit of bearing capacity (above 50%). Purple frames highlighted areas with insufficient institution of working valves for breakage points.

To conduct the study was taken the section of the monolithic slab thickness of 250 mm, a size of the selected parcel in the plan correspond to 22 $\times$ 23 m as the initial stress-strain state of the cross section the adopted value of the bending moment in the span Minit. = 11.5 kN m/m (hereinafter all calculations are carried out for 1 ML the width of the slab) from its own weight – assumes full unloading of the slabs at the time of strengthening with composite materials. The isofields of bending moments from the action of its own weight along the X axis for the considered area are shown in Fig. 2. The deformations in the section determined at the specified moment are the initial ones for the subsequent calculation taking into account the layer of composite material added to the section.

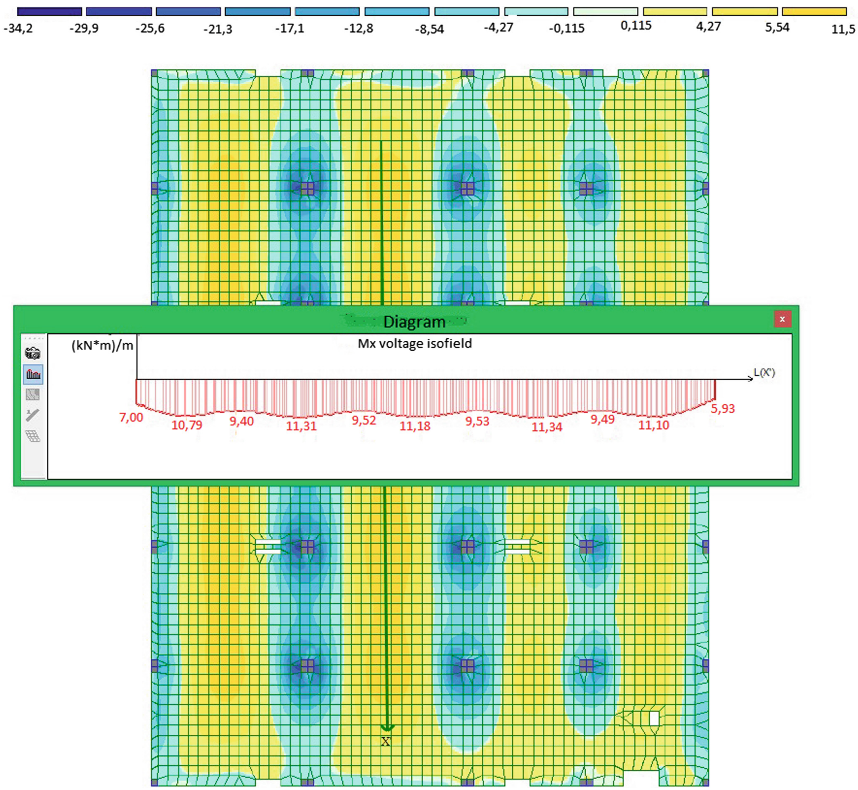

Fig. 2. The area of overlap. Values of bending moment on the X axis from the action of its own weight.

Figure 3 shows the isofields of bending moments along the X-axis at the calculated combination of loads. The maximum value of Mccl = 32.3 kN m/m. The Gain is considered sufficient if the limiting moment for the reinforced section is greater than the effective one.

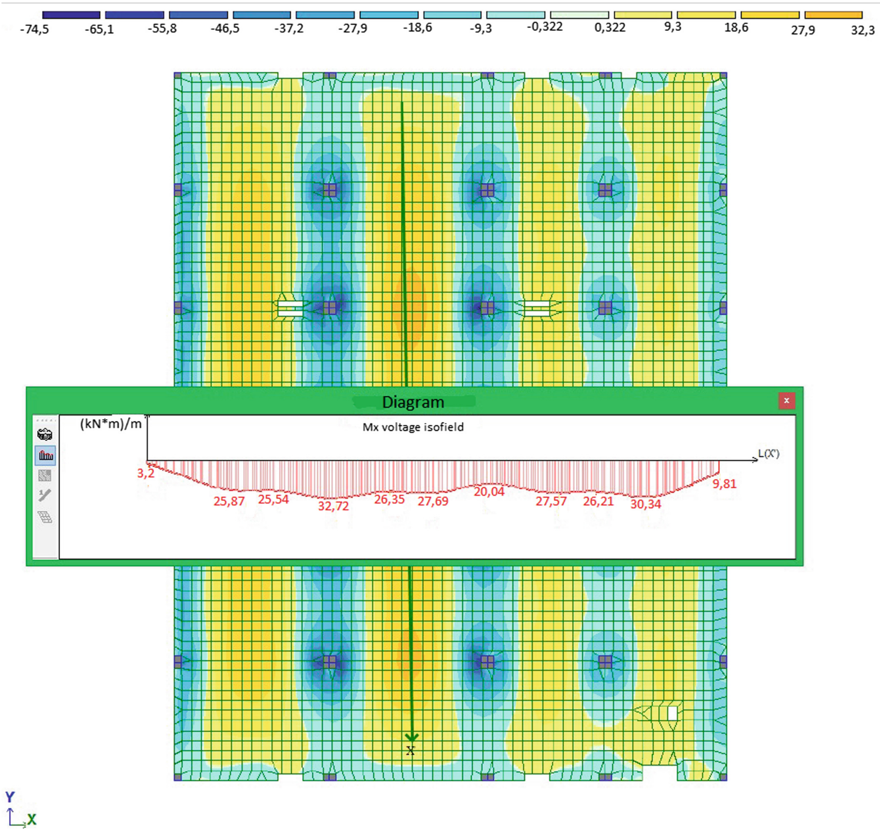

Fig. 3. The area of overlap. Values of the bending moment along the X axis at the calculated combination of loads.

3 Results

MBRACE LAMINATE lamellas produced by BASF were used as reinforcement materials. CF 165/3000 lamellas were adopted tensile strength - more than 3000 MPa, modulus of elasticity-more than 165000 MPa.

The calculated resistance of the composite material under the action of constant and prolonged loads was calculated based on the expression:

$$R_f = \gamma_{f1} \cdot \gamma_{f2} \cdot \gamma_{f3} \cdot R_{f,n}, \tag{1}$$

γf1 = 0.95 for indoor carbon composites;
γf2 = 0.9;
γf3 = 0.8 for carbon composite;
Rf, n – tensile strength, MPa.

Thus the calculated resistance of the composite material is set as follows:

$$R_f = 0.95 \cdot 0.9 \cdot 0.8 \cdot 3000 = 2052 \text{ MPa}. \quad (2)$$

The value of the ultimate strain at break corresponds to:

$$\varepsilon_{ft} = R_f/E_f = 2052/165000 = 0.0124, \quad (3)$$

Ef – modulator of elasticity.

Reduction of ultimate tensile strains for lamellas from the condition of preventing lamellas separation from concrete is taken into account by applying a correction factor equal to 0.524. With this in mind, the ultimate tensile strain εfu = 0.00649 (≈0.6%). During the study, the lamella pitch of 280 mm and their width of 50 mm was adopted. Then, 178.57 mm of the lamella width falls on 1 p.m. The thickness of the slats taken – 1.4 mm.

Figures 4 and 5 show the diagrams of strains and stresses (in concrete) in the cross section under the action of the initial and calculated moment, as well as the characteristic parameters of the stress-strain state (deformation in the extreme fibers, curvature, forces in the cross section). In Fig. 5, the extreme lower strain is assumed to be close to the ultimate tensile strain εfu = 0.00649.

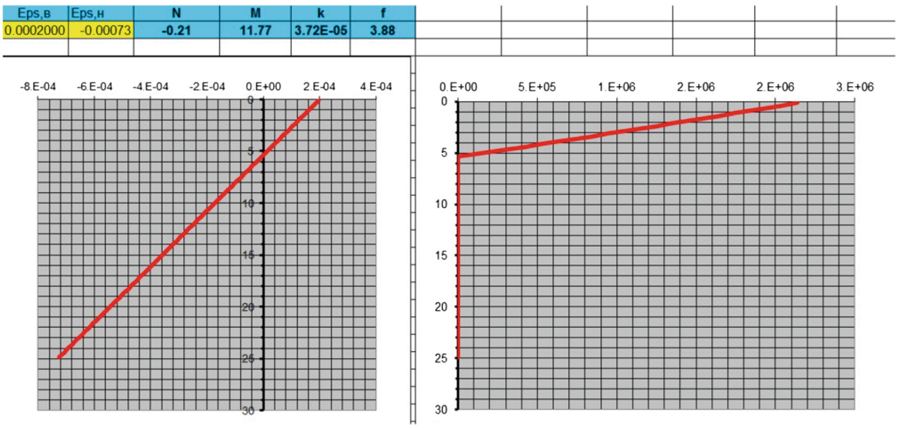

Fig. 4. Initial stress-strain state for the section of 1 linear meter of the floor slab. Yellow is the strain in the extreme fibers of the cross section, which determines the stress-strain state.

The resulting ultimate bending moment in the cross section with the added composite material Mult = 104 kN m/m, which is more than 2 times higher than the calculated bending moment Mccl = 32.3 kN m/m.

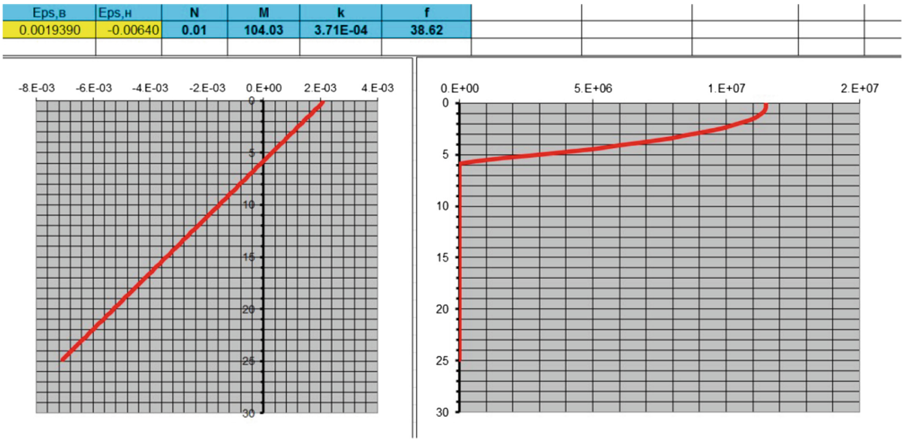

Fig. 5. Initial stress-strain state for the section of 1 linear meter of the floor slab. Yellow is the strain in the extreme fibers of the cross section, which determines the stress-strain state.

4 Discussion

Performance of strengthening of this site of a monolithic slab with use of steel beams would cause a number of certain difficulties. It is important to note that the feature of strengthening with steel beams is that for significant unloading of the ceiling, beams of significant cross-sections are needed, whose stiffness will be comparable to the stiffness of the floors. From using of composite materials it was possible to strengthen the floor slab with minimal labor costs and the greatest efficiency.

5 Conclusions

As a result of this work, it can be concluded that the strengthening of composite materials in no way inferior to traditional methods of strengthening (steel beam, increasing the cross-section of the element). According to the results of this work, it is clear that the load-bearing capacity of the reinforced element is provided, and there is a sufficiently large reserve of load-bearing capacity.

It should also be pointed out that reinforcement using composite materials is more economical and more effective in application for most designs.

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State and Prospects of Development of Self-regulation in Construction Industry of Russia

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Abstract. The present research is aimed at studying the current state and prospects of self-regulation development in the construction industry of Russia. The objective of the research is a comprehensive analysis of the condition and prospects of self-regulation as the institution of public management system, defining the problems of self-regulation of the construction industry and working out the ways to solve them. While the set aims were under realization, the following problems reflecting the logic of the present research were solved: the mechanism of statutory regulation of activities of self-regulatory companies regarding construction industry (construction itself, constructional design and engineering surveying) was studied; condition of and positive tendencies in self-regulation of the construction industry were investigated; problems in activities of self-regulatory organizations regarding construction industry (construction itself, constructional design or engineering surveying) were revealed, development prospects for the considered alternative to state control were defined. The study substantiated that at current development stage of construction industry self-regulation, the most efficient mechanism of the referred institution is ensuring compensation for damage caused to victims, who has suffered from lack of works and services, while performing construction, reconstruction or capital repair operations, engineering surveys or design works, at the expense of not insurance payouts according to civil law contracts, but compensation funds of self-regulatory organizations. The study enabled assessing the construction industry self-regulation institute as the effective institute ensuring the protection of interests of the state and consumers of works and services regarding the construction area.

Keywords: Self-regulation · Self-regulation organizations · Licensing · State control · Engineering surveys · Urban planning legislation

1 Introduction

The modern-day Russia's history of the establishment and development of self-regulation institution started in the mid-90s. The regulation of activities of self-regulatory organizations (hereinafter referred to as SRO) was initially performed on the

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basis of Federal Law № 7-FZ of January 12, 1996 “On Non-Profit Organizations”. Then the framework Federal Law № 315-FZ of December 1, 2007 “On Self-Regulatory Organizations” (hereinafter referred to as Law on SRO) was adopted, which introduced self-regulation with mandatory membership in ten areas of professional activity, including engineering surveys, architectural and construction design, construction industry. Self-regulation with voluntary membership was also developed further.

Introduction of self-regulation in the construction industry was entailed by the cancellation of state regulation of this industry in the form of licensing from January 1, 2009. The transition period involved the creation of self-regulatory construction organizations regarding three types of activities: construction, design, engineering surveys. The Law on SRO was preceded by the accumulation of significant experience in the uniting of market entities into professional communities in Russia and foreign countries, therefore traditions of self-regulation have developed [1]. Regarded literature contains doubts about the rate of influence of SRO Law on the regulation of entrepreneurship [2]. The study of the issue conducted by the authors shows that the effectiveness of self-regulation in various areas of economic activity is not the same, and its importance is incomparably higher in those areas where membership in SRO is mandatory [1–7].

2 Methods

The basic principles of legal sciences, modern economic theory and theory of state and municipal government became the methodological basis for the present study. The informational base of the research was provided by the regulatory legal acts of the Russian Federation on self-regulation of the construction industry, data from the state register of self-regulatory organizations and statistical data in the field of construction.

3 Results

292 construction organizations had the status of “self-regulatory organization” by the end of December 2009. At the beginning of July 2019, the state register of self-regulatory construction organizations contained information on 433 operating organizations (Fig. 1, Table 1) [7].

Construction business entities are allowed to carry out such entrepreneurial activity as engineering surveys, architectural and engineering design or construction only after obtaining admission to certain types of work from SRO, not just after joining the self-regulatory organization [7]. This situation raises a number of questions, since business entities of the construction industry are forced to join SRO, but it does not guarantee them getting the allowance for doing certain works from SRO. Violation of the “sectoral” unity principle within the framework of construction industry’s SRO entailed a number of problems that affected almost every important area of SRO’s functioning and conditioned the occurrence of restrictions on the influence of the self-regulatory institution on the increase in regulatory and business processes in the construction industry.

Table 1. Distribution of self-regulatory organizations by construction industry sectors by federal districts of the Russian Federation as of July 1, 2019

Federal district	Construction	Design	Engineering survey
The Russian Federation, totally	223	172	38
Far Eastern Federal District	13	4	–
Volga Federal District	33	23	4
Northwestern Federal District	30	32	11
North Caucasian Federal District	8	2	–
Siberian Federal District	25	12	2
Ural Federal District	11	7	2
Central Federal District	86	81	15
Southern Federal District	17	11	4

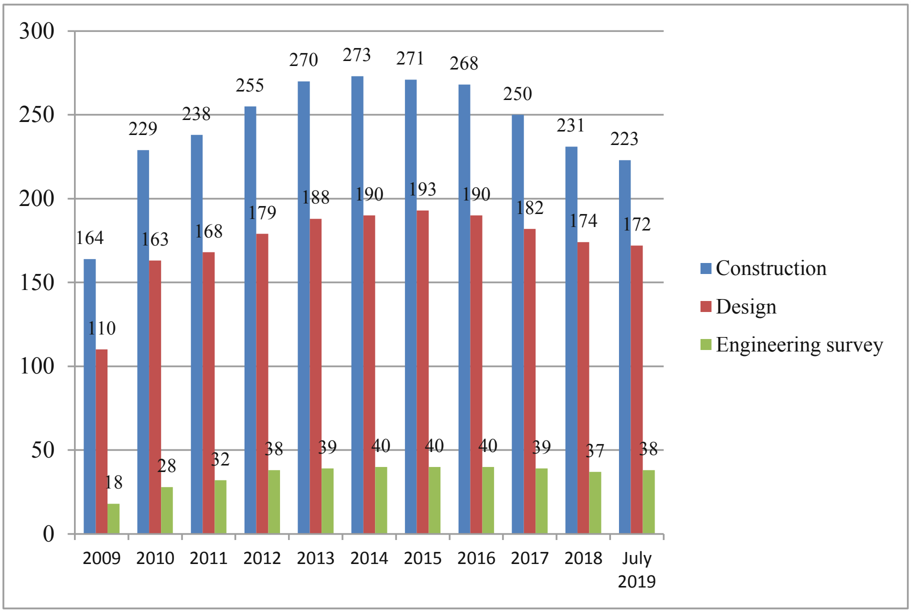

Fig. 1. Number of self-regulatory organizations by branches of the construction industry of the Russian Federation: authors

In Russia, the Administrative Provision in the field of engineering surveys, architectural design, construction, reconstruction and overhaul of capital facilities was approved by the order of Rostekhnadzor (Federal Environmental, Industrial and Nuclear Supervision Service of Russia) dated from July 25, 2013 № 325 (registered with the Ministry of Justice of Russia on February 4, 2014, registration number 31219) [6]. According to this regulatory document, Rostekhnadzor and its territorial divisions, as executive bodies, serve as the state supervisor of activities of self-regulatory organizations regarding the construction industry. Scheduled and unscheduled inspections of the activities of self-regulatory organizations are carried out annually (Fig. 2) [6].

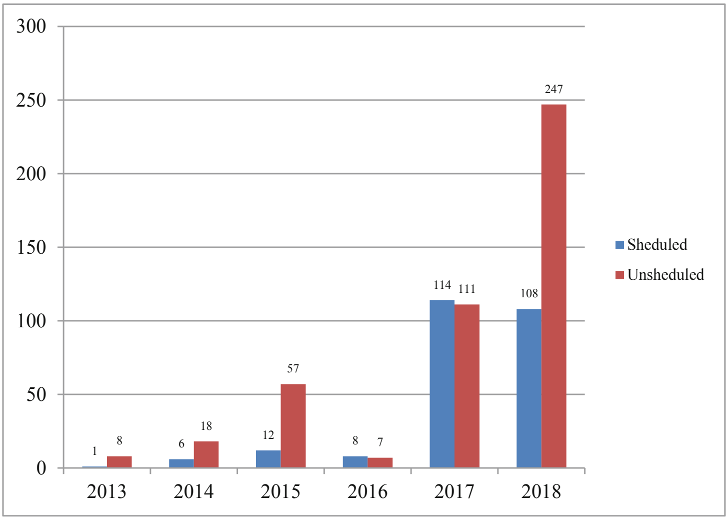

Fig. 2. The number of inspections of self-regulatory organizations in the construction industry: authors

The main violations by self-regulatory organizations identified in the course of control and supervision measures are violations of basic requirements of the urban planning legislation of the Russian Federation and the Law on SRO.

Article 55.13 of the Urban Planning Code of the Russian Federation (hereinafter – UPC of Russia) [5] provides for the control of the SRO over its members' activities. However, in practice, individual self-regulatory organizations carry out such control formally, which is evidenced by the results of monitoring or oversight measures. It is worth mentioning that it is the SRO's control over the activities of its members that is the main mechanism allowing the SRO to identify dishonest participants in the construction industry market and to influence the quality of work performed during construction, design and engineering surveys.

It should also be noted that the results of the self-regulatory system functioning were assessed as negative by certain media, which is incorrect. The SRO system of the construction industry is really well-functioning; while there are deficiencies in the legal regulation. However, some certain indicators showing the positive influence of the SRO introduction on the results of the construction industry are given further. For instance, since the self-regulatory system of the construction industry was introduced, there has been a steady tendency to decrease in the degree of injuries during performance of various construction works (Fig. 3).

There is a significant decrease in business activity indicator of the construction industry: the number of mothballed buildings and structures reduces (Fig. 4).

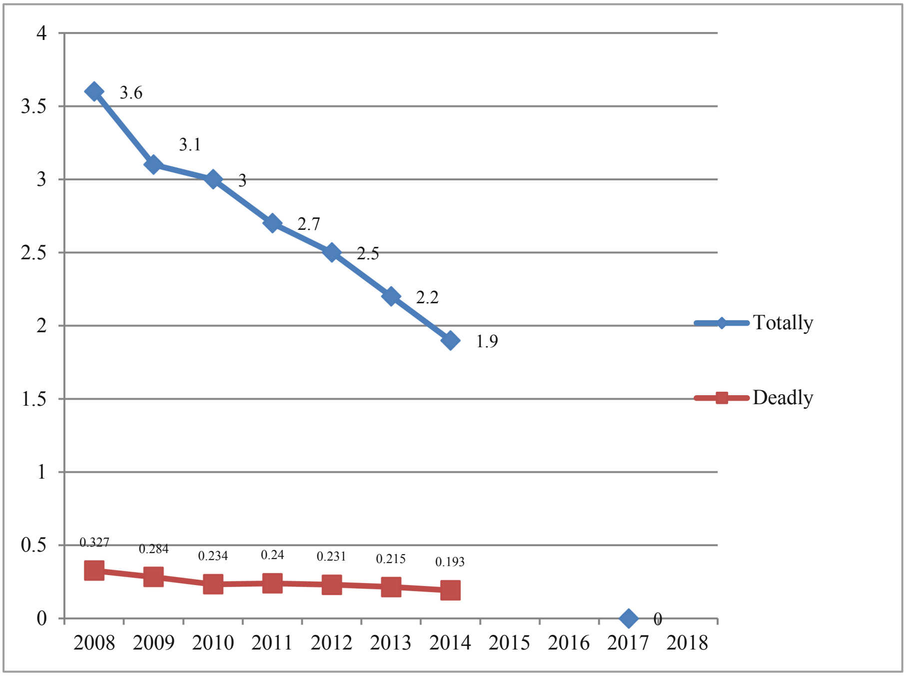

Fig. 3. Number of victims per 1000 employees in the construction industry: authors

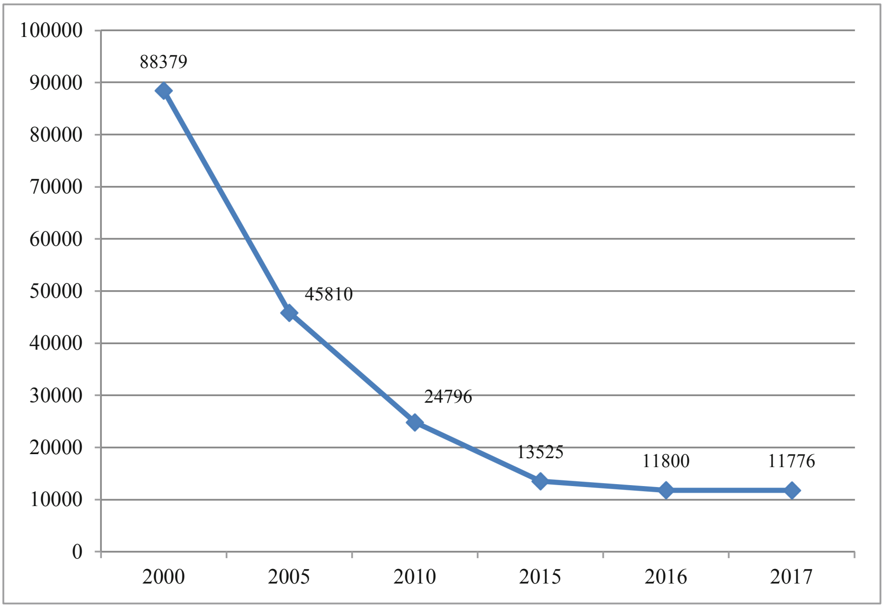

Fig. 4. Number of buildings and structures in a suspended or mothballed state: authors

4 Discussion

Today, in the construction industry, compensation funds are not used for their intended purpose of making payments to self-regulatory organizations when the joint liability under obligations of their members occurs in accordance with Art. 60 of UPC of the Russian Federation [5]. Instead of payments from the SRO compensation fund, insurance coverage under a civil liability agreement is used.

2017 became a transitional year for self-regulation in construction, since the SRO was reformed under the banner of "self-cleaning" of the system from dishonest and insolvent organizations. Self-regulation is gradually becoming a system of mutual responsibility of business entities regarding construction industry. The Compensation Fund for Securing Contractual Obligations gradually starts fulfilling the function of the tool of collective responsibility of SRO under the obligations of its members.

On October 25, 2018, the largest payment from the compensation fund in the history of self-regulation in the Russian construction industry was recorded under the article "Compensation of harm to third parties" as part of joint liability. The payment amounted approximately 89 million rubles. SRO "MOSP MSP-OPORA" made this payment for its member: LLC "Gorspetsstroy-2". In February 2017, at the construction site for a multi-level car parking in Vladivostok, during work on strengthening the soil through erecting pile structures, a collapse occurred due to a landslide. Because of the collapse, the municipal road was damaged. The pile structure was erected by the contractor LLC "Gorspetsstroy-2". The court qualified the case as a dispute arising from civil legal relations regarding non-fulfillment or improper performance of obligations under work contracts. The conclusions of the prepared Scientific and Technical Report qualified design errors as one of the reasons of the collapse.

The court delivered a judgment to recover 89 million rubles of losses jointly from LLC "Gorspetsstroy-2" and the Association, obliged them to pay court costs of 155 thousand rubles, and demanded 25.5 million rubles from OOO "Gorspetsstroy-2". After the court decision came into force, the execution writ was issued and enforcement proceedings for 89 million rubles against the Association were initiated. Thus, the court decided that the self-regulatory organization, as a joint defendant, should ensure the execution of claims in any amount, regardless of the size of the compensation fund for damages.

The event of payment from the compensation fund is indicative, since for nine years of self-regulation's existence, only 80 million rubles in total was payed to third parties suffered during construction processes. The total amount of compensation funds collected by construction SROs currently exceeds 100 billion rubles. The legislator implied that payments from compensation funds would compensate for damage to the life or health of citizens. However, over the past years, this important direction has been stagnant. The first significant step accounting 89 million rubles should be perceived as the positive one and as the responsibility to the professional community, citizens and the whole country.

5 Conclusions

Self-regulation should be assessed as an effective institution providing relevant protection for the interests of the state and consumers of works and services in the field of the construction industry. The most effective mechanism of the institute under consideration is the guarantee of paying compensation for harm caused to victims because of deficiencies in work and services performed during construction, reconstruction, overhaul of construction projects, engineering surveys or design, at the expense of not insurance payments under civil law insurance contracts, but compensation funds belonging to self-regulatory organizations. The system of self-regulation of the construction industry has approved itself as a worthy alternative to state regulation implying licensing for construction activities. This situation will entail further improvement of such areas of legislation as land, housing and urban planning legislation.

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Study of Deformation of Structural Elements as Result of Concrete Creep

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Abstract. The paper considers the basic principles of the linear theory of inherent creep and the possibility of its application to the calculation of shell structures made of concrete. A mathematical model of the deformation of the structure under consideration is shown in the form of a functional of the total strain potential energy. An algorithm based on the Ritz method is applied. The stability calculations of shallow shells of double curvature and square in plan are made, taking into account the creep of the material. The critical time values are found for different values of the applied load.

Keywords: Shells · Creep · Stress-strain state · Buckling · Rheology

1 Introduction

Studying the process of deformation of structural elements under various loads is of great importance in the design of buildings and structures [1–3]. In particular, such elements include a beam, a slab and a shell. Under the action of loads, depending on the material used, various properties may appear in the structure, for example, physical non-linearity or creep. For materials with a strongly pronounced creep property under constant load over time, significant deformations arise, which can lead to destruction or loss of stability.

The creep theory, which most fully takes into account the features of concrete deformation, was created by Harutyunyan [4], Gvozdev [5], Prokopovich [6], Ulitsky [7], Kharlab [8] and other scientists.

Also, studies of recent years devoted to the calculation of structures taking into account creep properties [9–16] should be noted. In this paper, we consider the basic principles of the linear theory of inherent creep and the possibility of its application to the calculation of shell structures made of concrete.

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2 Theory and Methods

2.1 Fundamentals of the Linear Creep Theory of a Body with a Constant Boundary

As the main object of the general linear creep theory, we will consider a deformable rigid body *V*, for which the following assumptions are valid [17]:

1. The body is continuous homogeneous isotropic - both before deformation and in the deformed state. The body material has the properties of elasticity, creep and hardening (see below for more details). The body boundary changes only due to the deformation of the body, but not due to the addition (removal) of material or interconnection with other bodies.
2. The deformations of the body are small (squared deformations can be neglected in comparison with the first degrees). The configuration of the body can be considered unchanged in time (calculation according to the undeformed state, the invariability of the design model of a structure).
3. Impacts on the body (loads, displacements of supports, forced deformations) are quasistatic. The inertia forces acting on the body particles in the process of deformation are negligible, so that they can be ignored.
4. The relationship between stresses and strains of all kinds is linear.
5. The support connections of the body are absolutely rigid, not allowing any movement of the support points in the direction of the connections.

These are the basic, fundamental assumptions that determine the formulation of the problem. In addition, in the future, assumptions related to the use of the mathematical apparatus are implicitly used (continuity of functions and their derivatives, piecewise smoothness of the body surface, etc.).

We define elasticity, creep, and hardening as material properties, due to which corresponding deformations arise in bodies made of this material under the action of stresses: elastic deformations ε_{ij}^{L}, creep deformations ε_{ij}^{C}, hardening deformations ε_{ij}^{T}. The phenomenological meaning of these values is revealed by the experiment. Let a constant axial load be applied to a rod made of a material with the properties of elasticity, creep, and hardening (for example, concrete) at a time *t*. The result will be as follows (Fig. 1).

When the load is applied, the rod will instantly receive elastic deformation $\varepsilon^{L}(t)$ (if then the load is immediately removed, this deformation will disappear). Further, the deformation will develop in time: the strain gauge will record a gradual increase in creep deformation $\varepsilon^{C}(t)$. In addition to this external process, there will also be an internal process that the strain gauge will not detect: part of the initial elastic deformation $\varepsilon^{L}(t)$ will gradually "freeze" - turn into an inelastic, completely irreversible deformation $\varepsilon^{T}(t)$. To detect this phenomenon, the rod must be subjected to instantaneous unloading at some intervals. Instantly disappearing elastic deformation with each new unloading will become less and less. The indicated process of "absorption" of elastic deformation at constant stresses is conventionally called "hardening" (in reality, this is only one manifestation of hardening - a complex physicochemical process of the

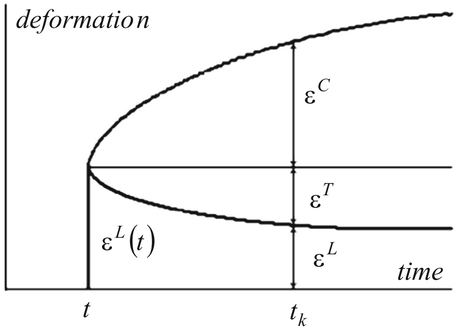

Fig. 1. Elastic deformation, creep deformation and hardening deformation.

formation of new internal bonds in a material). The resulting deformations ε^T can be called hardening deformations. The formation of new internal bonds, of course, “freezes” a part of the creep deformation, but we will not separate out the corresponding irreversible deformation separately. The dependence of elasticity and creep on the age of the material is described by the term “aging”, more general than the term “hardening”.

The considered concept of three deformations was proposed in [8].

We now give a mathematical definition of $\varepsilon_{ij}^L,\ \varepsilon_{ij}^C,\ \varepsilon_{ij}^T$.

Elastic deformations ε_{ij}^L are linear stress functions with time-varying coefficients, expressing Hooke’s law:

$$\varepsilon_{ij}^L = \Phi_{ij}(\sigma) \tag{1}$$

Here, σ denotes the entire set of components of the stress tensor; the dependence of values on coordinates and time is not indicated.

Creep deformations ε_{ij}^C and hardening deformations ε_{ij}^T are some linear functionals with respect to time, equal to zero at the initial time t_0 (the moment of stress generation):

$$\varepsilon_{ij}^C = \Psi_{ij}^C(\sigma),\ \varepsilon_{ij}^T = \Psi_{ij}^T(\sigma), \qquad \varepsilon_{ij}^C(t_0) = \varepsilon_{ij}^T(t_0) = 0. \tag{2}$$

The last relation means that creep and hardening deformations do not occur instantly, but develop only over time. The linearity of the functions Φ and the functionals Ψ is understood, as usual, in the sense of additivity plus homogeneity:

$$\mathrm{F}(\sigma' + \sigma'') = \mathrm{F}(\sigma) + \mathrm{F}(\sigma''),\ \mathrm{F}(\lambda\sigma) = \lambda\mathrm{F}(\sigma), \tag{3}$$

where λ = const.

Important consequences follow from this:

- The deformation properties of the body material (elasticity, creep and hardening characteristics) are independent of the stress state of the body. Indeed, otherwise additivity would not have taken place.
- The deformation characteristics of the material corresponding to tension and compression are the same.
- The deformation characteristics of the material corresponding to loading (i.e. positive increments of the absolute value of stress) and unloading (i.e. negative increments of the absolute value of stress) are equal.

2.2 The Relationship of Stress and Strain

We proceed from the condition that the relationship between all types of deformations (strains) and stresses at a point in the body is linear. The general form of recording such a relationship is

$$\varepsilon_{ij}^{m} = L_{ij\alpha\beta}^{m}\sigma_{\alpha\beta}, \tag{4}$$

where $L_{ij\alpha\beta}^{m}$ – some linear time operators depending only on the material of the body (expressing the deformation properties of the material); index $m = L,\ C,\ T$; double occurring Greek indices mean a summation from 1 to 3.

If the body is homogeneous in material, then the operators L for all points of the body are the same, i.e. they are independent of coordinates.

Omitting the known transformations, we give the relationship of stresses and strains:

$$\varepsilon_{ij}^{m} = \left[L_1^m\sigma_{ii} + L_2^m(\sigma_{kk} + \sigma_{ll})\right]\delta_{ij} + L_3^m\sigma_{ij}\left(1 - \delta_{ij}\right), \tag{5}$$

where δ_{ij} – unit sphere tensor (Kronecker symbol); indices $i,\ k,\ l$ form a circular permutation, but there is no summation over repeating Latin indices. Moreover, $L_1^m = L_2^m + L_3^m$ is fair.

Let all the stresses in (6) be applied at a moment in time t and remain unchanged. Then they can be taken out of the signs of the operators (due to the linearity of the latter). As a result, the operators themselves will turn into multiplication operators, and the result of their application will be some functions of the current moment of time t_k and the initial moment of time t. We denote these functions by $C_1(t_k, t)$, $C_2(t_k, t)$, $C_3(t_k, t)$ and call the measure of longitudinal creep, the measure of transverse creep, and the measure of shear creep, respectively. Thus, at constant in time stresses applied at a moment in time t,

$$\varepsilon_{ij}^{C}(t_k) = [C_1(t_k, t)\sigma_{ii} + C_2(t_k, t)(\sigma_{kk} + \sigma_{ll})]\delta_{ij} + C_3(t_k, t)\sigma_{ij}\left(1 - \delta_{ij}\right). \tag{6}$$

Ultimately, the relationship between stresses and strains can be reduced to the Maslov-Harutyunyan equation (for complete tensile and shear strains)

$$\varepsilon_f(t_k) = \frac{\sigma(t_k)}{E(t_k)} - \int\limits_{t_0}^{t_k} \sigma(t)\frac{\partial}{\partial t}\left[\frac{1}{E(t)} + C(t_k,\ t)\right]dt, \tag{7}$$

$$\gamma_f(t_k) = \frac{\tau(t_k)}{G(t_k)} - \int\limits_{t_0}^{t_k} \tau(t)\frac{\partial}{\partial t}\left[\frac{1}{G(t)} + \omega(t_k,\ t)\right]dt, \tag{8}$$

where t_0 – age of concrete; $C(t_k, t)$, $\omega(t_k, t)$ – measures of creep of concrete under tension (compression) and shear, respectively, and $\omega(t_k, t) = 2C(t_k, t)$.

In relations (8), the first terms reflect the elastic-instantaneous deformation, and the second ones reflect the creep strain.

The specific form of functions $C(t_k, t)$ and $E(t)$ is established by approximating experimental data (in this case, it is possible to base on physical considerations). This is a very difficult task for a number of reasons, which include: the difficulty of conducting experiments; the dependence of the rheological properties of the material on many factors; inconsistency of the results of various experiments; the need to think not only about reaching agreement with experience, but also about the conveniences of using the calculating apparatus of the theory.

2.3 Shell Structures

Thin-walled shell structures are widely used, including in construction. We consider shallow shells of double curvature made of concrete and prone to creep.

We will use the mathematical model obtained in [18]. But here we consider it for the case of shells without stiffeners. Since all relations of the model have already been deduced earlier, let's present only its final result - the functional of the total potential energy of deformation. For smooth shells, taking into account the creep of the material according to the linear theory of inherent creep, it can be written as

$$E_p = E_p^L - E_p^C, \tag{9}$$

where E_p^L – part of the functional reflecting linearly elastic deformation; E_p^C – deformation associated with the development of creep deformations. They are written as

$$\begin{aligned} E_p^L = \tfrac{E}{2(1-\mu^2)}\int\limits_0^a\int\limits_0^b \Big\{ h\Big[\varepsilon_x^2 + 2\mu\varepsilon_x\varepsilon_y + \varepsilon_y^2 + \tilde{\mu}\gamma_{xy}^2 + \tilde{\mu}k(\Psi_x - \theta_1)^2 + \tilde{\mu}k\big(\Psi_y - \theta_2\big)^2\Big] \\ + \tfrac{h^3}{12}\left(\chi_1^2 + 2\mu\chi_1\chi_2 + \chi_2^2 + 4\tilde{\mu}\chi_{12}^2\right) - 2(1-\mu^2)\tfrac{q}{E}W\Big\}ABdxdy, \end{aligned} \tag{10}$$

$$\begin{aligned} \Big[h\Big(\varepsilon_x^2(t) + 2\mu\varepsilon_x(t)\varepsilon_y(t) + \varepsilon_y^2(t)\Big) + \frac{h^3}{12}\left(\chi_1^2(t) + \chi_2^2(t)\right. \\ + 4\bar{S}\tilde{\mu}\gamma_{xy}(t)\chi_{12}(t) + \frac{h^3}{12}4\tilde{\mu}\chi_{12}^2(t)\Big] R_2(t_k, t)\Big\} ABdxdydt. \end{aligned} \tag{11}$$

Here $\widetilde{\mu} = (1 - \mu)/2$; q – external uniformly distributed lateral load directed flatwise.

To reduce the problem of the minimum of the energy functional to the solution of a system of algebraic equations, we will use the Ritz method. In the Ritz method, when expanding the desired functions in series, we take the number of terms $N = 9$. All calculations will be carried out in a program developed in the environment of analytical calculations Maple.

2.4 Numerical Results

We will consider the shallow shell structures of double curvature and square in plan (Table 1). In this case, the Lame and curvature parameters are $A = B = 1,\ k_x = 1/R_1$, $k_y = 1/R_2$.

Table 1. Dimensional and dimensionless parameters of shells of different options.

Option	Dimensional parameters, m		
	$a = b$	$R = R_1 = R_2$	h
1	18	45.3	0.09
2	27	67.95	0.27

All results are presented below in dimensionless parameters [19]:

$$\xi = \frac{x}{a}, \quad \eta = \frac{y}{b}, \quad \bar{W} = \frac{W}{h}, \quad \bar{\sigma} = \frac{a^2 \sigma}{h^2 E}, \quad \bar{a} = \frac{a}{h}, \quad \bar{P} = \frac{a^4 q}{E h^4}, \qquad (12)$$

In this regard, concrete parameters (elastic modulus, Poisson's ratio) are not specified.

We will investigate the unlimited transient creep of the material. The influence functions (relaxation nuclei) of the material we take in the following form (old concrete):

$$R_1(t_k, t) = \gamma E C_\infty e^{-\gamma(1 + EC_\infty)(t_k - t)}, R_2(t_k, t) = 2\frac{G}{E} R_1(t_k - t) \qquad (13)$$

where $\gamma = 0.01\ [1/days]$, $EC_\infty = 3$, $C_\infty = 1 \times 10^{-4}$ MPa^{-1}, $E = 3 \times 10^4$ MPa.

As a result of the development of creep deformations of the material over time, a rapid growth of the shells' bucklings begins (10…15 times exceeding the bucklings of the shells at $t = 0$). The time at which this comes is taken as a critical time t_{cr}.

For the shell of option 1, Fig. 2 shows the dependences "$\overline{W}(0.5, 0.5) - t$" obtained at various dimensionless load values: curve 1 corresponds to the load $\overline{P} = 1500$, curve 2 – $\overline{P} = 2000$, 3 – $\overline{P} = 2500$, 4 – $\overline{P} = 2700$, 5 – $\overline{P} = 2800$.

For the shell of option 2, Fig. 3 shows dependences "$\overline{W}(0.5,\ 0.5) - t$" obtained at various load values: curve 1 corresponds to the load $\overline{P} = 300$, curve 2 – $\overline{P} = 350$, 3 – $\overline{P} = 400$, 4 – $\overline{P} = 500$, 5 – $\overline{P} = 510$.

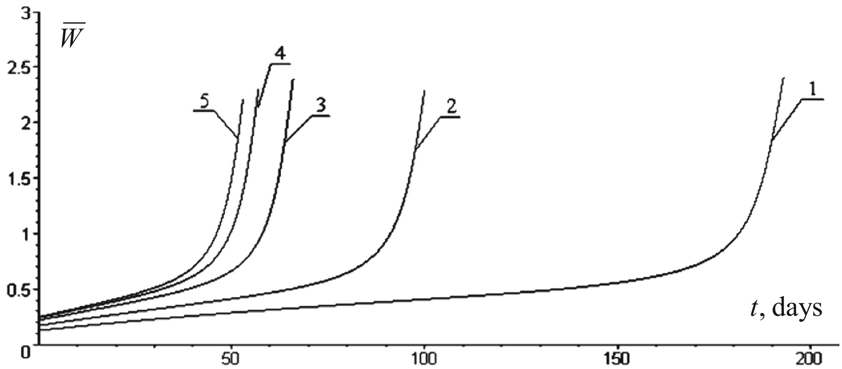

Fig. 2. Results for the shell of option 1.

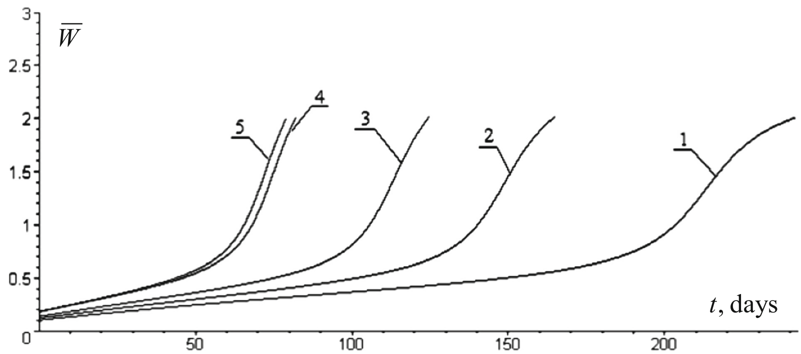

Fig. 3. Results for the shell of option 2.

In Fig. 4, at $\overline{P} = 2500$, the nature of the change in the time of buckling $\overline{W}$ and stress $\bar{\sigma}_g = \sigma_1 - \frac{R_{bt}}{R_b}\sigma_3$, indicated as a function of intensity, for the shell of option 1 is presented.

It can be seen from the figures that for the shell of option 1 with the development of creep deformations of the shell concrete, the stresses increase and redistribute over the shell field over time.

For the shell of option 1, loss of strength will occur at $t < t_{cr}$ (approximately at $0.75\,t_{cr}$), for the shell of option 2, loss of strength will occur at $t < t_{cr}$ (approximately at $0.6\,t_{cr}$).

The dependences "$\overline{P} - t_{cr}$" for shell options 1 and 2 are shown in Table 2.

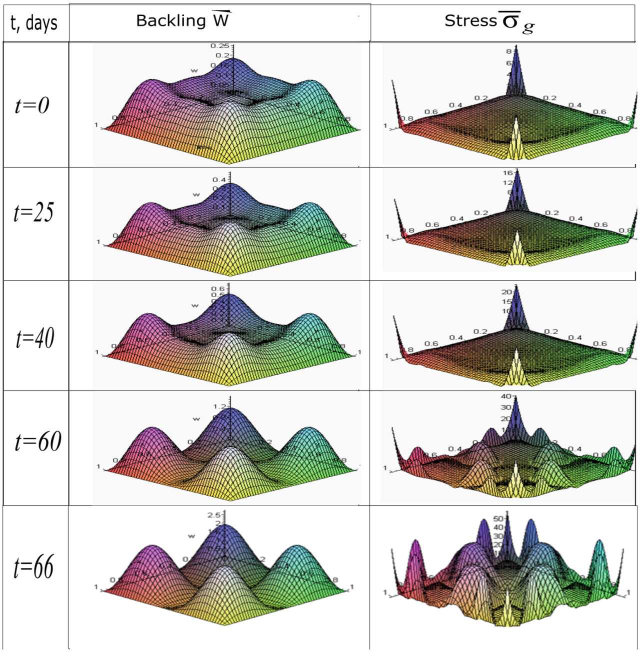

Fig. 4. The nature of the change of buckling and stress over time.

Table 2. Creep deformation of concrete shell over time

$\overline{P}$	t_{cr} (days)	$\overline{P}$	t_{cr} (days)
1500	193	300	220
2000	115	350	170
2500	70	400	135
2700	55	500	90
2800	50	550	80

3 Conclusion

The proposed approach can be used to study the stress-strain state, strength and stability of thin-walled structural elements, taking into account the creep of the material.

The process of deformation of shell structures made of concrete significantly depends on the creep property, which makes it necessary to take it into account in designing.

As can be seen from the data obtained, with the development of creep strains of the shell material over time, not only the growth of bucklings and stresses occurs, but also the redistribution of stresses over the shell field. So, for example, the maximum stress from the corner points of the shell is shifted along the entire outer contour of the shell.

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The Influence of Green Roofs on a Humanitarian Balance of the Biotechnosphere

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Abstract. Greening roofs of existing buildings in urban areas with high build-up density is a reasonable way to mitigate the human impact on the biosphere in the absence of free space for landscaping. According to the results of statistical analysis for the Moscow city from 1999 till 2011 16 thousand hectares roof greening can reduce the number of patients with malignant neoplasms by 3.5%, that means green roofs have a potential to improve the urban population health, to increase the life expectancy and working capacity of the population. The absence of standards, regulates green roofs setting up in a particular place, leads to the impossibility of their distribution in megacities. Confirmation of the necessity and feasibility of green roofs installing can lead to the creating of regulatory documents obliging designers to use green roofs on new and reconstructed buildings.

Keywords: Green roof · Humanitarian balance · Biotechnosphere · Mortality rate · Air emissions · Contaminated wastewater

1 Introduction

Currently, there is widespread concern of the World Health Organization (WHO), and in the Russian Federation, in particular, of the Ministry of Health, due to an increase in the incidence of malignant neoplasms. Of course, where are many factors influence on this indicator: anthropogenic pollution of soil, air and water, level of radiation, heredity, lifestyle, etc. The most important among these criteria is anthropogenic environmental pollution [1]. According to the International Agency for the Study of the Origin of Cancer (IARC), the appearance of up to 85% of tumors is interrelated with the influence of environmental factors [2]. With economic development, there has been a rapid increase in stationary and mobile sources of emissions, such as industrial plants and vehicles, leading to air pollution.

Landscaping of territories improves air quality, reduces the effect of solar radiation, the level of maximum permissible concentration (MPC) of suspended particles and dust. Setting up of green roofs, in particular, applicable in conditions of dense urban development, requires more detailed, including experimental and analytical study.

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The construction technologies currently used for landscaping roofs have come a long way in historical development. The first examples of landscaping horizontal surfaces of artificially created structures date back to ancient times [3]. The prototype of green roofs can be considered greened terraces of Sumerian structures - ziggurats that appeared in the XXII century BC. The building art of ancient times laid the foundation for the appearance of green roofs in the world and, in particular, in Russia.

Hanging gardens appeared in Russia relatively recently and were called "upper gardens" [4]. The first place to use them was the terrace of the Moscow Kremlin (XVII century). Later, in the middle of the XVII century, Moscow built the Upper Garden, surrounded by a stone fence, and then the Lower Garden, located on the arches of the Reserve Palace and at the Tainitsky Gate. Their areas were 0.26 and 0.15 ha, respectively. In the same XVII century in Moscow, the "red" gardens of the Golitsyn and Ordin-Nashchokin boyars, located on the facades of residential buildings, became famous.

Later, "upper gardens" became very typical for Russia, keeping up with their famous predecessors in the world. The architect Rastrelli transformed the Winter Palace in St. Petersburg with hanging green gardens; similar gardens were planted in Tsarskoye Selo and in the palace stables at the Small Hermitage (Fig. 1).

Fig. 1. The hanging garden of the small hermitage.

In central Europe the global arrangement of green gardens on the roofs of houses began in the middle of the nineteenth century, which is explained by the emergence of new building materials [5–10]. At the Paris World Exhibition in 1867, Karl Rabitz (a German inventor and civil engineer) presented to the public a model of a roof garden.

In addition to the “upper gardens” on flat roofs, covered pavilions began to appear, called winter garden. French and American architects Le Corbusier [11] and F. L. Wright were passionate about creating green roof projects, considering them an integral part of the cities of the future. F. L. Wright designed and built a restaurant in Chicago with green roofs - terraces. And Le Corbusier, along with a large number of roof greening projects, created a green city on the administrative buildings of the Indian city of Chandigarh.

Later hanging gardens were used in the design of Derry and Toms department store, where the area of landscaping was 6 thousand square meters [12] (Fig. 2).

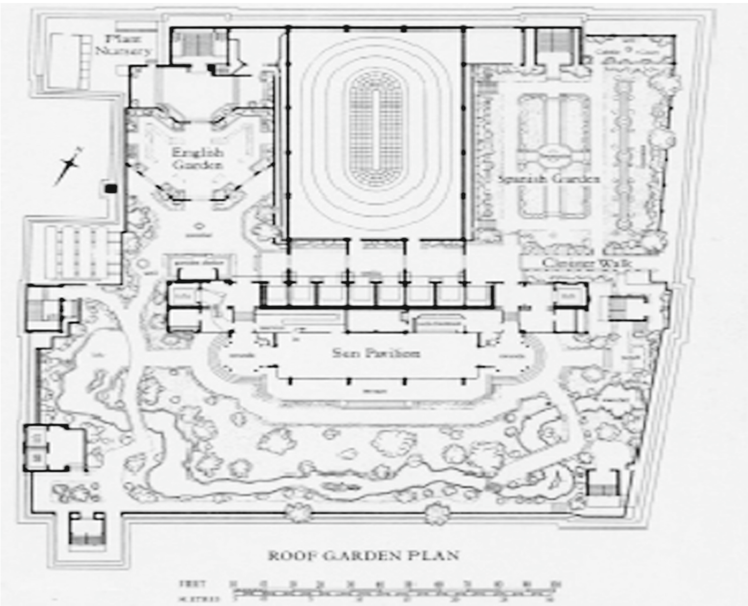

Fig. 2. Layout of hanging gardens, Derry and Toms department store, Ralph Hancock, 1938 [12].

Architects G. Barkhin, I. Leonidov and the Vesnin brothers in Russia began the introduction of the construction of buildings with flat roofs. On these roofs observation platforms with gardens and recreation areas were arranged.

The Second World War had a devastating effect on the development of European-Soviet architecture. Designing houses with green roofs resumed only at the end of the twentieth century, most of the projects for landscaping roofs of that time belonged to architects from Germany. The implementation of most of these projects was possible thanks to the creation of a lightweight green roof [13]. A roof greening design was developed with the addition of a substrate having a lower weight relative to the weight of the soil for planting green spaces, with the device of a layer holding the growth of the root system of plants to prevent destruction of the roof by the roots.

In the 21st century, megacities are rapidly absorbing more and more space. Negative anthropogenic impact on the ecological balance of urbanized areas should be compensated by an increase in urban areas of green spaces and plantings. The imbalance between the technosphere and the biosphere leads to a number of global problems such as irreversible environmental pollution (pollution of soil, water and oceans), the occurrence of ozone holes in the stratospheric layer, acid rain, lack of fresh water, and the greenhouse effect.

Starting from the second half of the 19th century, a gradual increase in temperature on the Earth is observed, as a result, this can lead to the greenhouse effect (Fig. 3).

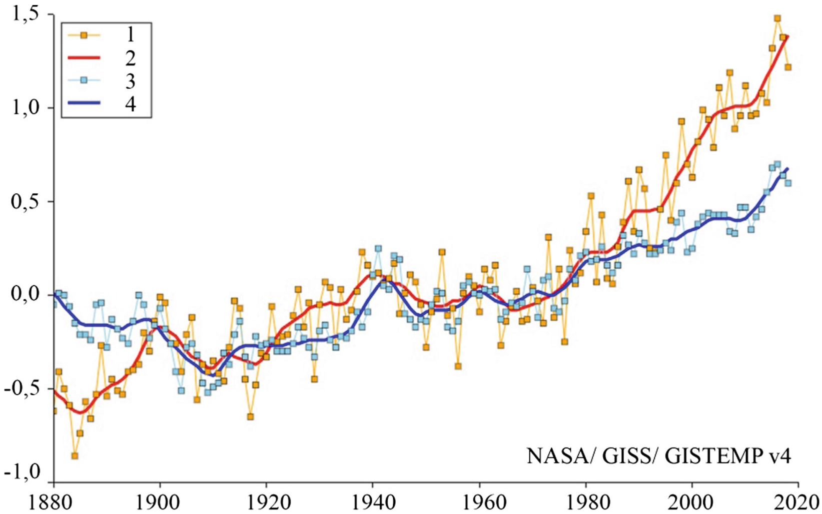

Fig. 3. Temperature anomalies over Land and over Ocean, 1880–2019, where: 1 – Land surface air temperature, 2 – Land lowess smoothing, 3 – Sea surface water temperature, 4 – Sea lowess smoothing.

An analysis of the environmental threats leads to the need to revise the existing approach to design and construction in accordance with the principles of sustainable development, and there is a need to use green technologies in construction [14, 15]. The arrangement of green areas (parks, squares, boulevards, etc.) in densely built megalopolises is difficult, therefore, the possibility of achieving the required landscaping areas without demolishing existing buildings can be economically justified [16]. Roof greening of existing buildings under conditions of high urban area development density can be an economically feasible way to mitigate the human impact on the biosphere in the absence of free areas for landscaping.

Roof landscaping of existing residential and especially public buildings [17] can reduce air temperature, will improve both air quality, reducing the content of impurities and dust harmful to the human body [18–23], and as a result, the quality of life. Especially, the development and implementation of roof greening technology in Russia is relevant for the city of Moscow [24].

2 Materials and Methods

Using the example of the subject of the Russian Federation in Moscow, we will assess the state of the humanitarian balance of the biotechnosphere [25, 26], analyze the effect of greening the urban area (greening the roofs of existing buildings in particular) on the incidence of malignant neoplasms.

The research methods of the collected statistical data are based on correlation-regression analysis using multivariate nonlinear analysis [27].

Preliminarily, we examine the dynamics of the incidence rate of malignant neoplasms for Moscow, taking the contingents of patients with malignant neoplasms as an indicator of the humanitarian balance of the biotechnosphere, namely, the number of patients registered per 100,000 people for the selected urban area (Table 1).

Table 1. Contingents of patients with malignant neoplasms, the number of patients registered per 100,000 people for Moscow (values for the year) [28].

Year	The number of patients registered per 100,000 people	Year	The number of patients registered per 100,000 people
1999	1564,7	2009	1856,3
2000	1392,6	2010	1804,4
2001	1246,5	2011	1916,1
2002	1317,0	2012	2006,3
2003	1403,3	2013	2074,3
2004	1453,8	2014	2193,0
2005	1479,1	2015	2224,0
2006	1613,2	2016	2357,6
2007	1704,8	2017	2326,7
2008	1774,5	2018	2466,9

For the period 2001–2002 no statistics were found, so we calculate the missing values by linear regression. To do this, according to the available data, we build a graph with the addition of a straight trend line, using MS Excel PPP tools. Substituting the values in the equation of the line $y = 70,501x - 139826$, we determine the data for the period 2001–2002 (Fig. 4).

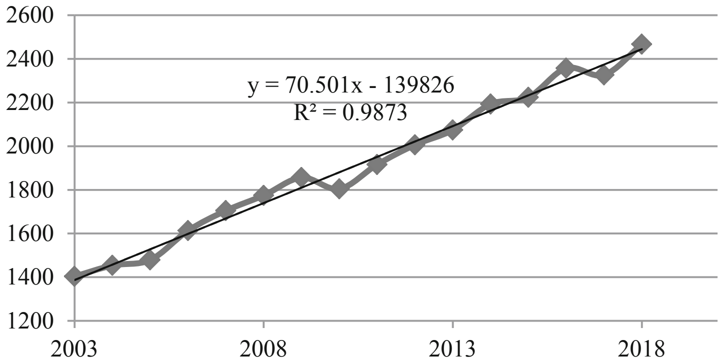

Fig. 4. The dynamic of the number of patients registered per 100,000 people for Moscow 2003–2018.

According to the table, a graph was built (Fig. 5), which shows the dynamics of the number of patients registered per 100,000 people for Moscow.

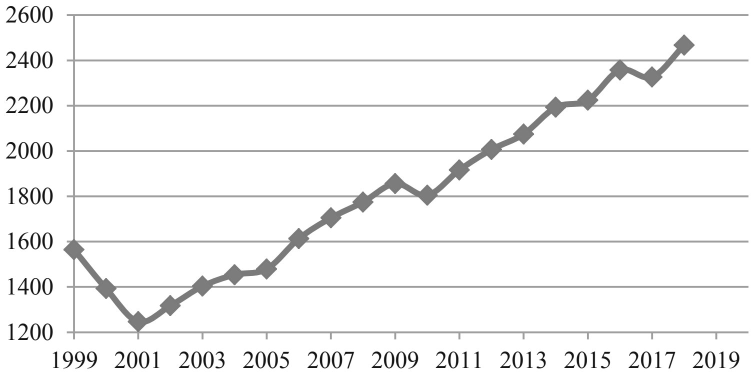

Fig. 5. The dynamic of the number of patients registered per 100,000 people for Moscow 1999–2018.

Figure 6 shows the trend line of the approximating curve found by the least squares method.

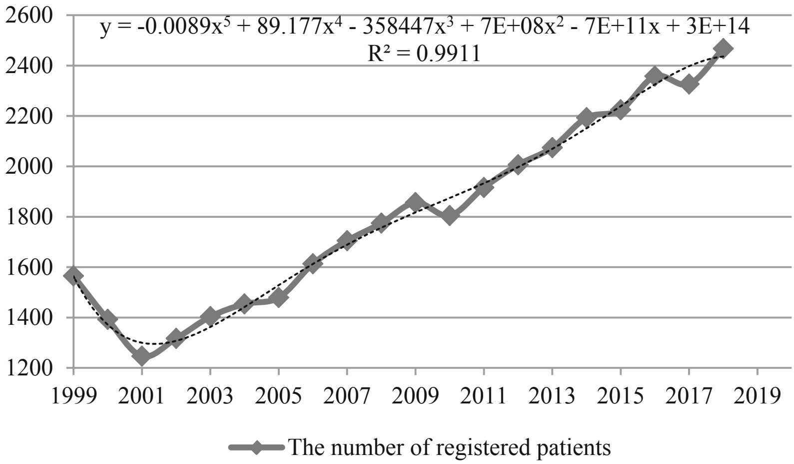

Fig. 6. Field of correlation of the number of patients registered per 100,000 people population for Moscow.

The equation of the approximating curve in the form of a polynomial of the fifth degree has the following form:

$$y(x) = -0{,}0089\mathrm{x}^5 + 89{,}177\mathrm{x}^4 - 358447\mathrm{x}^3 + 7\mathrm{E} + 08\mathrm{x}^2 - 7\mathrm{E} + 11\mathrm{x} + 3\mathrm{E} + 14$$

The determination coefficient in this case is R^2 = 0,9911.

According to the equation, it is possible to predict the number of patients registered per 100,000 people population for the city of Moscow for subsequent years.

The environmental factors affecting human health were selected as the main data on the characteristics of the state of the humanitarian balance of the biotechnosphere in Moscow:

1. emissions of air polluting substances from stationary sources (z_1), thousand tons;
2. discharge of polluted wastewater into surface water bodies (z_2), including water collected in the Moscow Region and used in Moscow, million m^3;
3. The area of green spaces and plantings in cities (z_3), thousand hectares.

The numerical values of factors affecting the state of the humanitarian balance of the biotechnosphere in Moscow (Table 2) were taken on the website of the Federal State Statistics Service [29].

Table 2. Numerical values of factors affecting the state of the humanitarian balance of the biotechnosphere in Moscow.

Year	Air emissions z_1, thousand tons	Contaminated wastewater volume z_2, million m^3	The area of green areas within the city z_3, thousand ha
1999	128,0	2145,0	46,100
2000	111,0	2115,0	45,700
2003	97,0	2015,0	45,700
2004	91,0	2012,0	45,700
2005	89,0	1959,0	45,700
2006	95,0	1857,0	47,900
2007	79,0	1726,0	34,300
2008	70,0	1684,0	34,300
2009	60,0	1595,0	29,600
2010	63,0	909,0	29,600
2011	61,0	908,0	29,600

To meet the reliability requirement of a statistical model, the following condition must be met:

$$m \leq \frac{n}{3}$$

Where

m – number of selected factors z1 … zn;
n – number of time series levels.

In this case, $n = 11$ for the period from 1999–2000 and 2003–2011 (before the expansion of the territory of Moscow), and the number of factors is $m = 3$ (z1, z2, z3), i.e.:

$$m = 3 \leq \frac{11}{3} = 3,67$$

The condition is satisfied.

To assess the completeness of the relationship between the mortality rate of the population Y and the explanatory factors z_1, z_2, z_3, we will perform a correlation analysis and calculate the pair correlation coefficients (Table 3).

Table 3. Matrix of pair correlation coefficients.

	Y	z_1	z_2	z_3
Y	1			
z_1	−0,790375	1		
z_2	−0,8288546	0,8069525	1	
z_3	−0,906027	0,8630358	0,8431483	1

Let us analyze the matrix of pair correlation coefficients to identify the most significant factors. Compare the pair correlation coefficients with the critical value from the Pearson critical values table (Table 4) in order to identify the acceptance or rejection of the relationship between the two factors.

Table 4. Pearson critical values for the number of time series n = 11.

Significance level	0,05	0,01
$r_{кр}$	0,6	0,74

After analysis and comparison of Table 3 with Table 4, the following conclusions were formulated:

1) All factors z1, z2, z3 have a relationship with an explainable variable;
3) Factors z1 and z3 are highly dependent on each other, the area of green spaces to a large extent affects air quality. Thus, we exclude z1.

Subsequently, we perform a regression analysis using the linear regression method. The desired function will have the following form:

$$\hat{Y} = a_1 + a_2 z_2 + a_3 z_3 \tag{1}$$

Using the least squares method, using MS Excel IFR means, we find the coefficients of Eq. (1) using Table 2 in the calculation.

The numerical values of the regression parameters are presented in Table 5.

Table 5. Numerical values of the regression parameters obtained using MS Excel IFR.

Regression statistics								
Multiple R					0,914042			
R-squared					0,835472			
Normalized R-squared					0,79434			
Standard error					85,56251			
Observations					11			
Analysis of variance								
	df		*SS*		*MS*	*F*		*Significance F*
Regression	2		297405,4		148702,7	20,31196		0,000733
Remainder	8		58567,54		7320,943			
Total	10		355973					
	Coefficients	Standard error	t-statistic	P-value	Lower 95%	Top 95%	Lower 95,0%	Top 95,0%
Y-intersection	2479,451	139,3969	17,78698	1,02E −07	2158,001	2800,901	2158,001	2800,901
Variable X_1	−0,09675	0,114878	−0,84219	0,424143	−0,36166	0,168161	−0,36166	0,168161
Variable X_2	−17,2275	6,411725	−2,68687	0,02763	−32,013	−2,44203	−32,013	−2,44203

We substitute the obtained coefficients a1 = 2479.451, a2 = −0.09675, a3 = −17.2275 into Eq. (1).

As a result, the equation takes the following form:

$$\hat{Y} = 2479{,}451 - 0{,}09675 z_2 - 17{,}2275 z_3 \tag{2}$$

Let's check the developed model. We substitute the known values of the factors in Eq. (2) for the entire study period.

$$\hat{Y}(1999) = 2479{,}451 - 0{,}09675 \cdot 2145 - 17{,}2275 \cdot 46{,}1 = 1477{,}7$$

$$\hat{Y}(2000) = 2479{,}451 - 0{,}09675 \cdot 2115 - 17{,}2275 \cdot 45{,}7 = 1487{,}5$$

$$\hat{Y}(2003) = 2479{,}451 - 0{,}09675 \cdot 2015 - 17{,}2275 \cdot 45{,}7 = 1497{,}2$$

$$\hat{Y}(2004) = 2479{,}451 - 0{,}09675 \cdot 2012 - 17{,}2275 \cdot 45{,}7 = 1497{,}5$$

$$\hat{Y}(2005) = 2479{,}451 - 0{,}09675 \cdot 1959 - 17{,}2275 \cdot 45{,}7 = 1502{,}6$$

$$\hat{Y}(2006) = 2479{,}451 - 0{,}09675 \cdot 1857 - 17{,}2275 \cdot 47{,}9 = 1474{,}6$$

$$\hat{Y}(2007) = 2479{,}451 - 0{,}09675 \cdot 1726 - 17{,}2275 \cdot 34{,}3 = 1721{,}6$$

$$\hat{Y}(2008) = 2479{,}451 - 0{,}09675 \cdot 1684 - 17{,}2275 \cdot 34{,}3 = 1725{,}6$$

$$\hat{Y}(2009) = 2479{,}451 - 0{,}09675 \cdot 1595 - 17{,}2275 \cdot 29{,}6 = 1815{,}2$$

$$\hat{Y}(2010) = 2479{,}451 - 0{,}09675 \cdot 909 - 17{,}2275 \cdot 29{,}6 = 1881{,}6$$

$$\hat{Y}(2011) = 2479{,}451 - 0{,}09675 \cdot 908 - 17{,}2275 \cdot 29{,}6 = 1881{,}7$$

As a result, we obtain analytical values of the number of patients registered per 100,000 people population for Moscow from 1999–2000 and 2003–2011 and compare them with the actual ones (Table 6).

The relative calculation error in forecasting ε is not more than 10%.

Next, we consider the effect of roof greening on existing residential and public buildings in Moscow on the contingent of patients with malignant neoplasms, namely the number of patients registered per 100,000 people for the selected subject of the Russian Federation.

Table 6. Comparison of analytical and actual data on the number of patients registered per 100,000 people population for Moscow from 1999–2000 and 2003–2011.

Year	z_2, million m^3	z_3, thousand ha	Analytical coefficients values $\hat{Y}$	Actual coefficient values Y	$\Delta = Y - \hat{Y}$	ε, %
1999	2145	46,1	1477,7	1564,7	87,0	5,9
2000	2115	45,7	1487,5	1392,6	−94,9	6,4
2003	2015	45,7	1497,2	1403,3	−93,9	6,3
2004	2012	45,7	1497,5	1453,8	−43,7	2,9
2005	1959	45,7	1502,6	1479,1	−23,5	1,6
2006	1857	47,9	1474,6	1613,2	138,6	9,4
2007	1726	34,3	1721,6	1704,8	−16,8	1,0
2008	1684	34,3	1725,6	1774,5	48,9	2,8
2009	1595	29,6	1815,2	1856,3	41,1	2,3
2010	909	29,6	1881,6	1804,4	−77,2	4,1
2011	908	29,6	1881,7	1916,1	34,4	1,8

Before the project to expand 2012, the area of Moscow was 107 thousand hectares, after 2012 - 256.15 thousand hectares.

The area of flat coatings of residential and public buildings, on the roof of which green roofs can be arranged, in Moscow is approximately 15% of the total area of the subject, namely 16.05 thousand hectares until 2012, after 2012 - approximately 38, 42 thousand ha.

Given the additional landscaping area (roof greening), we will calculate the possible number of patients registered per 100,000 people. Population for Moscow

$$\hat{Y}(2009) = 2479{,}451 - 0{,}09675 \cdot 1595 - 17{,}2275 \cdot (29{,}6 + 16{,}05) = 1538{,}7$$

$$\hat{Y}(2010) = 2479{,}451 - 0{,}09675 \cdot 909 - 17{,}2275 \cdot (29{,}6 + 16{,}05) = 1605{,}1$$

$$\hat{Y}(2011) = 2479{,}451 - 0{,}09675 \cdot 908 - 17{,}2275 \cdot (29{,}6 + 16{,}05) = 1605{,}2$$

3 Results

A comparison of the calculation results, taking into account the additional roof area of the existing buildings in Moscow for the period 2009–2011, is presented in Table 7.

Table 7. Comparison of the results of calculating the actual and analytical number of patients registered per 100,000 people population for Moscow, taking into account the greening of the roofs of existing buildings, 2009–2011.

Year	z_2, million m^3	z_3, taking into account gardening of roofs, thousand ha	Analytical coefficients values $\hat{Y}'$ taking into account gardening of roofs	Actual coefficient values Y	$\Delta = Y - \hat{Y}'$	ε, %
2009	1595	45,65	1538,7	1856,3	317,6	3,2
2010	909	45,65	1605,1	1804,4	199,3	3,5
2011	908	45,65	1605,2	1916,1	310,9	3,2

Thus, the positive dynamics of the influence of the number of green roofs in the region on the incidence of urban population is visible.

4 Discussion

Table 3 shows that all three factors affect the selected indicator - the contingents of patients with malignant neoplasms, namely, the number of patients registered per 100,000 people. Y, but landscaping affects to a greater extent from the proposed environmental factors:

1. emissions of air polluting substances emanating from stationary sources (z_1), the correlation coefficient is −0.790375, the values are inversely dependent;
2. discharge of contaminated wastewater into surface water bodies (z_2), including water collected in the Moscow region and used in Moscow, the correlation coefficient is −0.8288546, the values are inversely dependent;
3. the area of green massifs and plantings in cities (z_3), the correlation coefficient is largest in magnitude and is −0.906027, the values are inversely dependent.

Therefore, we can conclude that these environmental factors can affect the population of patients with malignant neoplasms in Moscow, indirectly affecting the incidence and health of a person as a whole.

As can be seen from the results of the statistical analysis (Table 7), the greening factor of the city z_3 due to the installation of green roofs for 16 thousand hectares can affect the contingents of patients with malignant neoplasms, reducing the value of the indicator by 3.5%.

5 Conclusions

Of course, along with other measures to reduce the incidence of the population, roof gardening can affect the improvement of air quality, the decrease in the influence of solar radiation, the MPC level of suspended particles and dust, thereby indirectly reducing the incidence of malignant tumors in the urban population.

The device of green roofs on 16 thousand hectares is able to reduce the contingent of patients with malignant neoplasms by 3.5%. Thus, landscaping, as well as landscaping of existing buildings in Moscow, in particular, is an extremely important integral part of improving the urban environment, quality of life and public health.

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The Influence of Polyethylene Additives on Asphalt Pavement Properties

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Abstract. The article is devoted to determining the possibility of adding high-pressure polyethylene to the asphalt concrete, its optimal quantity in the mixture and the effect on the coating properties. When using a thermoplastic polyethylene in the mixture of the asphalt concrete compositions fillers the environmental impact is minimized and their physical and mechanical properties are improved while reducing the share of natural sources. The solution of these two determined tasks meaning providing the best quality properties of asphalt concrete using mass polymer solid household waste was the purpose of this work. The composition of hot dense fine-grained asphalt concrete type B grade II according to the national Russian Standard 9128-2009, manufactured in the research laboratory "Far East" was adopted as the source composition. The optimum concentration of polyethylene additive in asphalt concrete composition equal to 1% by weight of mineral materials was determined. The research results of physical and mechanical properties of standard and modified asphalt concrete were described, tests for rutting resistance when rolling the loaded wheel on the coating were carried out. Conclusions and decisions, indicating the improvement of asphalt concrete endurance with the addition of 1% polyethylene by weight of mineral fillers are made.

Keywords: High-pressure polyethylene · Asphalt concrete · Asphalt roads

1 Introduction

Asphalt roads are the most important elements of the transport infrastructure in developed countries. Issues of effective development of asphalt road network demand generalization and the world and domestic experience analysis of their construction and operation, studying of modern engineering tendencies, mixtures design, establishment of the requirements imposed to compositions, structures and components used at their production.

Road availability is the ratio of the road network total length to the number of inhabitants. By the end of the twentieth century in Russia it was 4.2 m per 1 person, while in Japan 6.2 m/person, in the UK 6.4 m/person, in Germany 8.1 m/person, in Sweden 11.7 m/person, in France 13.4 m/person, in the United States 14.4 m/person.

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By road availability per capita, our country is 1.5–3 times behind the most developed countries [1].

A distinctive feature of road pavement with asphalt concrete coating is significant changes in their characteristics during the service life due to the influence of climatic factors, fatigue and aging processes on their properties under the external loads. A wide range of changes in the deformation and strength properties of asphalt concrete coatings during their service life allowed us to consider them as a special class of engineering structures made of composite materials with non-stationary performance characteristics. This feature of asphalt concrete coatings requires a deep analysis of their deformation behavior under different conditions of operational loads impact, analysis of changes patterns in their strength characteristics over time.

A variety of conditions for the construction and road pavement operation impose different requirements for the layers characteristics and bases of asphalt concrete coatings due to the fact that the mixtures composition used in the practice of road construction are very diverse. Depending on the composition, properties and ratios of components several dozens types of asphalt concrete coatings can be prepared. Along with the standard mixtures that meet the requirements various kinds of non-standard mixtures are applied in accordance with specially developed technical specifications [2–4].

Recycling is the priority and up-to-date tendency of the industry development. It is necessary to focus on the secondary use of elements produced from waste in all sectors of the economy. The employment of natural sources should be minimized. As components of composite materials for road coverings, it is possible to use waste of industrial chemical, mining and metallurgical and other productions, solid household waste, for example, thermoplastics. Huge quantities of thermoplastics are the main part of landfills and are practically non-degradable. The most common of thermoplastics is high-pressure polyethylene commonly used as thin films, packages and other products of wide use. Since 1953, when Giulio Natta was awarded the Nobel Prize for the catalyst development and the introduction of its mass production technology, a huge amount of waste polyethylene has been accumulated in landfills. Recycling by burning has a negative impact on the environment, but the secondary use of polyethylene is still insignificant. When using high-pressure polyethylene as a filler of asphalt concrete, the environmental impact is greatly reduced. The solution of these two determined tasks meaning providing the best quality properties of asphalt concrete through the use of mass polymer solid household waste, high-pressure polyethylene, was the purpose of this work.

2 Results

Development of production technology of asphalt concrete mixtures modified by polymeric materials, their direct application in the mixer is one of the promising areas [5–14].

In this case, almost no special equipment for the manufacture of expensive binder with improved properties is required. In the manufacture of asphalt concrete mixture with the additive concerned, it is necessary to pre-mix this additive with crushed stone and crushed sand and then add mineral powder and bitumen with additional mixing to obtain a homogeneous mixture.

It is expected that the thermoplastic polymer will increase the strength of asphalt concrete and resistance to cyclic loads, namely rutting resistance. At least one of the functional groups present in ethylene copolymer, such as hydroxyl, carboxyl, carbonyl or epoxy group, or carbonyl group with maleic anhydride grafted present in polyethylene binds to bitumen asphaltenes, thereby combining a thermoplastic polymer with bitumen [3]. This combination increases the mechanical strength of asphalt concrete and its resistance to cyclic loads. In addition, this combination allows a thermoplastic polymer to work more efficiently as part of the asphalt concrete mixture, which provides higher strength of asphalt concrete with a small amount of additives.

Another important characteristic of the interaction of bitumen and mineral material is their adhesion. Mineral material for the preparation of asphalt concrete mixture is characterized by different quantity of silica. According to the quantity of SiO_2, rocks are divided into ultrabasic rock – SiO_2 in the rock is less than 45%, basic rock – SiO_2 ranges from 45% to 54%, medium rock – SiO_2 ranges from 54% to 65% and acid rock – SiO_2 is more than 65%. The adhesion of bitumen with acid rocks is much weaker than with the basic ones.

The role of ethylene copolymers with the presence of these functional groups or polyethylene with maleic anhydride grafted is to increase the degree of adhesion between bitumen and mineral material (crushed stone) due to the interaction of these functional groups with SiO_2 on the surface of crushed stone.

In this paper, some properties of hot dense fine-grained asphalt concrete type B grade II according to Russian Standard 9128-2009, made with the use of 1% high-pressure polyethylene by the mass of mineral material as an additive in its composition are given as the source composition.

Usually the asphalt concrete mixture design is developed according to the highway project specifications. The specifications indicate the type and grade of asphalt concrete mixture, as well as the pavement layer for which it is intended. Proportioning of asphalt concrete mixture includes tests and selection of constituent materials based on tests results, and then establishment of an efficient ratio between them, ensuring the production of asphalt concrete with properties that meet the standard requirements. Mineral materials and bitumen are tested in accordance with current standards. When the whole complex of tests is carried out the suitability of materials for the asphalt concrete mixture design of a given type and grade that conform to Russian Standard 12801-98 “Materials based on organic binders for road and airfield construction. Test methods” is established.

The choice of an efficient ratio between the constituent materials begins with the calculation of the grain-size composition. The mineral part of large – and fine-grained asphalt concrete mixtures containing coarse or medium sand, as well as screenings of rock fragmentation are recommended to be designed for continuous grain compositions. Asphalt concrete mixtures containing fine natural sand are recommended for intermittent compositions, where the base of crushed stone or gravel is filled with a mixture containing virtually no grains of 5–0.63 mm.

Mineral part of hot and warm sand and all kinds of cold asphalt concrete mixtures are designed only for continuous grain compositions.

For the convenience of calculations, it is appropriate to use the limit value curves of grain compositions, described in accordance with Russian Standard 9128-2009 (Figs. 1 and 2).

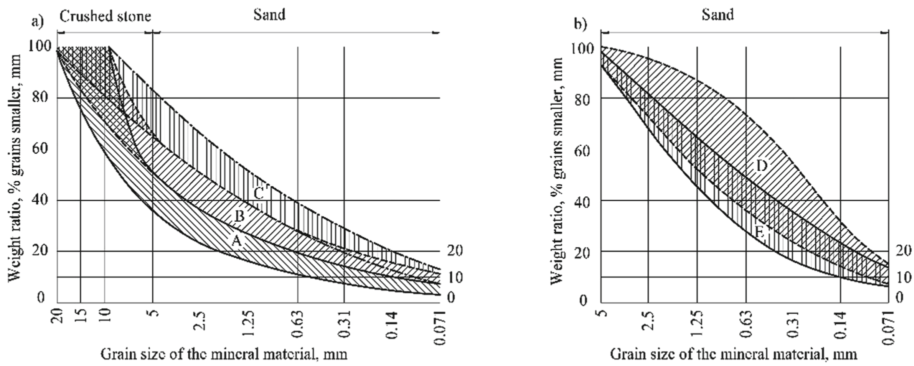

Fig. 1. Continuous grain compositions of the mineral part of hot and warm fine-grained mixtures (a) and sand mixtures (b) for dense asphalt concrete used in the upper layers of coatings

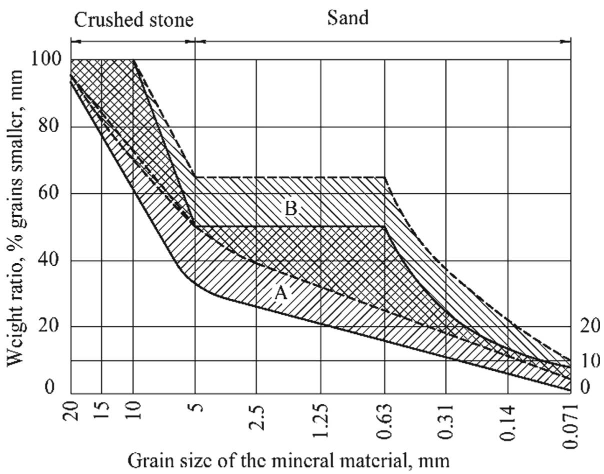

Fig. 2. Intermittent grain compositions of the mineral part of hot and warm fine-grained mixtures (a) and sand mixtures (b) for dense asphalt concrete used in the upper layers of coatings

The mixture of crushed stone (gravel), sand and mineral filler is designed in the way that the curve of the grain composition is located in the zone limited by the limit curves, and is as smooth as possible.

When designing the grain composition of the mixtures with crushed sand and crushed gravel, as well as with the materials from screenings of rock fragmentation, which are characterized by a high amount of fine grains (smaller than 0.071 mm), it is necessary to consider the amount of the latter in the total mineral filler content (Figs. 3 and 4).

When using materials from the screenings of volcanic rock fragmentation, complete replacement of the mineral filler with their fine-dispersed particles is allowed in mixtures for dense hot asphalt concrete grade III, as well as in mixtures for porous and highly porous asphalt concrete grades I and II. In mixtures for hot, warm and cold asphalt concrete grades I and II only partial replacement of mineral filler is allowed; wherein the mass of the grains smaller than 0.071 mm, included in the composition of the mixture must contain at least 50% limestone mineral filler that meets the requirements of Russian Standard 32761-2014.

Compaction of mixture samples containing crushed stone up to 50% of weight was carried out under pressure (40.0 ± 0.5) MPa with hydraulic presses in molds. When compacting, a two-way load application was provided. It was achieved by transferring pressure to the compacted mixture through two liners being in the mold that moved freely towards each other. When producing samples from hot mixtures forms and liners were heated up to 90–100 °C.

The test results of physical and mechanical properties of control samples of dense fine-grained asphalt concrete type B grade II using 1% high-pressure polyethylene by

Table 1. The test results of physical and mechanical properties of dense fine-grained asphalt concrete control samples using 1% high-pressure polyethylene by weight of mineral material

Indicator name for dense asphalt concrete	Russian Standard 9128-2009 requirements to dense fine-grained asphalt concrete	Actual value	
		Without high-pressure polyethylene addition	With the addition of 1% high-pressure polyethylene
Compressive strength, at 50 °C, MPa, not less than	1.0	1.7	Compressive strength, at 50 °C, MPa, not less than
Compressive strength, at 20 °C, MPa, not less than	2.2	3.3	Compressive strength, at 20 °C, MPa, not less than
Compressive strength, at 0 °C, MPa, not more than	12.0	6.3	Compressive strength, at 0 °C, MPa, not more than
Water resistance, not less	0.85	1.1	Water resistance, not less
Water resistance at prolonged saturation, not less than	0.75	1.0	Water resistance at prolonged saturation, not less than
Shear resistance at: the coefficient of internal friction, not less than	0.81	0.87	Shear resistance at the: the coefficient of internal friction, not less than
Shear resistance at the: shear clutch at temperature 50 °C, MPa, not less than	0.35	0.44	Shear resistance at the: shear clutch at temperature 50 °C, MPa, not less than
Crack resistance at ultimate tensile strength during splitting, at temperature of 0 °C and strain rate 50 mm/min, MPa: – not less than – not more than	3.0 6.5	3.1	Crack resistance at ultimate tensile strength during splitting, at temperature of 0 °C and strain rate 50 mm/min, MPa: – not less than – not more than
Percentage of water saturation by volume	1.5–4.0	2.9	Percentage of water saturation by volume

weight of the mineral material, determined using the full factorial experiment, are shown in Table 1.

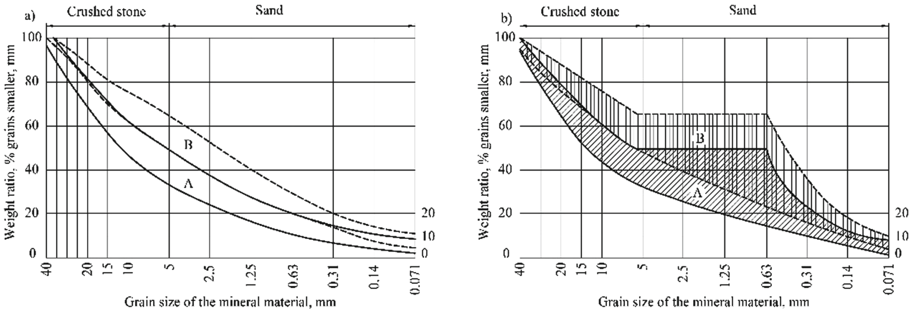

Fig. 3. Continuous (a) and intermittent (b) grain compositions of the mineral part for hot and warm coarse-grained mixtures for dense asphalt concrete used in the lower layers of coating and the base layers

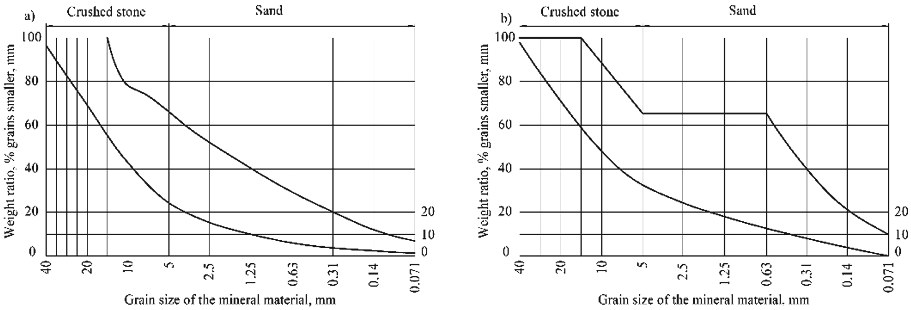

Fig. 4. Continuous (a) and intermittent (b) grain compositions of the mineral part for hot and warm coarse-grain and fine-grained mixtures for porous and highly porous asphalt concrete used in the lower layers of coating and base layers

Figures 5 and 6 show test results of asphalt concrete for resistance to rutting when rolling a loaded wheel. To observe the obvious differences in the characteristics of the mixtures, 1000 load cycles were enough (2000 rolling in one trace).

The essence of the method consists in rolling the loaded wheel on the test sample at a temperature of 60 °C ± 1 °C and determining the rut depth after 10,000 load cycles (20,000 rolling) or upon reaching the ultimate value (in our case, the ultimate value is rolling up to 1000 cycles).

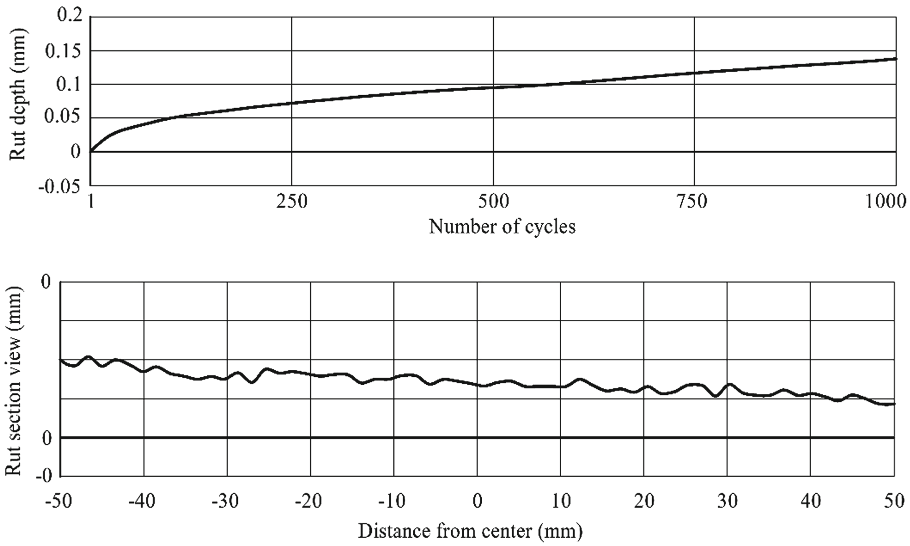

Fig. 5. Graphs for the rutting of asphalt concrete type B grade II according to Russian Standard 9128-2009 with the addition of 1% high-pressure polyethylene by weight of mineral material

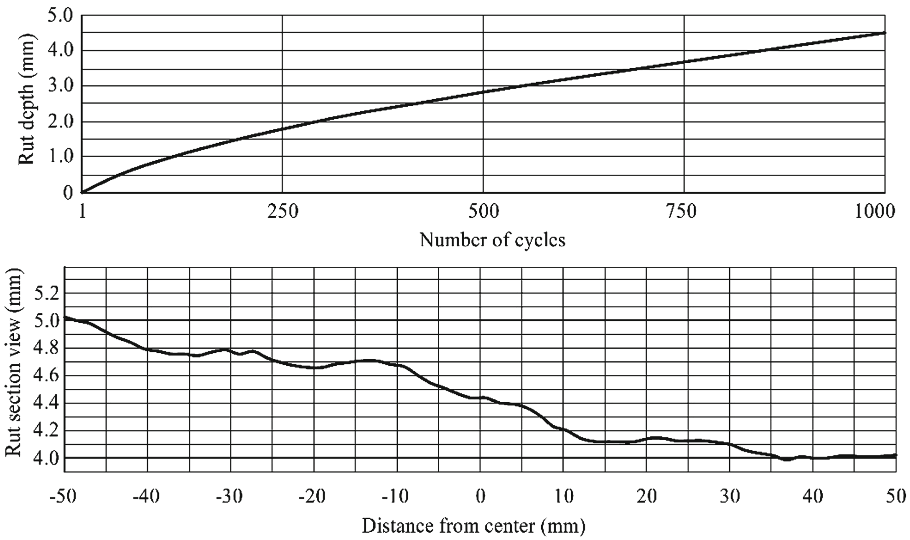

Fig. 6. Graphs for rutting of asphalt concrete type B grade II according to Russian Standard 9128-2009 without the addition of high-pressure polyethylene

3 Discussion

Comparative analysis of physical and mechanical properties of asphalt concretes leads to the conclusion that the introduction of the optimal amount of thermoplastic polyethylene in the asphalt mixture has no negative effect on the binding properties of bitumen and, on the contrary, improves some physical and mechanical properties of asphalt concrete. The research results of the effect of high-pressure polyethylene as an additive to hot dense asphalt concrete type B grade II revealed its optimal amount as 1% by weight of mineral material. The reliability of the obtained test results of the properties is confirmed by a sufficient sample information because when determining each indicator, the arithmetic mean value of the results of the three samples is taken.

The test of road pavement for rutting was carried out. The “Method of rutting resistance determination by rolling a loaded wheel” was used. This method revealed the deformability characteristics improvement when using high-pressure polyethylene as an additive to the asphalt concrete mixture.

The analysis of the samples test results shows that under other stable conditions the introduction of 1% high-pressure polyethylene decreased the amount of rutting tenfold. At the same time, the main physical and mechanical properties of the modified asphalt concrete mixture (compressive strength, shear resistance, cracking, etc.) remained within the limits set by Russian Standard 9128-2009, and some properties even improved.

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Identifying the Positioning Systems in Conditions of Insufficient Primary Measurement Information

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Abstract. The article describes the development of a method for identifying the parameters of the positioning systems components in conditions of insufficient primary measurement information using the proportional electromagnets as example. A review and analysis of the existing classification methods applicable to the dynamic characteristics of magnetization is carried out. The requirements are put forward for choosing a classification method as applied to proportional electromagnets. Based on the requirements, the most suitable method has been selected. Also considered is the stage of identifying the parameters of the constituent elements of proportional electromagnets by various methods of constructing regression models, among which the model most suitable for solving the problem is selected. For the subsequent data processing, a work algorithm was compiled combining soft independent modeling of class analogy method with the regression on latent structures method. Based on this algorithm, an experiment was conducted to identify the parameters of the constituent elements of proportional electromagnet in conditions of insufficient primary measurement information. A matrix of the obtained responses of the parameters of the constituent elements of positioning systems has been compiled and the method error of 5% has been calculated. This error is permissible for magnetic measurements. With such an error, one or another positioning system can be accurately identified.

Keywords: Positioning systems · Proportional electromagnet · Identification · Classification · Regression

1 Introduction

Proportional electromagnets can be used as systems of positioning, which serve for precise movement with a given force [1–3]. During the production of such systems or their operation, the characteristics of the proportional electromagnets change, which can lead to high positioning errors [4]. To diagnose positioning systems, identification of the parameters of their components can be carried out [5–8]. We have proposed a method that allows to determine the functional state of such systems even with lack of primary measurement information (dynamic magnetization characteristic (DMC) [9, 10].

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2 Methods

To implement the proposed approach, we will consider methods that allow the parameters of the positioning systems components with a lack of primary measurement information. For this, we will use compatible methods for applying the classification and constructing of regression model.

We will analyze the most appropriate classification methods. In our case, classification is a procedure in which DMC belongs to a group of proportional electromagnets (PE) without deviations.

Consider the following classification methods [11–14]:

I. Linear discriminant analysis (LDA) – is a classification method designed to be divided into two classes. Moreover, each class appears to be a normal distribution and the covariance matrices of these two classes are the same.
   Classification rule – the new sample x belongs to the class to which it is closer in the Mahalanobis metric

$$d_k = (\mathbf{x} - \boldsymbol{\mu}_\mathbf{k}) \sum\nolimits^{-1} (\mathbf{x} - \boldsymbol{\mu}_\mathbf{k})^t,$$

$$k = 1, 2$$

   where dk – Mahalanobis distance (generalized concept of Euclidean distance), μk – vector of mean values, x – matrix's Xc row, Σ – covariance class matrix.
   Disadvantages of the LDA method:
   1. Does not work with a large number of variables. Regularization is required, for example, by the method of principal components (PC), in order to exclude retraining.
   2. Not suitable if covariance matrices of classes are different.
   3. Implicitly uses the assumption of normality of distribution.
   4. Does not allow setting error levels of the 1st and 2nd kind.

   Advantages of the LDA method: it easy to use.

II. Quadratic discriminant analysis (QDA) is a generalization of the LDA method. QDA is a multiclass method; it can be used to simultaneously classify several classes. QDA accounts for the k-th class are calculated by the formula

$$f_k = (\mathbf{x} - \boldsymbol{\mu}_\mathbf{k}) \sum\nolimits_k^{-1} (\mathbf{x} - \boldsymbol{\mu}_\mathbf{k})^t + \log\left(\det\left(\sum\nolimits_k^{-1} (\mathbf{x} - \boldsymbol{\mu}_\mathbf{k})^t\right)\right),$$

$$k = 1, \ldots, k$$

   where Σk – covariance matrix for each class, det – characteristic operator.
   Classification rule of the QDA method: the new sample x belongs to the class for which the QDA-scale fk is the smallest.
   Disadvantages of the QDA method:
   1. Does not work with a large number of variables. Requires regularization by the PC method, in order to exclude retraining.

2. Implicitly uses the assumption of normality of distribution.
3. Does not allow setting error levels of the 1st and 2nd kind.

Advantages of the QDA method:

1. It easy to use.
2. Can be used for simultaneous classification into several classes.

III. Partial least squares discriminant analysis (PLSDA) – classification method designed to be divided into two or more classes.

For example, we take two matrices: the training matrix Xc and the test matrix Xt. We supplement them with response matrices—training Yc and testing Yt. – which are formed according to the following rules:

1. The number of columns in the matrices Y must be equal to the number of classes.
2. Each row of the matrix Y must have zeros (0) or units (1) depending on which class this row belongs to - if the row corresponds to the k-th class, then in the k-th column should be 1, in the remaining columns zeros.

A PLS regression is constructed between the Xc and Yc and the predicted response values Yhat are calculated from it for the training and test sets. The PLS projection is calculated for the new sample X, i.e. line of new responses y1, … yK. The classification rule in PLSDA – the sample belongs to the class for which the corresponding element yk is closer to one, i.e. the index k is determined at which is achieved

$$min\{|1 - y_1|, \ldots, |1 - y_K|\}$$

Disadvantages of the PLSDA method:

1. Requires prior regression analysis of data.
2. The result depends on the choice of the number of PC.
3. Emission sensitive.
4. Poor performance for a small number of samples in a training set.
5. Does not allow setting error levels of the 1st and 2nd kind.

Advantages of the PLSDA method:

1. Does not use distribution type.
2. Applicable for a large number of variables, resistant to a significant exponential increase in the complexity of the problem with an increase in the number of variables.

IV. Soft Independent Modeling of Class Analogy (SIMCA) – classification method designed to determine whether a sample belongs to a particular class. It has a number of distinctive features:

1. Each class is modeled separately, independently of the rest. Therefore, the SIMCA method is a single-class method.
2. Classification by this method is ambiguous - each sample can be simultaneously assigned to several classes.
3. In the SIMCA method, it is possible to set the error value of the 1st and 2nd kind and build the corresponding classifier.

Consider the method in more detail.

Let the PC decomposition of the training matrix be constructed X

$$X = TP^t + E$$

where T – matrix of counts, P – load matrix, E – decomposition error matrix. When implementing the classification method, the following parameters are used: range h and deviation ν, which are calculated for the matrix X by the formulas:

$$h = \sum_1^n \left(\frac{t_i}{\sqrt{\lambda_i}}\right)^2,$$

$$v = \frac{1}{l}\sum_1^n e_i^2$$

where ti – matrix T's elements; λi – matrix T's eigenvalues, ei – matrix E's elements, l – dimension of the source data space.
Using the training set Xc, we find p values of the ranges h1, …, hi and standard deviations v1, …, vi. According to them, we can estimate the corresponding average values:

$$h_0 = \frac{1}{p}\sum_1^p h_i, v_0 = \frac{1}{p}\sum_1^p v_i$$

and their corresponding variance values:

$$S_h = \frac{1}{p-1}\sum_1^p (h_i - h_0)^2, S_v = \frac{1}{p-1}\sum_1^p (v_i - v_0)^2.$$

Degrees of freedom Nh, and Nv determined by the formulas:

$$N_h = \frac{2h_0^2}{S_h}, N_v = \frac{2v_0^2}{S_v}.$$

The estimated coefficient f, by which the classification is carried out, is calculated by the formula

$$f = N_h\frac{h}{h_0} + N_v\frac{v}{v_0}.$$

The critical value of the coefficient f is determined by the expression:

$$f_{crit} = \chi^{-2}(\alpha, N_h + N_v)$$

where $\chi^{-2}(\alpha, n)$ – the α-quantile of the chi-square distribution with $N_h + N_v$ degrees of freedom.

Classification rule in SIMCA: the sample is accepted as belonging to the class if $f < f_{crit}$.

This rule guarantees that (1 – α) 100% of the samples from the training and test sets will be correctly classified.

Disadvantages of the SIMCA method:

1. Requires preliminary analysis of the data by the PC method
2. The result depends on the choice of the number of PC. However, his choice is facilitated by the fact that you can take the minimum number at which the training set is correctly recognized.
3. It is sensitive to emissions, however, they are easily recognized by the method itself.
4. Requires more samples in the training set.

Advantages of the SIMCA method:

1. Not tied to the type of distribution.
2. One-class method.
3. Errors of the 1st and 2nd kind can be set.
4. Applicable for a large number of variables.

V. k-Nearest Neighbors method (kNN). Let there be a training set Xc divided into classes, and a new unknown object x, which must be classified. Let calculate the Euclidean distance from x to all samples of the training set (x1, …, xi) and select among them k nearest neighbors, the distance to which is minimal. The new object x belongs to the class to which most of these k neighbors belong. The parameter k is selected empirically. An increase in k leads to a decrease in the influence of errors, but worsens the division into classes.

Disadvantages of the kNN method:

1. Poor for a large number of classes.
2. The result depends on the choice of metric and the amount of classified data.

Advantages of the kNN method:

1. Not tied to the type of distribution.
2. It can be used with a small number of samples in the training set.

VI. K-means method – classification method that does not require a training sample. This method splits the initial set of samples into a known number of K clusters. Moreover, each sample xi necessarily belongs to one of these clusters. Each cluster K is characterized by its centroid mk – the point that is the center of mass of all cluster samples.

Disadvantages of the K-means method:

1. The number of clusters K is not known in advance. The number of clusters K is determined by increasing its values and examining the result.
2. The result depends on the initial choice of centroids. Need to sort through different options.
3. The result depends on the choice of metric.

Advantages of the K-means method: no training set required.

Table 1 presents the classification methods and their advantages and disadvantages.

Table 1. Classification methods and their main properties.

Classification method	Method property									
	Works with a large data array	Setting errors of the first and second kind	Depends on the type of distribution	Data pre-processing required	Training sample required	Works poorly with few samples	Emission sensitive	The result depends on the amount of PC	It is difficult to split the source data into clusters	Deviations from requirements
Linear Discrimination Analysis (LDA)	**No**	**No**	**Yes**	**Yes**	**Yes**	**No**	**Yes**	**Yes**	**No**	**5**
Quadratic Discrimination Analysis (QDA)	**No**	**No**	**Yes**	**Yes**	**Yes**	**No**	**Yes**	**Yes**	**No**	**5**
PLS discrimination	**Yes**	**No**	**No**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**4**
Soft Independent Modeling of Class Analogy (SIMCA)	**Yes**	**Yes**	**No**	**Yes**	**Yes**	**Yes**	**No**	**Yes**	**No**	**2**
k-Nearest Neighbors	**No**	**No**	**No**	**No**	**Yes**	**Yes**	**No**	**No**	**No**	**3**
K-means	**Yes**	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**Yes**	**2**
Is required	**Yes**	**Yes**	**No**	**–**	**–**	**No**	**No**	**No**	**No**	

The following requirements were put forward to select a method:

1. Ability to work with a large source data array - since in our case the data array can have a large dimension.
2. The ability to set the level of errors of the first and second kind, since they are an important indicator of assessing the quality of identification of the parameters of the PE components.
3. The result should not depend on the selected type of distribution, to exclude an additional error.
4. It is desirable that the method work with a minimum number of samples in the training set, to simplify and reduce time costs.
5. The method should not be sensitive to outliers and should enable their determination.
6. It is desirable that the result does not depend on the amount of PC in order to minimize their amount.
7. The method should allow the easiest way to split the source data into clusters.

As a result of the analysis on the minimum number of deviations from the requirements, two classification methods turned out to be the most suitable: formal independent modeling of class analogies; clustering using k-means.

Given that it is important to be able to set the level of errors of the first and second kind, the most relevant for the stage of “sifting” PE without deviations is a formal independent modeling of class analogies.

For the stage of identifying the parameters of the PE components, we consider the methods of constructing regression models and analyze taking into account the advanced requirements [11, 15].

One-way regression. If one row is selected from the initial data matrix X then we obtain several vectors x. Then, using training data, we can construct for each row the simplest one-dimensional regression

$$x = ys$$

where x and y – elements of training samples of source data, s – conversion factor (sensitivity value).

Fierordt’s Method. In this method, unlike single-factor regression, regression equations are considered not independently, but together

$$\tilde{\mathbf{X}}_c = \mathbf{Y}_c\mathbf{S}$$

where is the matrix $\tilde{\mathbf{X}}_c$ has as many columns as there are groups defined, matrix Yc – these are known response values in the training set, and the matrix S – this is an unknown coefficient matrix that needs to be estimated.

Indirect regression – a method of constructing a regression that uses several rows of matrices at once:

$$X = YS$$

where Y – response matrix in the training set, X – matrix of factors in the training set, S – coefficient matrix to be estimated.

Multiple linear regression. Its basic equation is:

$$Y = XB$$

where B – transformation coefficient matrix, which is located:

$$B = YX^{-1}$$

I. Stepwise regression – a method of constructing a regression in which the selection of variables is a way to handle reevaluation. The idea of the method is as follows. Let there be a model constructed from M selected rows of the matrix X. Add one more M + 1 to them. The choice of this additional line is based on the following principle - the line is added that gives a minimum value of the standard deviation. Addition continues until there is a risk of revaluation, i.e. before the start of the growth of the standard deviation.

II. Regression on the main components (PCR). Such regression is usually based on a centered training set (Xc, Yc). In order to obtain a forecast for a test or a new set of samples (Xt, Yt), they must also be centered and projected onto an existing subspace. In other words, we need to find Tt counts of new samples

$$\mathbf{T}_t = \mathbf{X}_t\mathbf{P}$$

where **P** – this is a load matrix built on a training set.

III. Regression on latent structures. In this method, the regression task consists in constructing a mathematical model that connects the matrices x and y, with which you can further predict the values of the indicators $y_1, y_2, \ldots$, yK, from a new line of values of the analytical signal x. It is important to use all available data and at the same time, to avoid revaluation and multicollinearity, which are inevitable with a large number of regression variables. The solution to this problem is to use new latent variables ta, $(a = 1, \ldots A)$, which are a linear combination of the original variables xj $(j = 1, \ldots J)$

$$t_a = \mathbf{p}_{a1}\mathbf{x}_1 + \ldots + \mathbf{p}_{aJ}\mathbf{x}_J$$

or in matrix form

$$X = TP^t + E.$$

In this equation T is the score matrix. The matrix P is the load matrix. E – is the matrix of residues.

During the analysis of regression construction methods, a number of requirements are identified:

1. Regression - should not lead to underestimation or revaluation, which lead to additional errors.
2. It should be possible to use several values of the response matrix.
3. The method should take into account multicollenarity, as the constituent points of DMC are correlated with each other.
4. It is necessary to use the smallest amount of PC in order to simplify the solution of the task.
5. The method should allow calibration with the lowest values of systematic deviations.

Table 2 presents the methods of constructing a regression model, their advantages and disadvantages [11, 15].

The most suitable methods for solving the formulated problem were: regression on latent structures and regression on the main components, because they take into account the phenomenon of multicollenarity in the matrix x and give the most accurate solution to the problem. Since the method of regression on latent structures uses a smaller amount of HA for the same result as when using regression on the main components, he was given preference.

Thus, the regression method on latent structures was chosen.

3 Results and Discussion

In the analysis of existing methods, an algorithm of the methodology was developed in relation to the task:

1. PC decomposition of the training matrix X is created, scope h and deviation ν are calculated. Using the training set Xc, p values of the ranges h1, …, hi and standard deviations v1, …, vi are found. According to them, the corresponding average values, variance values can be estimated.
2. The degrees of freedom Nh, and Nv are determined, the coefficient f is calculated and its critical value is found. After that, the sample is accepted as belonging to the class of PE without defects if $f < fcrit$.
3. Two data sets are formed: training (Xo, Yo) and testing (Xt, Yt) sets. Regression is based on a centered training set (Xo, Yo), which includes the matrix of projections of DMC in the space of PC Xo and the corresponding parameter values of the constituent elements of high-precision positioning systems Yo.
4. A multiple regression is constructed between the matrices Yo and Xo. Regression coefficients are determined (matrix A).
5. The values of the test sample Xt are substituted into the obtained regression model and the values of the calculated parameters of the constituent elements of the high-precision positioning systems YB are determined as

Table 2. Methods for constructing a regression model and their main properties.

Model building method	Method description					
	The method leads to underestimation or revaluation	It is possible to use a response matrix for several values	Multicollinearity is taken into account	Small amount of PCs required	Small values of systematic deviations	Deviations from requirements
Univariate regression	**Yes**	**No**	**No**	**No**	**No**	**4**
Fierordt's method	**Yes**	**No**	**No**	**No**	**No**	**4**
Indirect regression	**Yes**	**No**	**No**	**No**	**No**	**4**
Multiple regression	**Yes**	**No**	**No**	**No**	**No**	**4**
Incremental regression	**No**	**No**	**No**	**No**	**No**	**4**
Regression on PC	**No**	**No**	**Yes**	**No**	**Yes**	**2**
Regression on latent structures	**No**	**Yes**	**Yes**	**Yes**	**Yes**	**0**
Is required	No	**Yes**	**Yes**	**Yes**	**Yes**	

$$Y_B = X_t A.$$

The deviation of the vector YB from the vector of the training set Yt is checked. If the calculations meet the accuracy requirements, the regression model is ready for use. Otherwise, complement the training set (Xo, Yo).

In accordance with this algorithm, an experiment was conducted to identify the parameters of the constituent elements of PE in conditions of insufficient primary measurement information.

The training set is formed by: matrix X0 – is the PC values of the first forty-two DMCs, and the matrix Y0 – is the corresponding parameter values of the constituent elements of high-precision positioning systems. The test set is formed by: the matrix Xt – is the DMC group of values with numbers from forty-third to forty-sixth, and the matrix Yt – is the corresponding parameter values of the constituent elements of high-precision positioning systems.

After building a regression between matrices X0 and Y0 we get three response matrices YBn (n – is the number of PCs involved in the construction of multiple regression) (Table 3).

Table 3. Matrices of received responses and errors in calculating the parameters of the high-precision positioning systems components.

Parameter/number of DMC	Number of winding turns	The saturation induction of the magnetic material, T		
		Anchor	Yoke	Hull
43	763	1,8	1,8	1,8
44	850	2,1	2,1	2,1
45	939	1,9	1,6	1,9
46	950	1,6	1,8	2,1
	Error, %			
43	0,4	0	0	0
44	0,6	5,0	***5,0***	5,0
45	***1,2***	***5,0***	0	***5,0***
46	0	0	0	5,0

It can be seen from the results that the parameters of the PE components are determined with an error not exceeding 5%.

The accuracy obtained in this case is sufficient for magnetic measurements, in particular, for estimating the deviation of the dynamic magnetization characteristics depending on the parameters of the components of the electromagnet.

4 Conclusion

A method based on the joint use of methods of class analogy and regression on hidden structures is proposed for determining parameters of components of devices even in the absence of primary measurement information. The results obtained in the study of proportional electromagnets showed its effectiveness. This makes it possible to recommend the use of the method to identify precision positioning systems and other electrical devices.

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Algorithmic and Software Optimization Approach for Diagnosis of High-Precision Positioning Systems

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Abstract. This publication describes the algorithmic and software optimization approach for identifying and diagnosing high-precision positioning systems. When constructing such systems, with the aim of the most effective control during operation and production, they use a method based on solving inverse problems. This is an iterative method that requires the use of an optimization algorithm, the use of the method of simplex optimization or simplex planning is proposed, which allows faster and more efficient reduction of the inverse problem to convergence. This approach is often used in solving iterative problems with a small number of factors (less than 6). The authors described the functioning algorithm of the simplex optimization method, examined the problems associated with the impossibility of changing the dimensions of the simplex, and found ways to solve them. Experimental studies based on the simplex optimization method for a deformable polyhedron, reflecting the effectiveness of this approach. The experimental results presented in the table and on the graph show a high convergence rate of the inverse problem (which was obtained for 13 iterations).

Keywords: Optimization · Positioning systems · Simplex · Algorithmic

1 Introduction

In the identification and diagnosis of high-precision positioning systems, it is often necessary to solve the inverse problems of electrical engineering [1–4]. As known, tasks of this nature involve the use of iterative approaches to search for the parameters of the original model from a known simulation result. Thus, the choice of the most effective optimization algorithm is the key to rapid convergence of the inverse problem [2–5]. The authors proposed to use the method of simplex optimization (simplex planning), which has a number of important advantages over other optimization methods [6–8]. These advantages include: the need to use fewer experiments for each subsequent step of the iterative process, shorter convergence time of the inverse problem, simplicity of the algorithmic component of this method, which allows less hardware resources to be used to implement this approach.

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2 Methods

The simplex is defined as a regular polyhedron having n + 1 vertices, where n is the number of factors that influence the process [9, 10]. If, for example, there are two factors, then the simplex is an equilateral triangle. The essence of the simplex optimization method is illustrated in Fig. 1.

Initial experiments correspond to the vertices of the initial simplex (points 1, 2, and 3). The conditions of these first experiments are taken from the range of factors corresponding to the most favorable of the known modes of the optimized process. Comparing the results of the experiments at points 1, 2 and 3, they find among them the most «bad», from the point of view of the chosen optimality criterion. Let, for example, the experiment at point 1 turn out to be the most "unsuccessful". This experiment is excluded from consideration, and instead the experiment at point 4 is introduced into the simplex, which is symmetrical to point 1 relative to the opposite side of the triangle connecting points 2 and 3.

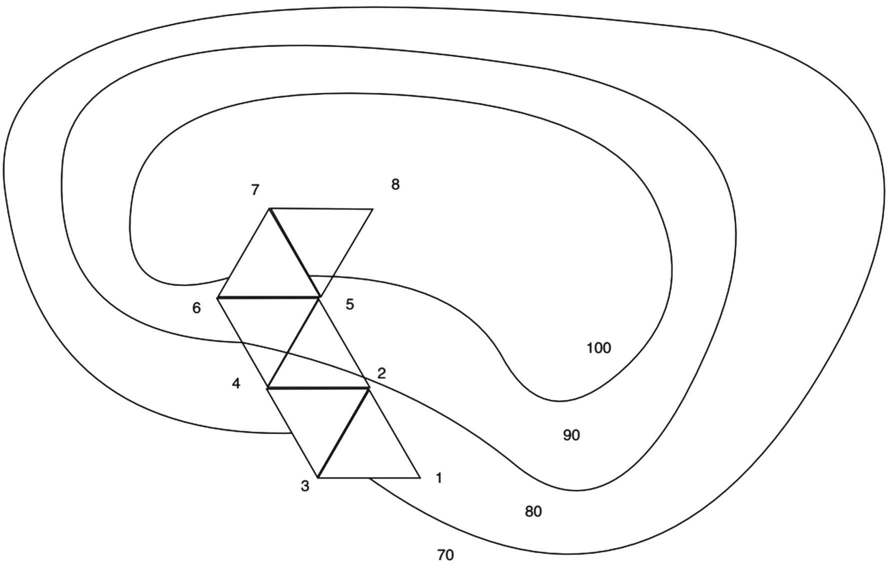

Fig. 1. Simplex optimization.

Calculation of the reflected point's coordinates are carried out according to the formula [9]:

$$x^* = \frac{2}{n}\sum_{i-1}^{n+1} x^i - \left[\frac{2}{n} + 1\right] x^j$$

n – number of factors, j – vertex number of the initial simplex with the smallest response value, i – vertex number of the obtained simplexes, x^* – coordinate of the new point.

The following is a comparison of the results of the experiments at the vertices of the new simplex, discard the most «unsuccessful» of them and (point 3) transfer the corresponding vertex of the simplex to point 5. Then, the considered procedure is repeated throughout the entire optimization process. If the extremum is reached, then the further movement of the simplex stops.

However, this approach has low efficiency [10, 11], and therefore it is recommended to use a modification of this method, allowing the simplices to be incorrect. A simplex is moved using three basic operations: reflection, extension, and compression.

Consider the sequence of steps in the implementation of the procedure.

A. We find the function values by the formula f1 = f(x1), f2 = f(x2) … fk + 1 = f(xk + 1) at the vertices of a simplex.
B. «Sorting». From the vertices of the simplex, we select three points: xh with the largest (from the selected) value of the function fh, xg with the next largest value of fg after fh and xl with the lowest value of the function fl. The aim of further manipulations will be to reduce at least fh.
C. We find the center of gravity of all points, except for the point xh. Let the center of gravity be:

$$x_0 = \frac{1}{k}\sum_{i \neq h} x_i$$

and calculate f(x0) = f0.
D. It's best to start moving from xh. Reflecting the point xh relative to the point x0, we obtain the point xr and find f(xr) = fr. The reflection operation is illustrated in Fig. 1. If a > 0 – is the reflection coefficient, then the position of the point xr is determined as follows:

$$x_r - x_0 = a(x_0 - x_h)$$

Note: $a = |x_r - x_0|/|x_0 - x_h|$
E. Compare function values fr and fl.
   1. If fr < fl, then we get the smallest value of the function and the direction from the point x0 to the point xr which is most convenient for moving. Thus, we stretch in this direction and find the point xe and the value of the function fe = f(xe). The stretch factor $\gamma > 1$ can be found from the following relations:

$$x_e - x_0 = \gamma(x_r - x_0)$$

Note: $\gamma = |x_e - x_0|/|x_r - x_0|$

(a) If fe < fl, then replace the point xh with the point xe and check the (k + 1)-th point of the simplex for convergence to a minimum (see step H). If convergence is achieved, then the process stops; otherwise return to step B.
(b) If fe > fl, then discard the point xe. Obviously, that we have moved too far from x0 to the point xr. Therefore, you should replace the point xh with the point xr, at which the improvement was obtained (step D, 1), check the convergence and, if it is not achieved, return to step B.

2. If fr > fl, but fr < fg, then xr is a better point compared to the other two points of the simplex and we replace the point xh with the point xr and, if convergence is not achieved, we return to step B described above.
3. If fr > fl and fr > fg, move to the step F.

F. Compare function values of fr and fh.
   1. If fr > fh, then we go directly to the compression step F, 2.
   If fr < fh, then replace the point xh with the point xr and the value of the function fh with the value of the function fr. We note the value fr > fg from step E, 2 above. Then go to step F, 2.
   2. In this case fr > fh, therefore it is clear that we have moved too far from the point xh to the point x0. We will try to fix this by finding the point xc (and then fc) using the compression step. If fr > fh, then we immediately go to the compression step and find the point xc from the relation

$$x_c - x_0 = \beta(x_h - x_0)$$

   β(0 < β < 1) – compression factor.
   If fr < fh, then we first replace the point xh with the point xr, and then compress it. Then we find the point xc from the relation:

$$x_c - x_0 = \beta(x_r - x_0)$$

G. Compare function values fc and fh.
   1. If fc < fh, then replace the point xh with the point xc and if convergence is not achieved, then return to step B.
   2. If fc > fh, then it is obvious that all our attempts to find a value less than fh failed, so we go to step 3.
   3. At this step, we reduce the dimension of the simplex by halving the distance from each point of the simplex to xl - the point that determines the smallest value of the function.

   Thus, the point xj is replaced by the point xl = (xl + xi)/2, i.e. replace the point xi with the point (xi – xl)/2. Then we calculate fi for i = 1, 2, …, (k + 1), check the convergence and, if it is not achieved, return to step C.

H. The convergence check is based on the fact that the standard deviation of the (k + 1)-th value of the function is less than some given small value of e. In this case, it is calculated as

$$\sigma^2 = \sum_{i=1}^{n+1} \frac{(f_i - \bar{f})^2}{n+1}, \bar{f} = \sum_{i=1}^{n+1} \frac{f_i}{n+1}$$

If σ < e, then all values of the function are very close to each other, and therefore, they probably lie near the minimum point of the function xl. Based on this, such a criterion of convergence is reasonable.

3 Results and Discussion

Consider the application of the simplex method to the problem of finding the nonlinear characteristics of a proportional electromagnet [12–15] acting as a high-precision positioning system. For this, the functional J is calculated by the formula:

$$J = \frac{\sum_{1}^{n} \left| I_{q_m} - I_{q_e} \right|}{\sum_{m=1}^{n} I_{q_e}},$$

I_{q_e} and I_{q_m} – q-th harmonics measured and calculated on the model of currents in the working winding of a proportional electromagnet.

The functional calculations subroutine is implemented in LabVIEW as operations on arrays of current harmonic values (Fig. 2).

LabVIEW is a hardware-software complex for working with measuring equipment and processing data received from it on a personal computer. This software product was selected due to the convenience of programming, the ability to quickly build a model of the device and carry out the necessary calculations.

To find the nonlinear characteristics of a proportional electromagnet, it is necessary that its computer model corresponds to a physical object.

The algorithm of the simplex optimization method for a deformable polyhedron is presented in the form of a block diagram in Fig. 3.

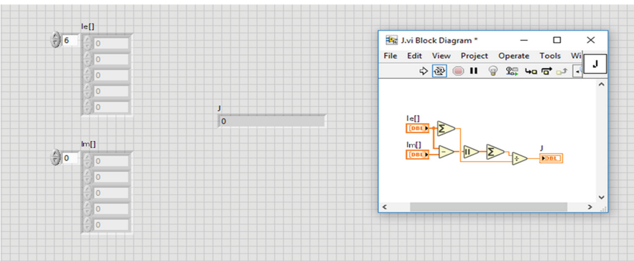

Fig. 2. User interface and functional diagram of the function calculation routine.

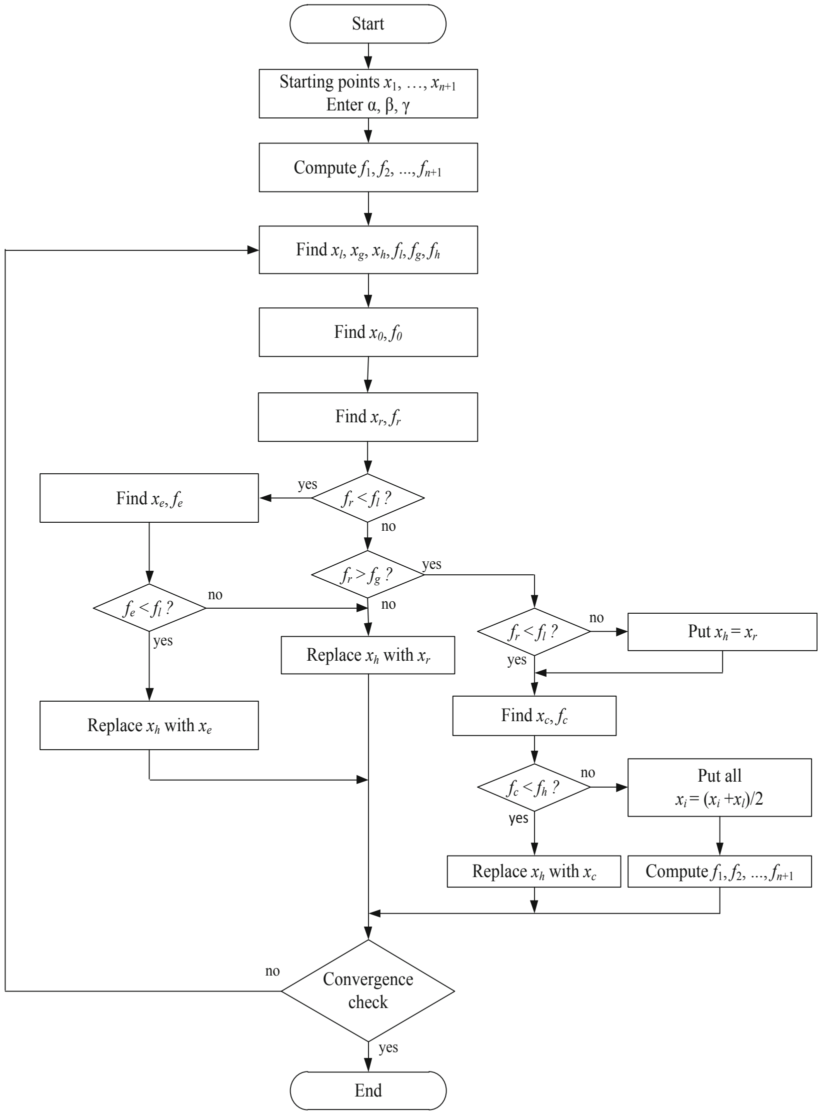

Fig. 3. The algorithm of the method for a deformable polyhedron.

The coefficients α, β, γ in the above procedure are, respectively, the coefficients of reflection, compression and tension. In this case, the point x1 is the starting point, then the points are formed:

$$x_2 = x_1 + de_1, x_3 = x_1 + de_2, \ldots, x_{n+1} = x_1 + de_n,$$

d – arbitrary step length, a e – unit vector.

Figure 4 shows the implementation of the method for a deformable polyhedron algorithm in the LabVIEW software package.

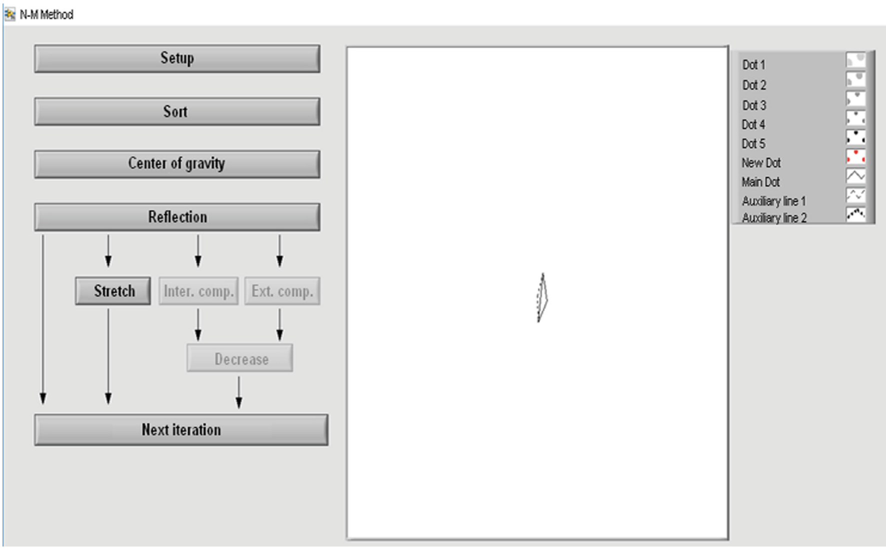

Fig. 4. The interface of the program in LabView that implements the algorithm for a deformable polyhedron.

This software product allows using the solution of the inverse problem to obtain the initial nonlinearity inherent in the proportional electromagnet from the known voltage on its winding and the current flowing through it. An experiment was conducted using the developed software. The results of the experiment with two factors are shown in Table 1 and in Figs. 5 and 6, that shows an example of the program and a graph for displaying the simplex.

Table 1. Iterations in simplex method using 2 factors and 1 response.

Iterations	No of point	Factor №1	Factor №2	Response
1	2	3	4	5
1	1	15	37,113	36,444
	2	17,5	41,444	31,444
	3	20	37,113	29,613
2	1	15	37,113	24,613
	2	17,5	32,783	31,443
	3	20	37,113	29,613
3	1	15	37,113	24,613
	2	17,5	32,783	22,783
	3	12,5	32,783	29,613

(*continued*)

Table 1. (*continued*)

Iterations	No of point	Factor №1	Factor №2	Response
1	2	3	4	5
4	1	15	28,452	24,613
	2	17,5	32,783	22,783
	3	12,5	32,783	17,783
5	1	15	28,452	15,952
	2	10	28,452	22,783
	3	12,5	32,783	17,783
6	1	15	28,452	15,952
	2	10	28,452	10,952
	3	12,5	24,122	17,783
7	1	7,5	24,1215	15,952
	2	10	28,452	10,952
	3	12,5	24,122	9,122
8	1	7,5	24,122	4,122
	2	10	19,791	10,952
	3	12,5	24,122	9,122
9	1	7,5	24,1215	4,1215
	2	10	19,791	2,291
	3	5	19,791	9,122
10	1	7,5	15,461	4,122
	2	10	19,791	2,291
	3	5	19,791	2,709
11	1	7,5	24,122	4,122
	2	10	19,791	2,291
	3	12,5	24,122	2,709
12	1	7,5	24,122	4,122
	2	2,5	24,122	2,291
	3	5	19,791	2,709
13	1	0	19,791	4,1215
	2	2,5	24,1215	0,8785
	3	5	19,791	2,709
14	1	7,5	24,122	4,122
	2	2,5	24,122	0,879
	3	2,5	22,678	2,709
15	1	7,5	24,122	4,122
	2	10	19,791	0,879
	3	5	19,791	2,709
16	1	3,75	24,8432	4,1215
	2	1,25	24,8432	0,8785
	3	2,5	22,678	2,709

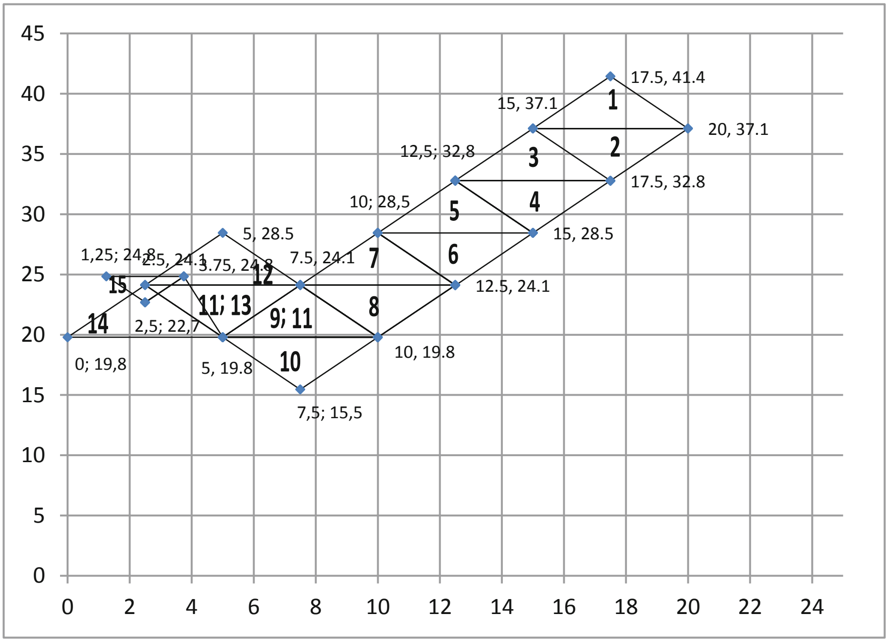

Fig. 5. Search for the optimal value using the simplex method.

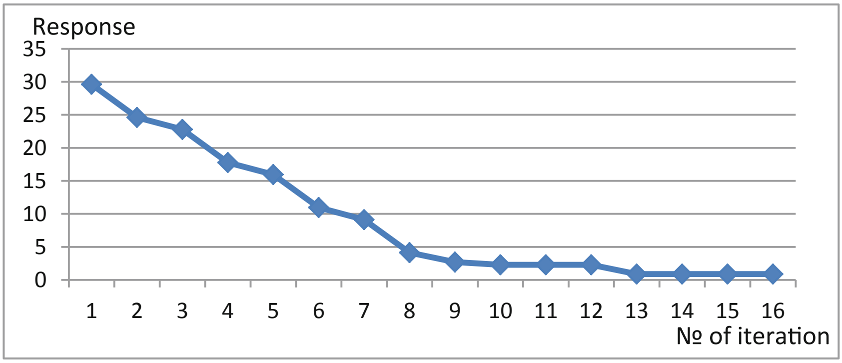

Fig. 6. Graph of response magnitude with increasing number of iterations.

The data presented from the experimental results confirm that the use of the simplex optimization method allows us to ensure the convergence of the inverse problem with the necessary accuracy (less than 1%).

Based on the above experiments, the effectiveness of the improved simplex optimization method was proved. Using this approach, the convergence time of this problem can be significantly reduced.

4 Conclusion

The invention proposes an algorithms and software optimization approach for identification and diagnostics of high-precision positioning systems. As an algorithm of optimization the simplex method of optimization of a deformable polyhedron as the most effective for a small number of factors is chosen ($k \leq 6$). It is useful to implement this approach using a software LabVIEW platform to automate and speed up the optimization process.

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Study of the Characteristics of Fine Binders for Injection in Construction

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Abstract. The injection mixtures based on finely dispersed mineral binders (microcements) are widely used to obtain soil concrete by injection into permeable soils when solving various geotechnical problems. However, the question of assigning the consumption of materials to implement the requirements of a construction project remains poorly studied. Nowadays, the regulatory framework for these binders is practically not presented in the Russian Federation. There is no scientific basis for the formation of soil concrete, including there are no adequate dependencies like the Bolomey-Skramtaev formula for concrete. The series of experiments showing the inapplicability of the basic laws for standard concrete when creating soil concrete obtained by injection methods. Various types of finely dispersed binders used in geotechnical construction are considered. There were assessed penetration at different modes of preparation and injection of the mixture into the soil, and the characteristics of the resulting concrete. Two technologies for creating soil concrete - by mechanical mixing and by the method of injection impregnation of control samples of sandy soil were compared for compliance with the principles of regulatory documents for concrete. Significant differences between the properties of soil concrete obtained by the methods of injection impregnation and mixing are confirmed. Studies have confirmed the possibility of injection impregnation with binders of a certain composition in order to strengthen sandy soils in accordance with the assigned technological parameters. The coefficients of the efficiency of the use of micro binders during injection are shown, data on the parameters of the formed soil concrete.

Keywords: Fine binder · Injection · Soil hardening · Soil-concrete · Microcement · Micro-filler · Impregnation injection

1 Introduction

The expansion of megacities and large cities of the Russian Federation sets the task of maximally efficient use of the underground urban space. The shortage of parking spaces and the requirements to preserve the historical appearance in the central parts of the city in the conditions of dense urban development necessitate the intensive development of the underground space [1]. The need to carry out work during the construction of underground structures in extremely difficult geotechnical conditions

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involves the use of a set of special production methods that provide compaction, stabilization and hardening of soils, the elimination of water ingress through building envelopes, protection against possible deformations, and the leveling of buildings and structures in the event of excessive deformations, etc. Besides, ensuring failure-free performance of work on the development of the underground space in the conditions of constantly functioning buildings and structures requires the introduction of new construction technologies and materials with increased safety requirements, sparing effect on the surrounding buildings, small size and noise level during the work [2]. At the same time, assessing the effectiveness of the practical application of injection methods for the production of work using finely dispersed binders, in contrast to the traditional ones with the use of standard cements or polymer systems, must take into account not only the cost and timing of the work, but also the special requirements for the work in conditions of dense construction [4, 5].

Injection work in the mode of soil structure impregnation doesn't allow deformations of the soil mass, avoiding the sediment of the surrounding structures. At the same time, hydraulic binders of a high degree of dispersion are used as the main injection material, which allow passing through open pores of the soil (without hydraulic fracturing) without changing the stress-strain state (SSS) of the soil [5]. Such binders were called micro binders, microcements or EFDB - especially finely dispersed binders, which are currently widely used in solving various geotechnical problems. An analysis of Russian and foreign experience in the implementation of injection projects for securing various soils allows us to confidently declare a high degree of efficiency of injection methods, especially with reference to the existing infrastructure of cities with a high degree of saturation with underground communications, complex engineering geology and structures located in the zone of influence of underground construction. The injection technology of cementing formation of the soil mass is based on the impregnation of the soil structure in the low-pressure feed mode at low pressures (up to 0.5 MPa). Moreover, during injection, the injection mixture completely fills the pore structure of the soil (except for closed pores) without violating its natural structure [6]. In cases where the fixed soil is in a state of complete water saturation, the injection mixture displaces the ground water during the impregnation process, providing the formation of a concrete mass, comparable in its performance to mortars and fine-grained concrete [7].

An analysis of the implemented soil compaction and hardening projects proves that the injection impregnation method maximally satisfies the requirements for geotechnical special works in the conditions of underground urban construction [8]. It should be noted that the quality of the work is determined by the observance of the injection schedule, the thoroughness of the work taking into account the control methods being performed, and the correct choice of the EFDB type, taking into account the actual geotechnical conditions and design tasks. The granulometric composition of EFDB, in contrast to other cementitious binders used in construction practice, consists in the fact that they are produced by the method of air separation of prepared composite binders or raw materials on a mineral basis with subsequent homogenization of the composition [22]. Moreover, the quality of EFDB needs to be assessed not so much by the specific surface index as manufacturers usually try to classify a number of building microcements, but by the grain composition of grains with an integral curve - d10, d50, d95.

Granulometric characteristics of various finely dispersed binders are presented in Table 1.

The balance and stability of the granulometric and chemical-mineralogical composition of a finely dispersed binder can be ensured only by a high level of manufacturability of the production and reproducibility of the properties of injection impregnation mixtures, which guarantees to achieve the specified design parameters of the soil-concrete massif (SCM) [5, 9].

As a rule, the main technological criteria for injection mixtures based on EFDB are:

- low sedimentation during preparation and injection;
- a high degree of penetration during the impregnation injection of a capillary-porous mass of soil at low pressures;
- a high rate of preservation of the mixture, which ensures continuity of the process (preparation, aging, injection) until the first signs of setting;
- stability of the characteristics of the EFDB compositions for all delivery production batches;

The parameters of the brands of finely dispersed binders most widely used in the construction industry from various manufacturers are presented in Table 1.

Table 1. Types of EFDBs and their efficiency.

Parameter\brand	Introcem extra	Microdur R-X	Spinor A12	Rheocem 900	Microleg 10
Particle size, d95<	5.5	6	7	8	9
Water/binding ratio (recommended)	4	4	2	3	1
Cost of 1 t. of material, rub.	80000	120000	180000	150000	180000
Specific efficiency (Kse)	1.25	0.83	0.16	0.27	0.13

Presented microcements with varying degrees of efficiency are used in solving a variety of construction problems. However, in view of the diversity of tasks both at the design stage and at the construction stage, it is necessary to provide the required level of efficiency of the use of EFDB. Thus, increasing the economic efficiency of solving soil hardening problems using EFDB is possible due to the use of compositions consisting of a combination of basic EFDBs and microfillers [5]. When using chemical additives that increase the penetration ability and technological properties of the injection mixture, the cost and time of work are significantly reduced [6, 10].

2 Materials and Methods

When assigning technological solutions and the type of EFDB, the selection of injection formulations and requirements for them, it must be borne in mind that the basic laws of concrete science are not always acceptable for the formed soil concrete.

Thus, the recorded parameters of soil-concrete created by mechanical mixing of the soil and the injection mixture of EFDB do not correspond to the obtained characteristics of the soil-concrete massif (SCM) created by injection impregnation of similar soil and a suspension of microcement.

The studied composite binders were made by homogenizing the base EFDB and the corresponding mineral microfillers.

In experimental works, the qualitative characteristic of a finely dispersed binder and its suitability to form a soil-concrete massif using injection impregnation technology (with fixing technology parameters and subsequent core drilling) were assessed. For comparative analysis, mechanical mixing of the injection mixture with the studied sandy soil was carried out with the subsequent study of its characteristics.

The compressive strength of the soil concrete prepared by injection impregnation was assessed taking into account the strength of the soil concrete created by mechanical mixing with fixing the hardening kinetics at various water-binding ratios. The quantitative characteristic of the comparison was expressed by the empirical coefficient of hardening "Kh":

$$\mathrm{Kh} = \mathrm{Rs}/\mathrm{Rm} \tag{1}$$

Rs, MPa is the compressive strength of the soil-concrete massif created by injection impregnation;

Rm, MPa is the strength of the sample created by the mixing method.

In addition to strength indicators, the characteristics of the pore structure of the formed soil concrete were assessed by mercury porometry. Hydration products were studied with the use of XRF and DTA.

3 Results of Experimental Studies

According to the classical theory of concrete science, the characteristics of hardened concrete are determined mainly by the ratio of the components of the concrete mixture in the system of "binder - coarse and fine filler - water - additives". When analyzing the properties of soil concrete, it was found that with an equal amount of binder in the composition of soil concrete prepared using injection technology and mechanical mixing, the strength characteristics of soil concrete differ significantly and do not correlate with each other (Fig. 1).

This can be explained by the fact that when mechanically mixing the soil with injection mixtures of a high degree of water content with a water binder ratio up to W/B = 5.0, the available amount of cement paste is not enough even to envelop individual particles of the soil, which prevents the formation of soil concrete with a dense solid structure. In the process of study, it was also established that during mechanical mixing, naturally compacted soil is decompressed, and an excess volume of the air phase is involved in the structure of the mixture of binder and soil solution, which is an important reason for the reduced strength also with incorrectly assigned control methods [11]. When injecting soil with an undisturbed natural structure, filling their pore structure with EFDB suspensions, most of the capillary-pore volume of the

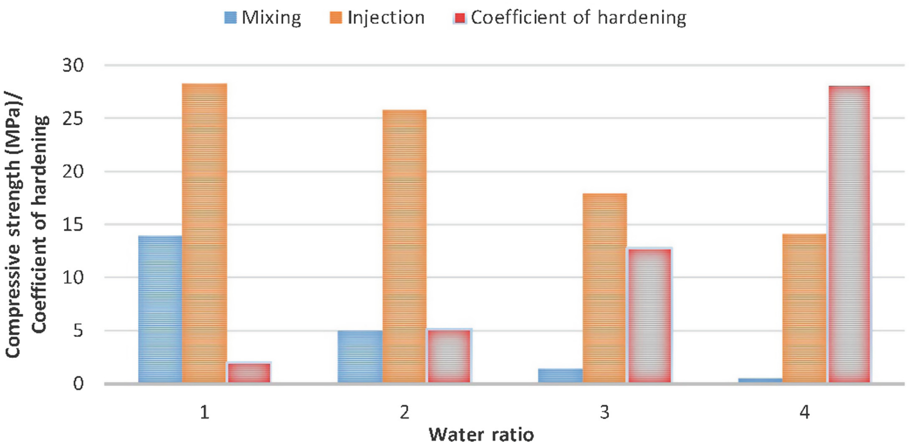

Fig. 1. A comparative analysis of the compressive strength of concrete prepared by injection impregnation and by mechanical mixing (Water/Binder = 1.0–5.0).

soil mass is filled with a hardening injection solution (cement paste), forming a dense cohesive structure of soil concrete. The excess water that was in the injection suspension with a high degree of water content to achieve high characteristics of penetration ability and rheological parameters is partially squeezed out, and the residue is bound physically-chemically or physically in the pore structure of the fixed massif. It is also noted that when the soil is injected with mixtures of finely dispersed binders with a high degree of water content, the so-called filtering process is developing. That is, it was established that the actual water-binding ratio of the injection composition that filled the pores of the impregnated soil mass will be lower than for the same indicator of the mixture immediately after preparation. The above conditions are factors of the improved physicomechanical properties of the soil created by the injection method compared to the mixing method (Fig. 2).

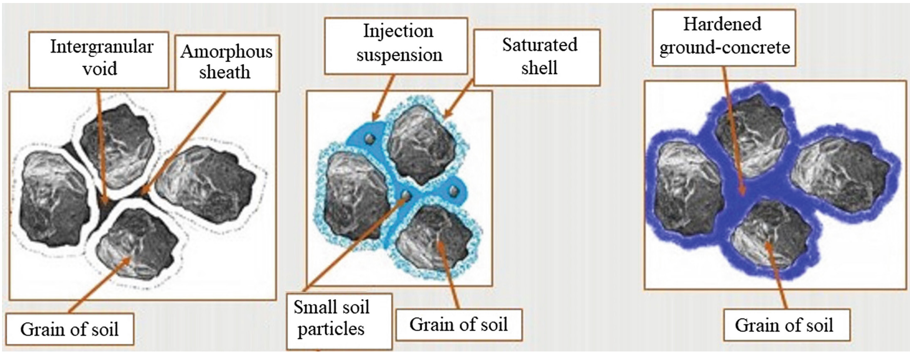

Fig. 2. A physical model of a soil mass injected with suspensions of finely dispersed binders.

Comparing the strength of soil concrete obtained by injection impregnation and mixing of the components, one can note a much higher strength of soil concrete created by the injection method. This is explained by the fact that the microstructure of the strengthened soil massif is a three-component system consisting of solid particles of naturally formed packing, water and air phases, soil particles are also usually covered with films of X-ray amorphous minerals and have inclusions of dusty and dispersed particles of various compositions with one or a different degree of reactivity. The intergranular volume of soil usually consists of air enclosed and open pores, in some cases filled with the surrounding aqueous phase when the soil is located in the water saturation zone [12].

The soil, which is fixed by the injection method, has a natural structure with a dense contact zone, the existing natural packing, often close to the maximum possible degree of compaction. For soil concrete obtained by mixing with cement mortar, the natural packing is destroyed, individual conglomerates are decompressed with close contact of particles, additional expansion occurs when additional water is introduced, and the total porosity increases due to additional air entrainment with mixing.

Impregnating the soil mass with injection mixtures based on EFDB, the smallest hydraulically active mineral particles penetrate into the pore space through capillaries and formed microchannels, precipitating as much as possible in closed and semi-closed pore channels, at the end filling all the pores with a mineral cement mix [13], which hydrates the entire source soil in a strong conglomerate - soil-concrete stone. The surface layer of soil grains during the reaction with the formed calcium hydroxide also participates in the process of creating neoplasms of cement stone in the contact zone, which additionally compacts and strengthens it [14].

An analysis of the results of experimental studies made it possible to establish a high degree of interdependence between the water-binding ratio, the injection rate V (injection of a unit volume of the injection suspension over time T), and the injection pressure P (pressure recorded by the outlet manometer of the injection complex).

In the framework of the previously conducted scientific and technical support for injection work, empirical relationships were established, which can be described by the equation:

$$T = 461 - 40.6\,W/B; \tag{2}$$

$$P = 0.233 - 0.036\,W/B. \tag{3}$$

The study of the structure of soil-concrete massifs, performed using electron microscopy, as well as X-ray phase and differential thermal analyzes, showed that microcement in the form of a nanomodified colloidal solution has a high hydration value in the early stages (immediately after adding water and mixing the injection mixtures), which should be reflected in the schedule of injection work and suspension production, taking into account its viability. It is determined that hydrate formation of crystals of calcium hydrosulfoaluminate, portlandite, hydrosulfurrite and calcium hydroaluminate occurs in the pores of the injected soil massif filled with EFDB, and a gel from microcrystalline formations of highly basic calcium hydrosilicates is also present.

The performed studies showed that the soil-concrete obtained by injection impregnation of the soil with suspensions based on EFDB (W/B = 1.0…3.5) has a strength of up to 30 MPa. While the samples prepared by mixing pre-ground soil and cement slurry with W/B = 4.0 had zero strength (Fig. 4).

It was noted that in the pores of the "soil-microbinder" system, a crystalline intergrowth is formed, consisting of hydration products of EFDB, as well as products of its interaction with soil components. Moreover, the development of hydration processes at the phase separation contact differ from the reaction parameters in the volume of the phase itself [14]. Within the volume of any phase, each molecule of the substance interacts with its own kind, while in the contact zone, the molecules also interact with molecules of a different chemical structure. It is known that a high phase potential difference contributes to a larger potential energy on the contact surface of phase states. At a high concentration of microparticles with a nominal diameter of less than 0.1 microns in the pore volume of the impregnated soil with a developed network of pores, the energy threshold of the onset of the hydration reaction decreases [5, 14] in a supersaturated solution of binder components, i.e. the effect of a high level of surface energy of microparticles and intensification of crystallization in a hardening system is realized [13].

The process of hydrate formation begins mainly in the contact zone of a particle of the injected soil due to the fact that the process of crystal formation in the liquid phase is a more energy-intensive process. Particles of new phases grow, forming the solvation shell of swelling layers of the cement paste, forming attractive coagulative nodes. In the supersaturated phase of the cement system, microcrystalline nuclei with a nominal diameter of 10^{-9} m are distinguished, which then stick together and coagulate, coarsening (up to 10^{-7} m) and settling on the surface of soil particles, forming soil-concrete.

Calcium hydrosilicates tend to absorb a significant amount of water in the phase of crystalline hydrate formation, when the intercrystal distance becomes approximately equal to the diameter of the water molecule. In this case, crystalline hydrates of similar phases coalesce, and fluctuation compaction of the solution molecules of the mixed binder occurs.

After impregnation with a suspension of microcement, the hydration processes begin in a thin layer of the modified suspension and the surface of the particles, and according to the theory of concrete science, as in standard concrete, the properties of the contact layer differ from the properties of the formed total volume of cement stone. The composition of the contact layer also depends on the physicochemical activity of the soil, which determines the nature of the neoplasms in the contact layer. In the studies of reactions that occur on the surface of various soils: acidic - with a content of $Si0_2$ = 65% (granulite, pyroxene quartz porphyry, granite); intermediate - with a content of SiO_2 = 52–65% (augito-porphyry), and basic - with a content of $Si0_2$ = 52% (basalt, diabase, weathered basalt), as well as orthoclase, albite, quartz, and carbonate rocks (dolomite, dolominated limestone), it was recorded that in the early stages of hardening, the basic rocks bind a little more lime than acidic [14].

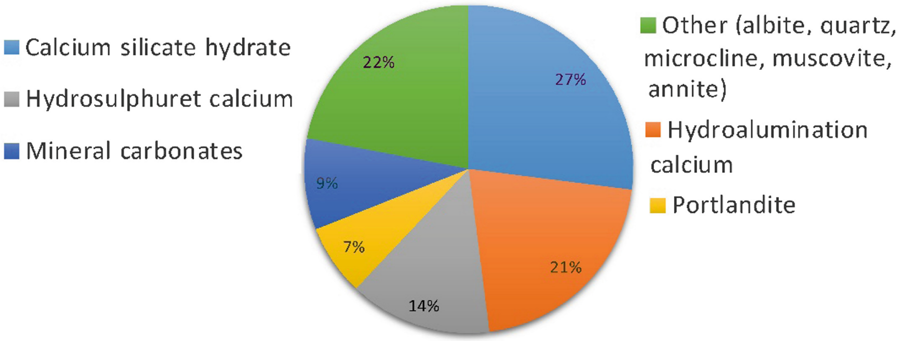

Fig. 3. Balance of soil hydration products: Introcem Extra; W/B = 3.0; soil - fine sand Mc = 1.2.

The studies of soil-concrete hydration products in the capillary-porous structure of the injected soil showed participation of amorphous sand grains along with silicate hydrate, calcium hydrosulfoaluminate and portlandite in the process of structure formation (Fig. 3).

After the process of intensive hydration in the soil concrete is completed (28–90 days, depending on the type of binder), a fixed mass is formed, which has specified physical, mechanical and geometric parameters.

Used injection mineral compositions of EFDB include a strictly selected dispersed composition of Portland cement clinker, calcium carbonate powder and amorphous reactive silicon oxide, an alkaline and slag component (for some types of microcement). Using the X-ray phase analysis of the formed soil concrete, the presence of the following hydrate formations was established in its composition: hydroaluminates, hydrosilicates and hydrosulfoaluminates of calcium, calcite, portlandite (calcium hydroxide) and other complex crystalline hydrates with muscovite, microcline and other inclusions of mineral-forming soil compositions subjected to injection impregnation in order to harden.

The analysis of the structure of soil concrete confirmed that the hydrated injection mineral composition filling the capillary system and pores of the intergranular space of the soil is a sufficiently dense hardened cementitious composition, tightly connecting adjacent grains, forming a strong and dense structure similar to the microstructure of fine-grained concrete, where a fine filler plays the role of individual fine-grained concrete particles of soil.

The study of the “cement stone-soil particles” contact zone showed a fairly homogeneous, dense, defect-free microstructure of the saturated soil mass, providing a joint mechanism for bearing loads as a dense conglomerate. In the soil-cement massif obtained by mixing, an increased pore volume and a specific volume of capillary porosity are noted (2.5–3 times in comparison with the impregnated samples) - an average of 85% of open pores and capillaries, and 15% of closed ones.

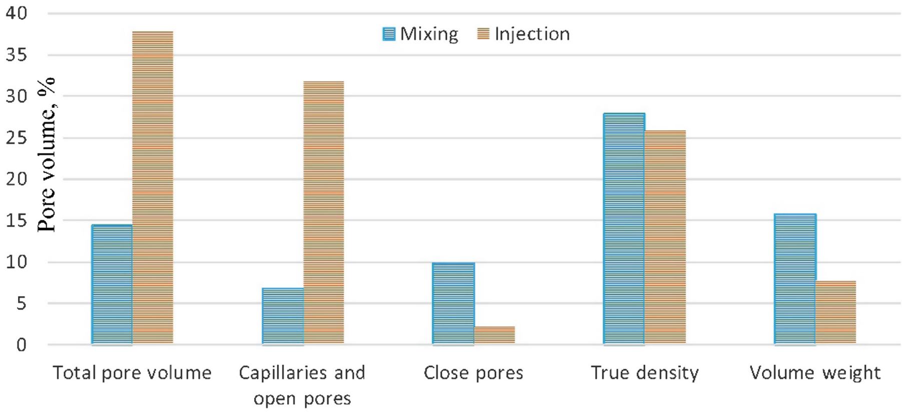

Fig. 4. Characteristic of the porosity of the structure of soil-concrete samples: “Introcem Extra”; W/B = 3.0; initial soil - fine sand with a coarseness modulus Mc = 1.2.

The density of the soil-concrete massif obtained by the injection method is comparable with the volumetric mass of fine-grained concrete, while on the contrary, the density of soil-concrete obtained by mechanical mixing is comparable with the density of porous concrete with a fine-grained structure.

A high degree of homogeneity of the dense structure of injection-impregnated SCM is formed due to the features of the technology, when the mineral mixture of FEDB with high-penetration ability penetrates into the intergranular space of soil particles without causing grain expansion.

4 Conclusions

Injection methods of soil hardening with the appropriate feasibility study are effective and allow solving various geotechnical problems.

Comparison of the properties of soil-concrete obtained by injection impregnation and by the method of mechanical mixing showed their significant difference and the absence of any correlation dependence. In this regard, when selecting the compositions of injection mixtures based on EFDB, it is necessary to study samples of soil-concrete massifs formed in the impregnation mode that simulate production conditions.

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Modification of Polyimide Surface in Multilayer Structures for Architectural Films by Plasmochemical Treatment

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Abstract. The paper presents the study of adhesive ability of metallic coating applied to the polymer substrate used in the multifunctional coatings of the intelligent architectural films. The studies of the polymer surface treated in argon and oxygen plasma showed that intermetallic layer is formed at the interface, which enhance metal film adhesion to the polymer surface. Technological modes of ion-plasma treatment of a polyimide film have been developed that increase the adhesive ability of the polymer surface, which will improve the performance characteristics of polymer materials and intelligent devices used in integrated systems for providing a comfortable environment.

Keywords: Smart glass · Architectural polymer films · Magnetron sputtering systems · Adhesion

1 Introduction

In the context of increased consumption and cost of energy resources and increased negative impact of man on the environment in order to create a comfortable and cost-effective environment, solutions related to increasing the economic and energy efficiency of buildings and structures are becoming in demand. A special role in creating a comfortable environment belongs to solutions related to the optimization of climatic comfort inside constructed and existing buildings, along with the tasks of increasing the level of protection against undesirable external influences, energy conservation and creating independent innovative energy sources. Modern architectural and design solutions involve the active use of intelligent materials with a combination of properties with elements of intelligence, energy conservation and information security.

Nowadays, the market for intelligent glasses providing effective light-climatic control has developed and is still developing. Their use contributes to the creation of light, acoustic and psychological comfort due to the degree of protection against unwanted visual access, together with systems that provide protection against

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unauthorized methods of acquiring information and unwanted electromagnetic effects, as well as hybrid solar energy devices [1–4].

As a part of light-transmitting systems, architectural polymer films applied to the glass surface have recently been used. The advantages of using such films include: flexibility and plasticity of the film structure during operation, an increase in the mechanical strength of glass, their use in light-transmitting systems with a complex surface shape, and the possibility of replacement during operation without dismantling [5, 6]. Architectural films are formed as multilayer sandwich structures consisting of thin layers of polymers with the addition of metallized layers and layers of metal oxides into the structure. The characteristics of smart films are determined by the composition and properties of the functional layers. These sandwich structures use gold, silver, copper, aluminum, nickel, chromium, and rare earth oxides. As a basis for sandwich structures, polymer films based on polyethylene terephthalate, ethylene vinyl acetate, polyaniline, polyimide, and also films from thermoplastic polyurethane have been widely used recently [7–9].

The main obstacles to the wider use of architectural films are their high cost and short life compared to other structural elements. Over time, the aging processes of the materials used to create the active layer lead to a noticeable degradation of their parameters. In this regard, the relatively high price/quality ratios currently determine only a narrowly targeted segment of their practical use. To solve these problems, new materials are required in combination with an increase in the manufacturability of production. To ensure a more reliable fixation of films in multilayer structures, adhesives are used (effective high-molecular adhesives based on acrylates, acrylic-epoxides and polyurethanes). The use of adhesives is one of the factors restraining the increase in the operational characteristics of multilayer structures used in architectural films. Therefore, the task of developing technological equipment for the manufacture of architectural films without the use of adhesives with the ability to control the thickness, structure and adhesive ability of the applied coating is becoming urgent. The use of vacuum metallization with the deposition of layers directly on the polymer base can be successfully used in the technology of obtaining multilayer structures for architectural films, providing improved traditional characteristics and creating new opportunities through the use of multilayer structures with thicknesses less than microns. Nowadays, the benefits of roll-to-roll technology are widely used. The combination of the use of polymeric materials, roll-to-roll technologies and ion-plasma methods of application provides nanoscale structures for creating intelligent glasses with high efficiency. There are several coating methods, which include resistive, electron beam evaporation, magnetron and electric arc sputtering. The use of setups with arc and magnetron spraying systems makes it possible to apply multicomponent coatings with the possibility of optimizing technological solutions for a specific process [10, 11].

The solution to the problem of increasing the adhesion ability of layers in multilayer structures used in architectural films can be the development of a technology for the modification of polymeric materials, which is carried out by treating their surface with low-temperature plasma. Under the influence of plasma on the polymer surface, its contact properties change, and the hydrophilicity and adsorption capacity of the material surface increase. The nature of the physicochemical processes, which can proceed in stages, simultaneously and in various combinations, depends on the properties and compositions of the processed material and the gas phase.

2 Materials and Methods

The main objective of the study was the development of technological methods with the aim of increasing the adhesion of the applied layer to the surface of the polymer film using the example of polyimide. To achieve the required parameters, the method of preliminary ion-plasma surface treatment of the polyimide film before spraying was used. The effect of the operation modes of the ion source and the composition of the gaseous medium on the adhesive ability of copper to the surface of the polyimide was studied. Studies were carried out in gaseous media using argon, oxygen, carbon fluoride, and a mixture of these gases.

During the main technological operations for activating the polymer surface, the surface of the polyimide film was cleaned, etched, and metallized. For applying a metal layer, an extended magnetron sputtering system optimized for a specific technological process was used [12]. The polyimide was metallized in Ar medium for 20 min. The surface of the polyimide was etched by an ion source in different media (Ar, O2, CF4, O2+CF4, Ar+O2) for 15–60 min. In the process of cleaning, etching and metallization, the polymer film was rotated at a speed of 5 revolutions per minute. To analyze the surface topography of the polyimide using an electron scanning microscope, a solution of ferric chloride was used.

To measure the adhesive ability, the peeling method was used. An electron raster microscope was used to analyze the surface topography of the base film and determine the size of microroughnesses on the surface of the polyimide film. The copper layer was removed by placing part of the film with an applied metal layer in a solution of ferric chloride.

3 Results and Discussion

One of the advantages of using the developed magnetron design [12] compared to standard devices described in [13] is the scheme of gas supply to the magnetron's target surface, which provides a more uniform gas distribution along the length of the target, which reduces the working pressure and, accordingly, reduces the flow rate of gas supply and helps to improve the quality of the applied coatings. The magnetron allows providing higher than standard operating voltage at maximum power on the target, which leads to high coating rates. The configuration of the magnetron does not provide for the use of polymer, rubber and ceramic gaskets, as a result of which the stability and reliability of its operation are increased.

The studies were conducted at the maximum operating conditions of the equipment for each gas. The maximum voltage values were limited by the technological capabilities of the design of an extended magnetron sputtering system.

The results of studies of the influence of the gaseous medium on the adhesive ability of copper to the surface of the polyimide film are presented in Table 1.

Table 1. The adhesive ability of copper to the surface of the polyimide base when the ion source is used in various gaseous media.

No.	Type of gas	Adhesive ability, N/m
1	Without treatment	15
2	O_2	1227
3	CF_4	40
4	O_2+CF_4	560
5	*Ar*	1290
6	*Ar*+O_2	490

The studies have shown higher values of adhesion when using a gas medium of argon and oxygen, for which the highest etching rate was observed.

Microphotographs of the polyimide surface relief of the studied samples are shown in Figs. 1 and 2. These photographs were obtained using an electron scanning microscope. As can be seen from the figure, the polymer surface untreated with ions of the gaseous medium looks quite smooth with a slight porosity. After treating the film surface with an ion flow, the surface relief acquires a pronounced porous structure.

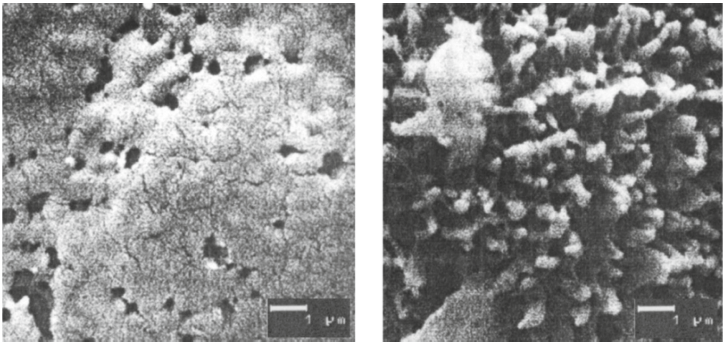

Fig. 1. The microphotograph of the polyimide surface relief treated with oxygen, obtained using an electron microscope before (a) and after (b) ion treatment.

Based on the results obtained, the pore sizes of the polyimide were tentatively determined. The pore size before processing was about 0.5 µm, after processing - 1 µm. The pore density per unit area is higher for the modified sample compared to unmodified. On modified samples, high pore accuracy remains while halving the treatment time. In this case, the porous structure is smoothed out with a decrease in pore depth.

Surface treatment in argon leads to the predominance of a sawtooth nature of porosity on the surface of the polyimide (Fig. 2), which helps to increase the adhesion of the metal coating to the polymer surface. When applying copper, it diffuses into the surface layers of the polyimide film. A transition layer is formed between the polymer and metal layers, which enhances the adhesion and hardening of the applied metal

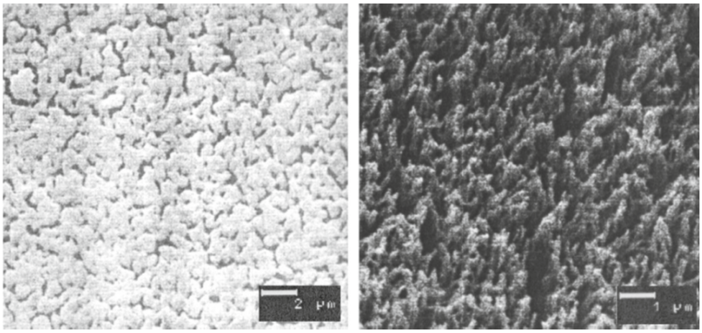

Fig. 2. A microphotograph of the polyimide surface relief, which is obtained using an electron microscope before (a) and after (b) ion treatment with argon with a resolution of 2 μm (a) and 1 μm (b)

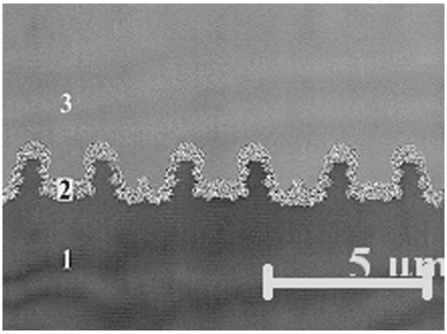

Fig. 3. A microphotograph of a thin section of a polyimide film with an applied copper layer: 1 - polyimide layer; 2 - transition region containing intermetallic compounds; 3 - copper layer.

layer. The depth value of the disturbed layer of the intermetallic layer, calculated on the basis of the analysis of the thin section of the sample, was 2.5 μm.

The results of measuring the adhesion of the copper layer to the polyimide depending on the discharge voltage of the source are shown in Figs. 4 and 5. An analysis of the above dependences shows that with an increase in the discharge voltage, the adhesion ability of the metal layer to polyimide increases.

A comparison of the graphs leads to the conclusion that it is advisable to use argon as a working gas, since in this case there is no need to use means for pumping active gases and the likelihood of contamination with the generated oxides of the applied coating is reduced.

In order to study the impact of thermal effects on the adhesive ability of copper to polyimide, the samples obtained after galvanization were subjected to heat treatment at a temperature of 105 °C. The values of residual adhesion of copper to the surface of the polyimide depending on the time of heat treatment are shown in Table 2.

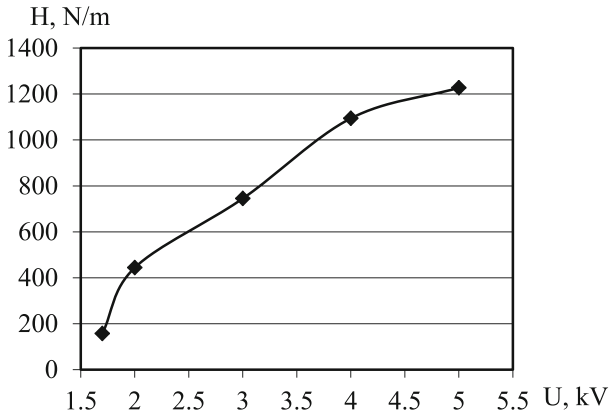

Fig. 4. The dependence of adhesion on the discharge voltage of the source when treating the surface of the polyimide with oxygen

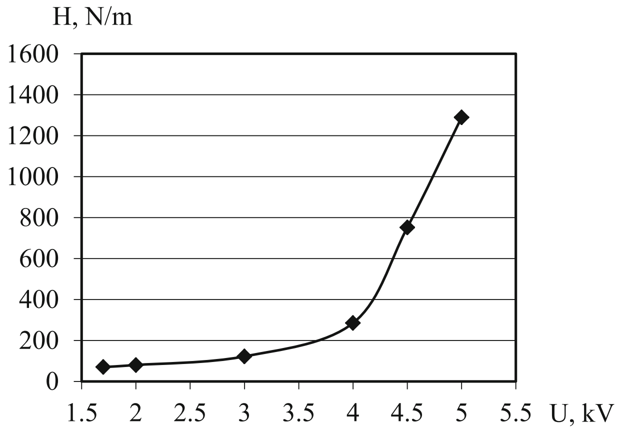

Fig. 5. The dependence of adhesion on the discharge voltage of the source when treating the surface of the polyimide with argon

The modes of surface modification in various gaseous media of argon and oxygen are presented in Table 3.

The results presented in Table 2 show that for all samples, the maximum value of adhesive ability varies in the range of processing time from 20 to 40 h. With a longer heat treatment, the value of residual adhesion decreases.

The contact properties of the polymer and metal change under the influence of plasma [14]. During ion surface treatment, the appearance of a sawtooth nature of the surface porosity with the growth of conical shape structures on the substrate surface is observed (Figs. 1 and 2). This effect is caused by the selectivity of the etching rate of individual sections of the polymer surface. The porous structure formed during

Table 2. Dependence of residual adhesion of a copper coating on heating time.

Sample number	Type of working gas	Heating time, hours	Adhesive ability, N/m
1	Oxygen	0	612
		24	895
		88	788
2	Argon	0	164
		24	1030
		88	728
3	Argon	0	224
		24	1574
		60	1468
		88	325

Table 3. Modes of ion-plasma surface treatment of polyimide.

Sample number	Type of working gas	Voltage, kV	Current, mA	Pressure, mmHg	Time of treatment, min
1	Oxygen	3.0	200	$7.7 \cdot 10^{-4}$	30
2	Argon	4.0	300	$4.5 \cdot 10^{-4}$	30
3	Argon	3.0	300	$4.5 \cdot 10^{-4}$	30

treatment with high-energy ions causes an increase in the effective contact area, an increase in the adhesion ability of the polyimide surface, and an intensification of diffusion processes.

As a result of ion-plasma treatment of the polymer surface, it is purified and activated. When surface bonds are broken, hydrophilic groups of various chemical nature are formed, which properties are determined by the nature of the film base, plasma-forming gas, and plasma properties that depend on the operating conditions of ion sources. In the oxygen atmosphere, processes of oxidation of the surface layer with the formation of polar groups occur, which entails the occurrence of chemical reactions of surface hydrophilization, a change in its energy properties and an increase in the adsorption capacity of the polymer.

When processing the surface of a polyimide in an argon atmosphere, the diffusion properties of the polymer change due to crosslinking of its surface layer. An increase in the adhesion strength of coatings in an inert gas atmosphere occurs due to the formation of free radicals in the plasma, as a result of which reactions occur with the formation of polar oxygen-containing groups on the polymer surface when interacting with air.

These processes can occur in various combinations during plasmochemical modification of the polymer film surface [15]. When chemical reactions occur at the interface between the metal and the polyimide, a new phase layer is formed (Fig. 3). Such a diffusion boundary has an increased adhesive strength due to a decrease in the concentration of mechanical stresses arising from a sharp jump in the mechanical constants of materials. This contributes to a change in the adhesive properties of materials and provides a higher value of the strength of the connection with the substrate.

The study of the impact of temperature effects on the adhesion ability of a metal layer to the surface of a polyimide showed a higher adhesion of the metal layer in the case of treating the polymer surface with argon.

4 Conclusions

To ensure high adhesion ability of the metal layer to the polymer base, it is advisable to use preliminary ion-plasma cleaning and etching of the surface of the substrate immediately before applying the active layer as an alternative to the use of adhesives in multilayer structures of architectural films. This type of treatment is a stable technological process, since the properties of the discharge are determined by the electrical parameters of the circuit and are easily controlled. It is recommended to use promising long magnetron systems optimized for a specific technological process as sources of metallization.

The studies have shown that it is preferable to use inert argon as the working gas. In this case, the process is simplified, since there is no need for specific operations when applying coatings.

The developed technological regimes of ion-plasma treatment increase the adhesion of metal layers to the surface of polymers, which will contribute to improving the operational characteristics of multilayer coatings in the sandwich structures used in the creation of smart glasses, and will increase the operating life in intelligent systems providing comprehensive support for a comfortable environment.

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Effect of Additives on the Properties of Fine-Grained Concrete

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Abstract. In modern technology of concrete, the fine-grained concretes are widely used. These concretes are highly manufacturable, allow getting a variety of structures and, accordingly, the properties of the material, significantly reduce the cost of concrete through the use of inexpensive local sand and secondary industrial waste. By changing the composition and structure of such concrete, it is possible to obtain fine-grained concrete for various functional purposes on the basis of the same raw materials (only with different complexes of additives). The goal: to study the effect of various additives, including the complex ones, on the physical and mechanical properties of modified fine-grained concrete. Results: the paper proved that the use of air-entraining and complex chemical additives does not increase the air entrainment, but converts the air phase into a system of smaller ordered pores, which leads to an increase in the strength of the material and its durability. The organization of the air phase in the form of a system of thin air pores makes it possible to increase the strength of the material and to improve its other properties: frost resistance, water resistance and others. Conclusions: it is shown that the use of multicomponent composite fine-grained concrete with a regulated air phase will make it possible to obtain materials with a different set of properties.

Keywords: Fine-grained concrete · Air-entraining additives · Superplasticizer · Silica fume · Porosity · Durability

1 Introduction

In recent years, significant changes have occurred in concrete technology: from traditional materials with limited capabilities, there has been a transition to multicomponent systems with a wide variety of structures and properties that greatly expanded the concrete area of implementation, their nomenclature, and the achieved technical and economic effect. New concretes fully meet the market economy and allow solving most construction problems.

This progress was achieved due to the appearance and introduction into production of various highly effective chemical and mineral additives in concrete, the creation of composite binders, the expansion of the raw material base of concrete, the intensification of the technology for preparing concrete and the molding of concrete and reinforced concrete structures and products [1].

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All the properties of concrete are determined by its structure. Of greatest importance is the microstructure of concrete. Managing the structure formation of the material at all stages of concrete production and structures is an essential feature of modern concrete technology. To create the optimal structure of concrete, designed for different operating conditions, special additives are widely used, modifiers of the structure and properties of concrete [2–4].

In the technology of multicomponent composite concretes with the aim of controlling structure formation, production technology and controlling the properties of the material, are used:

- composite binders on various bases (on cement, gypsum, magnesia binders and others), which are multicomponent binders of low water demand;
- complex modifiers of structure and properties, including various chemical modifiers and active mineral components, including the ultrafine ones;
- correctly selected mineral raw materials of aggregates, which provide obtaining of economical and durable concretes;
- intensive technology that ensures homogenization of the composition and the creation of conditions for optimal interaction of the components during the formation of the material structure and its hardening [5–7].

The basis of the modern technology of multicomponent composite concrete is the creation of high-quality artificial stone, characterized by high dispersion, low defectiveness and stability of the structure, including by reducing its restructuring during hardening. On its basis, a variety of high-quality concrete can be created by interspersing additional components and its modifications in the structure of the material [3, 4].

Fine-grained multicomponent concrete also has a number of advantages:

- the ability to create a finely divided homogeneous high-quality structure without large inclusions of large grains of a different structure;
- high efficiency of material modification with chemical and mineral additives;
- high thixotropy and ability to transform concrete mixture, high adaptability - the possibility of forming structures and products by casting, extrusion, stamping, spraying and others; easy transportability;
- the possibility of widespread use of dry mixes with a guarantee of high quality;
- the ability to obtain materials with various complexes of properties; obtaining special types of material: fiber reinforced concrete, reinforced cement, decorative, electroconductive, waterproofing and others;
- the opportunity to get new architectural and structural solutions: thin-walled and layered structures, products of variable density, hybrid structures, etc.;
- multifunctionality of the material, i.e. the ability to obtain structural, heat-insulating, waterproofing, decorative and other types of concrete on a specific cement and sand only by varying the composition, complex of additives and technological methods;
- the possibility of widespread use of local materials and, as a rule, lower cost price in comparison with conventional coarse-grained concrete [8–10].

The increased water demand and shrinkage inherent in fine-grained concrete in multicomponent compositions are corrected through the use of a complex of chemical additives, including expanding, dispersed fine-grained and fibrous components.

When additives are added to the concrete mixture, not a pure additive is adsorbed on the surface of the cement grains, but a solution of the superplasticizer and the active part of the superplasticizer decreases. Therefore, in the concrete mixture, the optimal content of superplasticizer is 0.7–1.2%, after which the effectiveness of the additive decreases. With the introduction of organic and mineral additives, the superplasticizer is adsorbed through the solution on the grains of cement, and its optimal proportion approximately corresponds to the indicators obtained when the superplasticizer was introduced directly into the concrete mix. However, the total content of superplasticizer in this case should be higher, since part of it is adsorbed by a finely divided filler [11, 12].

The degree of increase in the dosage of superplasticizer depends on the normal density of the finely divided filler, its proportion in the organic and mineral additive and the relative content of the additive on the mass of cement. For the silica fume with a normal density of 40%, with its total content in concrete of 10% (in % of the mass of cement), the dosage of superplasticizer increases by only 8%, with a content of 20% - by 20%, with a content of 40% - by 80%. Accordingly, with a 60% normal density of silica fume the increase in the dosage of superplasticizer will be 20, 40 and 200%. It is assumed that the silica fume replaces the corresponding part of cement.

Increasing the density of concrete, grinding the structure of neoplasms and pores, partially binding calcium hydroxide, an organic and mineral additive with silica fume as a result increases the strength of concrete. In this case, the mobility of the concrete mixture sharply increases, which allows obtaining cast self-compacting concrete at cement-water ratio = 2.5–4, which in turn helps to increase the density of concrete [8].

As experiments have shown, the use of superplasticizers makes it possible to reduce the water demand of fine-grained concrete of optimal compositions by 25–30%. The increased content of cement paste in these concretes contributes to a more effective (by 10–15%) effect of superplasticizers on the concrete mix. The best performance is achieved when using vibration compaction or cast concrete mixtures, but when using other technologies due to the high thixotropy of the mixture, the results are higher than when using conventional coarse-grained concrete. The best results are achieved when using a composite binder containing a superplasticizer and a particularly finely divided filler, for example, C-3 and silica fume or ash, with an increased specific surface area of the cement component (up to 500–600 m^2/g). In this case, the water demand of the mixture decreases by 40–50%.

Therefore, in modern concrete technology, fine-grained concretes are widely used. These concretes are highly manufacturable, allow getting a variety of structures and, accordingly, material properties, significantly reduce the cost of concrete due to the use of inexpensive local sand and secondary industrial waste. In these concretes, the effect of various modifier additives is more fully manifested. By changing the composition and structure of such concrete, it is possible to obtain fine-grained concretes for various functional purposes on the basis of the same raw materials (only with different complexes of additives). Of particular interest are fine-grained porous concretes with different densities and strengths.

Questions about replacing the common concrete with fine-grained one arise for various reasons. In addition to the difficulties with the presence or crushing of coarse aggregate, there are areas of application for fine-grained concrete in which it is practically irreplaceable. First of all, these are thin-walled structures reinforced with steel or polymer woven nets, as well as fibers of organic and inorganic origin. Fine-grained concretes allow obtaining effective durable decorative materials for facing works, small architectural forms, paving and road covering [8–10].

Nevertheless, the noticeable introduction of fine-grained concrete in the practice of civil and housing construction is limited by their increased shrinkage, and, consequently, reduced crack resistance. To reduce the negative impact of shrinkage on the structure and properties of fine-grained concrete, it is proposed to use composite binders for their preparation, including expanding cements based on sulfoaluminate. The use of fine-grained concrete with improved physical and technical properties increases the manufacturability of construction, reduces the complexity of pouring concrete and allows building structures of complex architectural forms.

Recently developed various technological methods (intensive mixing, the use of micro-fillers, chemical additives, etc.) make it possible to obtain fine-grained concretes with a cement consumption not exceeding the requirements of the standards for ordinary heavy concrete with coarse aggregate, which may provide some economic benefits in the construction of traditional structures.

In addition, fine-grained concrete has several advantages compared to conventional concrete: high water resistance, increased modulus of elasticity, which increases the durability of structures, reduced creep, which contributes to high crack resistance.

In fine-grained concrete, the air phase of the material is of great importance. Changing its volume and structure in combination with the introduction of various modifiers allows getting a wide range of materials with different properties, using local sands and inexpensive special equipment that ensures control of the air phase of concrete.

According to Yu. M. Bazhenov, as applied to fine-grained concretes, it is advisable to introduce a new generalized classification of the state of the air phase of the material: disordered and organized.

The first is the usual state when the air phase consists of small and large pores, capillaries, leaks, microdefects, etc. The second is when the introduction of special modifiers and the use of special technological methods transforms the air phase into a system consisting of tiny air pores with a finely dispersed cementing layer. With the same volume of the air phase in concrete, its reorganization into a finely dispersed system leads to a significant increase in the properties of fine-grained concrete and the possibility of obtaining materials with different properties intended for use in various conditions. In this case, open pores of concrete can be reconstructed into a system of closed pores waterproof under normal conditions.

In recent years, new modifiers of structure and properties, active components, multicomponent additives have been developed and began to be used in concrete. It seems appropriate to use new technological solutions to obtain fine-grained concrete [9–12].

The aim of the studies described in this paper is to study the effect of various additives, including complex ones, on the physic-mechanical properties of modified fine-grained concrete.

2 Materials and Methods

As test materials to obtain the fine-grained concrete Portland cement CEM I 42,5 and quartz sand with 1.9 fineness modulus with a bulk density of 1510 kg/m^3, density 2.61 kg/l were used. Cement consumption was taken as 545 kg/m^3. The following structures were used to modify the structure and properties of concrete: superplasticizer based on modified Sika ViscoCrete 3300/3180/5-600 polycarboxylates (0.6% by weight of cement), an air-entraining additive based on waste from the pulp and paper industry TsNIIPS-1 (0.04% from mass of cement) and silica fume MK (which replaced the 10% from the mass of cement). To determine the properties of fine-grained concrete from a concrete mixture of the composition cement: sand = 1:2.5 with a hardness of 12–16 with (G2), 10 × 10 × 10 cm cubes were made. Samples were tested after 28 days of normal hardening.

Systematic studies were carried out of changes in the mass of samples, strength, porosity, water resistance and frost resistance of concrete. Porosity was determined according to the method used in Russia (GOST 12730.4–78). First, the total volume of open pores of concrete W_p, the volume of open capillary pores W_0, the average pore volume λ and the pore size uniformity index α were determined.

To determine the volume of open pores of concrete (the volume of intergranular voids), the samples are saturated in water for 24 h, then stand for 10 min on a grate, and then their volume in the volumenometer is determined.

The total pore volume of concrete W_p in percent is determined to an accuracy of up to 0.1% according to the formula

$$W_p = \left[\frac{\rho_б - \rho_0}{\rho_б}\right] \cdot 100, \quad (1)$$

where $\rho_б$- density of powdered concrete determined using a pycnometer or Le Chatelier device, kg/m^3;

ρ_0 - density of dry concrete, kg/m^3.

The volume of open capillary pores of concrete W_o in percent is determined by the volumetric water absorption of concrete.

The average pore size and uniformity of pore sizes in concrete were determined by the kinetics of their water absorption and by nomograms.

Tests for frost resistance were carried out in accordance with the domestic standard according to the third (accelerated) method. When tested according to the third method, an aqueous NaCl solution with a concentration of 5% is used to saturate, freeze and thaw the samples. The main samples were placed in a freezer in closed containers, which were filled with a five percent aqueous NaCl solution. The temperature in the closed chamber was reduced to minus (50 ± 2) °C and maintained for 2.5 h. Then, the temperature in the chamber was raised to minus 10 C for (1.5 ± 0.5) h, after which the samples were thawed in a 5% aqueous NaCl solution with a temperature of (20 ± 2) °C for at least 2.5 h.

After 8 cycles of freezing and thawing, which should correspond to the frost resistance of concrete F300, the samples were examined. The material separating from the sample was removed with a stiff brush. Samples were wiped with a damp cloth, weighed and tested for compression.

The change in mass of the samples Δm, %, is calculated by the formula:

$$\Delta m = \frac{m - m_1}{m} 100, \qquad (2)$$

where m - sample weight before freezing and thawing, g;

m_1 - sample weight after freezing and thawing, g.

According to the data obtained as a result of the tests, in accordance with the standard (GOST 10060-2012), the following values were calculated: the average strength X^1_{av} and the standard deviation σ^1_n of the control samples, the average strength X^2_{av} and the standard deviation σ^2_n of the main samples, the coefficient of variation in strength V^1 and V^2, the lower confidence limit interval for control samples X^1_{min} and the lower boundary of the confidence interval for the main samples after freezing and thawing X^2_{min}.

The standard deviation σ_n is calculated by the formula:

$$\sigma_n = \frac{W_m}{\alpha}, \qquad (3)$$

Where W_m - the range of unit values of concrete strength in a series, defined as the difference between the maximum and minimum unit values of strength, MPa;

α - a coefficient depending on the number of unit values of concrete strength n in the series, α = 2.5 is taken for n = 6.

Coefficient of variation of strength V_m is calculated by the formula:

$$V_m = \frac{\sigma_n}{X_{av}}, \qquad (4)$$

The lower limit of the confidence interval for control samples X^1_{min} and samples after freezing X^2_{min} determined by the following formula:

$$X_{min} = X_{av} - t_\beta \sigma_n, \qquad (5)$$

where t_β - Student criterion with confidence probability p = 0,95, taken depending on the number of test samples, at n = 6 is taken as t_β = 2.57.

Determination of water resistance of concrete was carried out according to the method used in Russia (GOST 12730.5-2018) on an Agama-2R device. Water resistance was determined by the air permeability of the surface layers of concrete.

The sample was placed in a sealed chamber of the device. In the test, the sealing mastic with a bundle of 6 mm diameter was placed on the chamber flange along its midline and the ends were connected. The chamber was mounted with a flange on the lower (during molding) surface of the sample and a vacuum of at least 0.064 MPa was created in the chamber cavity. During the test, the value of concrete resistance to air penetration m (c/cm^3) was determined.

3 Results and Discussion

Rigid fine-grained mixtures under normal conditions are characterized by increased air entrainment. With an increase in the volume of the air phase of fine-grained concrete without its structuring, a tendency is observed for the transition of the material from a cellular to a granular structure, which leads to a decrease in the strength and durability of concrete.

The use of air-entraining and complex chemical additives does not increase air entrainment, but converts the air phase into a system of smaller ordered pores, which leads to an increase in the strength of the material and its durability by more than 1.5 times (Tables 1 and 2).

Table 1. Physico-mechanical properties of fine-grained concrete

Composition no.	Type of additive	W/C	Density of concrete, kg/m^3	R_{comp}, MPa	ΔR
1	–	0.34	2058	38.2	–
2	Sika	0.29	2062	42.1	1.1
3	TsNIIPS-1	0.33	2055	39.3	1.03
4	Sika + TsNIIPS-1	0.28	2067	54.0	1.41
5	Sika + TsNIIPS-1 + MK	0.26	2070	61.1	1.6

Studies have shown that the introduction of superplasticizer into a fine-grained concrete in combination with an air-entraining additive reduces the water-cement ratio, increases the strength of concrete (Table 1), reduces its total and opened porosity, as well as the average pore size, and increases their uniformity (Table 2). The same dependence can be observed if, in addition to an air-entraining additive and a superplasticizer, silica fume is introduced into the concrete mixture, replacing the part of the cement with it. The water-cement ratio decreases from 0.34 to 0.26, the total porosity from 19.0% to 16.3%, the open porosity drops from 6.8% to 4.9%, while the strength increases by 1.6 times. A denser structure with ordered porosity and increased strength is obtained.

Table 2. Indicators of fine-grained concrete porosity

Composition no.	W_p, %	W_o, %	λ	α
1	19.0	6.8	1.02	0.52
2	17.7	5.9	0.85	0.62
3	18.2	6.2	0.83	0.64
4	17.0	5.3	0.80	0.65
5	16.3	4.9	0.77	0.69

By analyzing the data on the resistance to penetration of air through the surface layers of concrete (Table 3), we see that the results obtained on the compositions both without additives and with only one air-involving additive is 4.1–4.5 s/cm^3, which corresponds to the W2 waterproof mark. But if we introduce a superplasticizer or complex additives based on a superplasticizer, an air-attracting additive and silica fume, then the resistance to air penetration through the surface layers of concrete increases to 5.2–5.9 s/cm^3. This allows us to conclude that these concretes have been successfully tested and have the W4 waterproof mark.

Table 3. The effect of additives on the water resistance and frost resistance of concrete

Composition no.	Resistance of concrete to air penetration, m, c/cm^3	The strength of the control samples, R_1, MPa	Concrete strength after 8 cycles of freezing and thawing, R_2, MPa	The mass of samples M, g		Mass change after freezing and thawing Δ_m, %
				Before testing	After testing	
1	4.1	37.4	30.2	2058	2013	−2.17
2	5.2	41.1	38.1	2062	2024	−1.85
3	4.5	39.2	30.6	2055	2012	−2.11
4	5.4	53.5	51.3	2067	2046	−0.98
5	5.9	60.8	59.4	2070	2058	−0.56

When tested for frost resistance, the change in the mass of concrete samples after 8 cycles of freezing and thawing should be no more than 2%. According to these requirements, only concrete modified with superplasticizer or complex additives have passed the test for frost resistance (Table 4).

When testing concrete for frost resistance, samples are considered to have passed these tests, if the ratio $X^2_{min} \geq 0{,}9\ X^1_{min}$.

The lower limit of the confidence interval for the strength of the control samples, taking into account a coefficient of 0.9 for the first composition, is 31.2 MPa, and the lower limit for the confidence interval for the strength of the main samples for this composition is 27.2, i.e., the above ratio is not obtained. The same picture is observed

Table 4. Estimated indicators of frost resistance

Composition no.	Values for control samples					Values for main samples			
	X^1_{av}	σ^1_n	V^1, %	X^1_{min}	0.9 X^1_{min}	X^2_{av}	σ^2_n	V^2, %	X^2_{min}
1	37.4	0.92	2.70	35.1	31.2	30.2	1.16	3.19	27.2
2	41.1	0.52	1.19	39.8	35.8	38.1	0.64	1.60	36.5
3	39.2	2.9	7.41	31.7	28.5	30.6	2.31	6.08	24.7
4	53.5	2.72	5.08	46.2	41.6	51.3	2.54	4.86	44.8
5	60.8	1.15	1.89	57.8	52.0	59.4	0.98	1.61	56.9

for the third composition - 28.5 and 24.7 MPa. Therefore, the frost resistance of these concrete does not correspond to the mark F_2300. For the remaining compositions, these values are 35.8 MPa and 36.5 MPa, 41.6 MPa and 44.8 MPa, 52.0 MPa and 52.9 MPa, respectively. Therefore, fine-grained concrete with a superplasticizer (composition 2) or with a complex additive (compositions 4 and 5) can withstand 8 cycles of freezing and thawing, which corresponds to the concrete mark for frost resistance F_2300.

The arrangement of the air phase in the form of a system of thin air pores allows increasing the strength of the material and improving its other properties: frost resistance, water resistance and others. The control of the structure of the air phase and the stone skeleton opens up the possibility of wide modification of fine-grained concrete and giving it multifunctionality, i.e. ability to receive materials for various purposes due to structural changes: structural, finishing and others. Moreover, the technology of the material is relatively simple and affordable, and its cost is much lower.

To obtain solutions for various purposes, finely dispersed mineral additives from cheap raw materials (specially processed waste from aerated concrete and silicate brick production, metakaolin and others) can be introduced into the material. However, in modern conditions it is advisable to introduce them simultaneously with effective superplasticizers and air-entraining additives. It is desirable that the sum of the volumes of particles of the solid phase “cement + finely divided mineral components + fine fractions of sand (less than 0.14 mm)” be 25–35% of the volume of sand.

The use of multicomponent composite fine-grained concrete with an adjustable air phase makes it possible to obtain materials with a different set of properties.

4 Conclusions

Analyzing the test results and summarizing the above, we can make the following conclusions:

– the use of complex additives reduces the water-cement ratio, reduces its total and open porosity, as well as the average pore size, increases their uniformity.
– the use of air-entraining and complex chemical additives converts the air phase into a system of smaller ordered pores, which leads to an increase in the strength of the material;

- arrangement of the air phase in the form of a system of thin air pores allows increasing not only the strength of the material, but also improving its other properties: frost resistance, water resistance, durability, etc.;
- the use of multicomponent composite fine-grained concrete with an adjustable air phase will allow obtaining materials with a different set of properties.

The control of the structure of the air phase and the stone skeleton opens up the possibility of wide modification of fine-grained concrete and giving it multifunctionality, i.e. ability to receive materials and products for various purposes due to structural changes: structural, finishing, small architectural forms and others.

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Selection of the Variant of the Aluminium-Glass Facade Implementation Using the AHP Method

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Abstract. The image of the whole building is primarily its shape, external casing and materials used. The investor has to make a decision already at the moment of preparing the design concept, in which technology and materials the office building or service and commercial object is to be made. Heavy concrete construction has disappeared over the years. Investors decide to use lightweight materials, such as aluminium and glass, to give buildings a light form and to avoid disturbing the architecture of the surrounding urban planning. The multitude of aluminium and glass facade systems offered by the manufacturers makes the investor face a difficult choice of such a system that will meet his or her expectations. The aim of the paper is to describe and evaluate the aluminium and glass facade systems offered by the manufacturers. The analysis was performed for three variants: mullion and transom system, semi-structural system and structural system. A model supporting the decision to choose an appropriate variant based on the identified criteria and multi-criteria Analytic Hierarchy Process method (AHP) was proposed.

Keywords: Aluminium-glass facade · Analytic Hierarchy Process method

1 Introduction

The deficit on the commercial market of office and retail space makes investors decide to build new public buildings. Newly built buildings must comply with their standard not only with the specified technical conditions, but also with the applicable construction law; moreover they need to attract potential customers with their architectural form. The image of the whole building structure is created primarily by its shape, external casing and the quality and aesthetics of the built-in materials.

The investor has to make a decision already at the moment of preparing the design concept, in which technology and materials the office building or retail and service facility is to be made [1]. Heavy construction with the use of concrete disappears over the years. Investors decide to use lightweight materials for the external cladding of large buildings in order to give them a light form and not to disturb the architecture of the surrounding urban planning. The lightness of the form and the original shape of the facade can be shaped by the use of aluminium and glass. Thanks to such a solution, the

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designer can shape both fully glass, curvilinear and highly transparent surfaces, which are part of a wide trend of natural space for employees and customers. The multitude of aluminium-glass facade systems offered by the manufacturers makes it difficult for the investor to choose a system that meets all his expectations. The most important criteria set by investors are time [2, 3] and cost [4, 5]. Additionally, the final choice is influenced by aesthetic and quality values, as well as the final visual effect. Often difficult to measure criteria influence the final choice of the decision-maker as to the form and materials used to create the external enclosure of public utility buildings. Moreover, the adopted structural and technological solutions influence the later exploitation of the object and the costs incurred throughout the life cycle of the building [6]. To evaluate the systems and materials proposed on the market, decision support methods can be used [7–11].

The aim of the paper is to describe and evaluate the aluminium and glass facade systems offered by the manufacturers. The analysis was carried out for three variants: mullion and transom system, semi-structural system and structural system. A model supporting the decision to choose a suitable variant was proposed, which uses the identified criteria and the multi-criteria Analytic Hierarchy Process method (AHP).

2 Aluminium-Glass Facade Systems

In this paper, the authors described and evaluated the external cladding of the building walls as aluminium-glass facades. Such solutions are implemented with the use of aluminium sections forming the frame of the structure together with a glass panel which fills the space between the posts and the transoms. Depending on the assembly technology and the applied connections between the individual elements, they can be divided into several systems. The authors analysed three most frequently used solutions in the construction of public buildings. Aluminium and glass facades as mullion and transom, semi-structural and structural systems (Fig. 1).

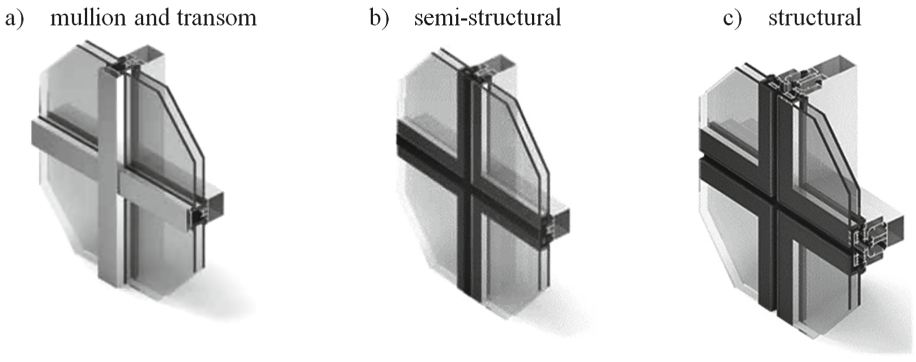

Fig. 1. Aluminium-glass facade systems [10]

Mullion and transom facades are solutions consisting of aluminium sections constituting the frame of the structure. The structure consists of posts and transoms, and the internal part is filled with glass. Pressure and masking strips are mounted outside, which disturb the aesthetics and visual perception of the outer casing. By using masking strips, the dividing lines between the individual fields of the structural skeleton are visible. Low aesthetic values are compensated for by additional advantages of the system, such as high technical parameters, thermal insulation or impact resistance.

The second system analysed is the semi-structural one. It is based on the solutions used for the mullion and transom system, where all the profiles and sections forming the framework of the structure in the form of posts and transoms can be used. An additional advantage of the semi-structural solution is the way the glass is fixed to the structure. By using a special mechanical connection between the sections and the glass, it is possible to achieve a smooth façade effect on the outside without visible pressure and masking strips. The resulting dividing lines between the spaces filling the structure are supplemented with appropriate weather silicones with appropriate technical parameters, ensuring long-term operation of such a solution.

The last solution of the aluminium-glass facade proposed by the authors is the structural system. This system is characterized by a completely smooth surface from the outside of the facade which is formed by glass panes. Such an effect is achieved by gluing glass to the aluminium structure. Gluing takes place in prefabrication plants under strict quality control of glued joints with the aluminium surface. Control and supervision over structural bonding requires manufacturers to use specialized equipment and qualified staff to ensure that the installation and further use of such a facade solution is fully safe for users. The advantage of the structural façade is the high aesthetics of the workmanship and the effect of the external cladding of the building as a completely glass body. High requirements of quality control of connections of individual structural elements with glass panel is the reason that not every type of glass package can be used for structural bonding, which affects the functionality and universality of such a solution.

3 The Multi-criteria Analytic Hierarchy Process Method (AHP)

The Analytic Hierarchy Process method (AHP) is a decision-aiding method. It was proposed in the 1970s by the American mathematician T.L. Satty. It is one of the methods facilitating decision-making in the case of multi-criteria decision-making problems by reducing them to a series of comparisons in pairs. Its aim is to quantify the relative priorities for a particular set of alternatives on a ratio scale on the basis of the decision maker's judgement. The model emphasizes the importance of the decision maker's intuitive judgements and the consistency with which alternatives are compared in the decision making process.

The main advantages of the AHP method are the presentation of a given decision problem in the form of a hierarchical model, which consists of a superior goal, main criteria, partial criteria and analysed variants. Another advantage of this method is the possibility to use measurable and immeasurable criteria [13, 14]. Individual criteria and variants are assessed at each level of the hierarchical structure through their mutual analysis and comparison in pairs. In order to properly evaluate each element of the hierarchical structure, a comparison matrix is created, whose degree is equal to the number of analysed elements. In addition, a priority vector is created, which expresses the assessment of individual variants and criteria in relation to the initial objective of the analysis. A higher value of the priority vector indicates the degree of significance of a given element. The reliability of the results obtained is carried out by calculating the CR compliance factor according to the following formulae [12]:

$$CR = \frac{CI}{RI} \cdot 100\% \quad (1)$$

where:

RI – random index, depending on the degree of matrix n; it takes the value in the interval 0 ÷ 1.45
CI – indicator of consequences

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (2)$$

where:

λ_{max} – maximum value of the matrix
n – degree of matrix.

The CR indicator should be less than 0.1, which indicates that the experts' assessments are consistent and assigned the principle of logical consequence, showing the correctness of grouping similar elements according to their homogeneity and the correctness of passability of assessments or the strength of relationship between the assessed elements.

The algorithm of the AHP method can be presented in several steps (Fig. 2).

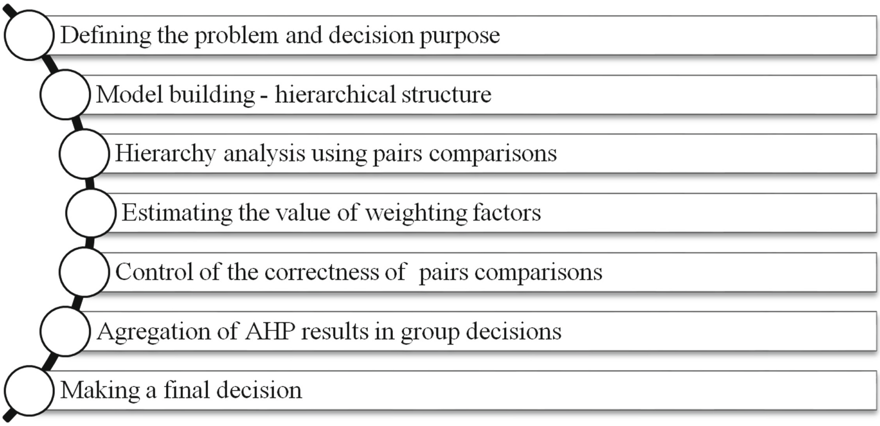

Fig. 2. Decision-making scheme in the AHP method

4 Facilitating Decision-Making Processes of Aluminium-Glass Facade Construction Using the Multi-criteria Analytic Hierarchy Process Method (AHP)

The right evaluation and the choice of the right aluminium-glass facade system by investors and designers is often a difficult and complex task. When choosing the right system, one should not only be guided by financial considerations, but also determine the technical parameters and the technology of implementation. Additionally, the choice of the appropriate system is influenced by difficult to measure elements, that is aesthetic, ecological or operational considerations.

Figure 3 shows the hierarchical structure for selecting the optimal aluminium-glass facade system.

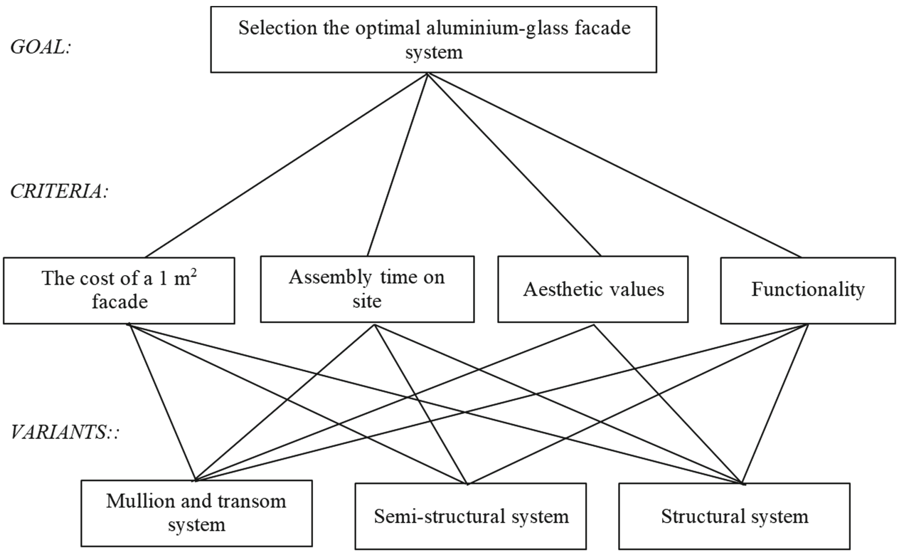

Fig. 3. Hierarchical structure for selecting the optimum aluminium-glass facade system

In this paper, the authors, using AHP method, attempted to identify the best variant of the solution of an aluminium-glass facade system depending on the four basic criteria influencing the decision-making process of the implementation of an aluminium-glass facade in public buildings. The criteria are as follows:

1. The cost of a 1 m^2 aluminium-glass facade, which includes the costs of labour, material and equipment; the cost of the material is the sum of costs for the frame of the aluminium structure, filling (glass panes) and appropriate system accessories and connectors; a detailed analysis of the costs is presented in the authors' publication [15]; the assembly of individual systems must be carried out by a specialist group of fitters using appropriate equipment; the additional cost taken into account

for the structural system is the cost of control and testing of glueing aluminium to glass,

2. Assembly time on site; the method of assembly and the technology used influence the speed of assembling the individual systems on site; the aim is to improve technological processes on site by prefabricating elements in production plants and delivering ready-made elements to the site,
3. Aesthetic values; difficult to measure as it is, this criterion is highly valued among potential customers, customers or employees; aesthetic values are affected by the form, shape line, sunshine, transparency or architectural details,
4. Functionality; this is the criterion determining the applicability of each system depending on technical parameters, thermal and acoustic insulation and the applicability of each glass package in the building.

Table 1 presents a comparison in pairs of criteria influencing the choice of an appropriate aluminium-glass facade system, taking into account the importance of particular criteria in relation to the intended purpose.

Table 1. Criteria comparison in pairs

	The cost of a 1 m^2 facade	Assembly time on site	Aesthetic values	Functionality
The cost of a 1 m^2 facade	1	4	5	6
Assembly time on site	0.25	1	5	5
Aesthetic values	0.2	0.2	1	2
Functionality	0.167	0.2	0.5	1

Evaluation scales are presented in Table 2.

Table 2. Evaluation scales

Numeric evaluation	Verbal evaluation
1	Equivalent
2	Equivalent to moderate
3	Moderate
4	Moderate to strong
5	Strong
6	Strong to very strong
7	Very strong
8	Very strong to extreme
9	Extreme

Table 3 presents the evaluations of the individual variants of aluminium and glass facades in relation to the relevant criteria, where:

1. Variant I [VI] – mullion and transom system,
2. Variant II [VII] – semi-structural system,
3. Variant III [VIII] – structural system.

Table 3. Variant evaluation

	The cost of a 1 m^2 facade			Asembly time on site			Aesthetic values			Functionality		
	VI	VII	VIII	VI	VII	VIII	VI	VII	VIII	VI	VII	VIII
Variant I	1	3	5	1	2	0.2	1	0.25	0.142	1	2	7
Variant II	0.333	1	4	0.5	1	0.2	4	1	0.2	0.5	1	4
Variant III	0.2	0.25	1	5	5	1	6	5	1	0.142	0.25	1

On the basis of the assessments made, the weights of individual elements of the hierarchical structure were calculated and the CR compliance coefficient was calculated. Through further analysis, a matrix of final ranking of particular variants of aluminium-glass facade systems was constructed. The data obtained are presented in Table 4.

Table 4. Final ranking

Variant I	0.442
Variant II	0.232
Variant III	0.326

The analysis performed with the use of the AHP method reveals that the most optimal solution for the implementation of an aluminium-glass facade is the mullion and transom system. This system is characterized by low cost and high functionality of such a solution.

5 Conclusions

The selection of an appropriate variant of the aluminium-glass facade implementation determines the success of the entire investment, both at the stage of design, execution and future exploitation. The application of the AHP method makes it possible to make the right decision and choose the right variant of the project depending on the criteria imposed by the decision-maker. Such a method may help to avoid accidental decisions based on suggestions or market trends. The analysis helps to make rational decisions, focused on parameters important both financially and qualitatively.

The authors' analysis of the choice of the aluminium-glass facade system took into account four most important criteria from the investor's point of view (the cost of the facade, installation time, as well as difficult to measure factors, namely aesthetic values and functionality). Based on the results obtained, it can be concluded that the most optimal solution is to use the mullion and transom system. It is characterized by low cost and high functionality. Such a system can be used for any type of building structure. In this example, only one level of criteria is defined. Further sub-criteria can be used for detailed and in-depth analysis. The result will be a more complex model but, at the same time, more supporting the selection of the most advantageous investor variant.

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Development of Polymer Composite Facing Material Using Anthropogenic Waste

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Abstract. The research presents the results of the composition development of the raw material mixture for producing construction polymer composite material on the basis of anthropogenic waste of production and consumption. Crushed solid ceramic material is used as a filler, polystyrene waste, previously dissolved in methylene chloride, is used as a binder for producing the developed material. This raw material mixture allows using cold mixing and cold forming, which in turn reduces production energy consumption and eliminates the possibility of polymer binder destruction during processing. To reduce solvent consumption, sealed equipment is used and methylene chloride vapor is removed during heat treatment after product molding at the solvent boiling point for the subsequent condensation and reuse in the production process. The research presents the dependence of the developed material compressive strength and water absorption on the raw mixture composition and pressing pressure. Basing on the identified dependences, polymer composite material was produced, which is characterized by low water absorption, high frost resistance and meets the regulatory requirements for construction materials and products regarding compressive strength and thermal conductivity. The raw mixture developed composition makes it possible to dispose of two types of large-capacity waste and reduce the anthropogenic load on the environment comprehensively, and the produced material on its basis can be used for outdoor cladding of walls in construction.

Keywords: Crushed brick · Polymer waste · Polystyrene · Polymer composite material · Facing material · Filler · Binder · Polymer dissolution · Methylene chloride

1 Introduction

Currently, the technologies for obtaining secondary raw materials and energy resources after the production and consumption waste processing are becoming increasingly actual and required. On the one hand, this trend is justified by the cost decrease of the production processes due to low prices for secondary resources, but on the other hand promotes more rational use of primary resources as their consumption is reduced thanks to their replacing by secondary resources and therefore reducing production waste losses. Waste application in the production processes is considered to reduce waste accumulation and anthropogenic load on the environment.

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The principle tasks to be solved in waste processing are the technologies simplicity, the environmental safety of the products, the possibility of waste recycling in large amounts, as well as finding new application areas of the waste which is environmentally hazardous and which is now not processed due to the recycling methods complexity and high expenses. The solution of these objectives is mostly effective when solved in the integrated processing using several types of waste in a single production process, besides when the waste is not the inert filler but the functional component in raw mixtures thus improving the performance and producing high quality materials and products.

Construction industry greatly facilitates the solution of these problems. This industry differs in large-capacity production and the possibility of producing items almost entirely based secondary resources. Waste processing as raw mixtures components for the construction industry is in most cases characterized by technology simplicity, low cost methods and high quality of the finished product.

In this paper we consider the possibility of complex utilization of crushed brick and polymer waste to obtain a composite material for construction purposes. The choice of these wastes is justified both by the need for their utilization due to the large volumes and rates of accumulation, and with the advantages of their use in the composition of the raw material mixture to obtain the developed material.

This research studies the possibility of complex utilization of crushed brick and polymer waste for the composite material manufacturing used in construction. This waste was chosen because of its utilization necessity, large amount and rate of accumulation and besides of the advantages of their use in the raw material mixture to produce the developed material.

The need to recycle crushed brick is firstly connected with the fact that, despite newly developed building materials, brick is still produced in large quantities, and secondly–significant part of buildings and structures built previously are from bricks. As a result, the sources of crushed brick are substandard products from brick factories, crushed bricks after loading and transportation, as well as waste after repair and construction works and old buildings demolition. Crushed brick is characterized by strength and hardness alongside high water absorption. It allows using it as backfill in road construction, drainage material, ceramic charge component or filler in concrete production, though waste processing capacity of this type is lower than its total amount. Thus, the utilization methods development of crushed brick allowing use its properties completely, is an urgent task [1–3].

Speaking about polymer waste, similar trend is observed, associated with high accumulation rate, which significantly exceeds their utilization capacity. It is especially typical for the consumption waste, which is characterized by impurities and partial destruction, reducing material quality [4–6]. At the same time, polymer waste disposal is complicated due to their decomposition duration and toxicity of combustion products. So the most effective processing ways are to be used as secondary raw materials in the polymer industry or as raw mixtures components for the production of composite materials in construction [7–9]. As for the composite materials production, complex utilization technologies allowing utilize heterogeneous waste as binders and fillers require special attention [10–12].

2 Materials and Methods

Crushed ordinary single solid ceramic brick, accumulated from various sources with subsequent grinding up to max particle size of 0.63 mm, composition averaging and drying to a constant mass, was used as a filler for producing the developed composite material, The advantages of using crushed brick as a filler are the possibility of increasing strength and hardness, reducing shrinkage and combustibility of the developed material and achieving good adhesion between the filler and the binder, which is confirmed by previous experiments with crushed brick conducted by the research authors [1].

In this research polystyrene waste packaging elements of household appliances, equipment, etc. separated from the total consumption waste, was used to produce binder. Expanded polystyrene is one of the most widely applied polymer materials, but in most cases its recycling is economically unprofitable because of the polymer production low cost from primary raw materials and due to the low material density, as it increases the cost of storage and transportation. Simultaneously its application for polystyrene production of polystyrene with further use as a binder for the composite materials production can increase products strength and reduce water absorption [1, 13, 14]. Prior the application expanded polystyrene waste was crushed up to the min particle size of 6 cm, averaged in composition and dried to a constant mass.

To transfer polystyrene into the viscous-flow state, resulted in obtaining polystyrene as a binder, in this research we have applied the polystyrene waste dissolution in methylene chloride of the first grade in compliance with GOST 9968-86 at 98.8 wt% of the basic substance content. Waste dissolving instead of melting allows grinding it into larger pieces, and makes it possible to use cold mixing and cold molding, thus reducing energy consumption for recycling and eliminates the possibility of polymer destruction during its processing. The main disadvantage of dissolution associated with the loss of solvent during its volatilization is minimized by the usage of sealed equipment with the solvent vapors removal for further condensation and reuse [1, 15].

The methylene chloride used as a solvent is explained by its high penetrating ability, which reduces polymer waste dissolution time, by low toxicity (hazard class 4), low combustibility, vast distribution and low cost [15].

The developed material samples were produced applying the following technology. The preliminary prepared expanded polystyrene waste was dissolved in methylene chloride in the required proportions, and the resulting solution was mixed with the prepared crushed brick until reaching a homogeneous raw mixture. Samples were formed from the raw material mixture by single-stage pressing, at the temperature of 45–50 °C with 45 min aging to evaporate the solvent. Samples for each composition were made in series of five samples each, followed by the arithmetic mean determination for the studied properties of the developed material.

The samples have been tested for compression strength (σ_{cs}, MPa), bending strength (σ_{bs}, MPa), water absorption (WA, %), frost resistance (FR, cycles) and thermal conductivity (λ, W/m ·°C) according the standard methods for construction materials.

3 Results

At the initial stage of experimental research, the ratio impact of polystyrene (PS), obtained by dissolving waste, and methylene chloride (MC) in the binder solution and the amount of crushed brick (CB) in the raw material mixture on the compressive strength and water absorption was determined, as these are the principle characteristics of the construction material. At the initial stage of research the samples were formed under the pressure of 8 MPa, at which the research authors produced composite material samples possessing good compaction and excellent operational properties in previous experiments [1, 15].

When preparing the binder solution it was found that at the ratio of PS:MC less than 1:1.2, the waste dissolution of takes long, and the resulting solution is characterized by high viscosity, which makes it difficult to produce a homogeneous raw mass by stirring and causes the transition of the binder begins into the vitreous state at the mixing and molding stages. The raw material mixture adheres to the mixing and forming tooling, and the sample is characterized by the loose structure in which certain areas are saturated with the binder, while other areas lack it. As a result, this material is characterized by low strength and high water absorption. It was also stated that the ratio of PS:MC over 1:2 heat treatment time for its removal significantly increases as a result of solvent excess, and PS amount in the resulting sample structure is not enough, which also causes the formation of heterogeneous structure, strength reduction and water absorption increase.

When binder solutions was mixed the with the filler, it was stated that with the introduction of more than 75 wt% CB there is a lack of binder, the samples edges crumble, material strength decreases, and water absorption increases significantly. When less than 35 wt% of CB is introduced, the filler amount is not enough to create solid frame from CB particles bound through PS layers in the material depth.

The measuring results of compressive strength and water absorption of the samples produced at different components ratios in the raw mixture composition in the amounts allowing to produce high-quality samples are shown in Fig. 1. The received data shows that the increase of CB in the raw mixture up to 50 wt% and the increase of PS:MC ratio to 1:1.6 causes the material compressive strength increase. Such dependence nature can be explained by the fact that the increase of CB particles amount leads to the distance decrease between them, and the filler particles begin to create a frame in the material depth, thus increasing its hardness and strength. In this case, the PS amount in the binder solution is sufficient to create PS layers of the thickness, providing the material strength increase among the majority of CB particles for their integration into the frame.

Further increase of the filler amount and the increase of PS:MC ratio up to 1:1.6 leads to the decrease of the resulting material strength, which indicates that binder lacks, and results in the considerable reduction of the binder layers thickness among the filler particles so that the PS amount seems not enough for strong binding of CB particles. Alongside this process the contact area between the CB binding particles starts to decrease, reducing the strength of CB particles frame in the material depth and the material strength as a whole.

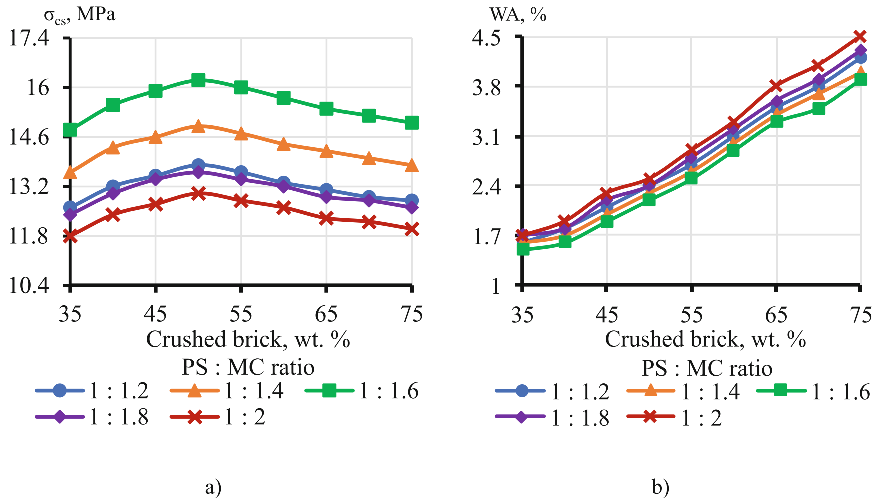


Fig. 1. The dependence of the resulting composite material compressive strength (a) and water absorption (b) on the ratio of the raw mixture components

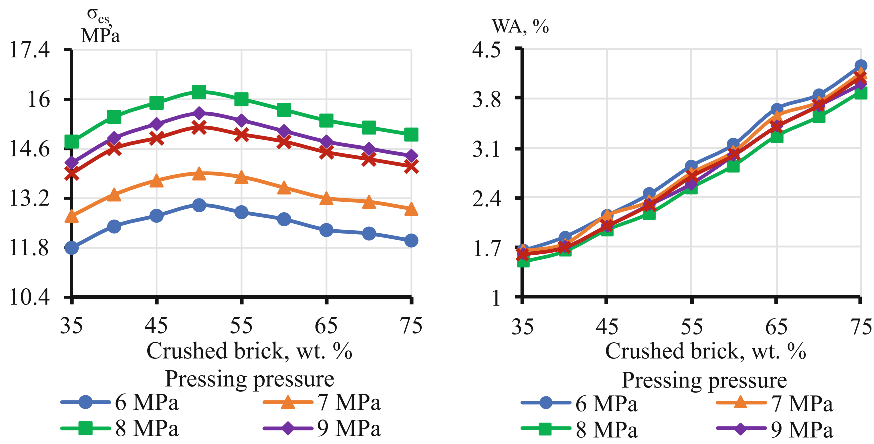
The developed material water absorption in its turn increases with the increase of CB amount in the raw mixture and MC amount in the binder solution. Such nature, on the one hand, depends on the increase of CB and MC amount in the raw mixture causing the decrease of PS share in the developed material, which leads to the pores and voids formation thus increasing water absorption. On the other hand, due to the imperfect wettability of CB particles with PS solution after mixing, air bubbles remain on the surface of the filler particles, leading to the pores formation, the number of which increases with the increase of CB share of the developed material. Herewith water absorption slightly depends on the CB and MC ratio in the binder solution, that is why the dependency lines are close to each other in Fig. 1b.

Basing on the received data, it was decided to keep PS:MC = 1:1.4 ratio for further experiments, producing sufficiently solid material characterized by average water absorption and MC flow rate.

It is necessary to consider the influence of the main technological parameters for producing the developed material together with the composition of the raw material mixture. In this case, these parameters include pressing pressure and temperature-temporal mode of samples processing after molding. It should be considered that the samples are thermally treated at MC boiling point (45–50 °C), when no physical or chemical transformations of the filler and the binder occur. Consequently, the change of temperature-temporal mode will affect only the duration and energy intensity of heat treatment process associated with the need of MC removal, but will not affect the material properties.

In this regard, at the second stage of experiments the influence of pressing pressure on the compressive strength and water absorption of the developed material has been studied. It was determined that at the pressure reduction up to max 5 MPa a loose structure with fragile bonds between individual sample areas was formed in the material. As a result, the sample edges and surface crumble, its strength is significantly reduced, but water absorption increases. At the same time, with an increase of pressure over 11 MPa, an overpressure of the material occurred, which manifested in the sample stratification in height, overpressure cracks formation and partial binder extrusion from the sample, leading to binder spots on the surface and structure heterogeneity. At the same time strength decrease and water absorption increase occurred.

The dependences of the samples compressive strength and water absorption, manufactured under the pressing pressures from 6 to 10 MPa, on pressing pressure and CB content in the raw mixture are shown in Fig. 2.



a) b)

Fig. 2. The dependence of compressive strength (a) and water absorption (b) of the resulting composite material on the pressing pressure

The received data revealed that the dependencies nature of the considered properties on CB content is similar to the dependencies presented in the results at the first stage of research. The pressing pressure increase from 6 to 8 MPa leads to the compressive strength increase and water absorption decrease, and with the further increase of this parameter, the strength tends to decrease, but water absorption - to increase. Such nature of the relationship depends on the fact that the increase of the pressure of compression makes material compacted, further reducing the distance between the CB particles causing the frame strength increase from the filler particles, and promotes the binder penetration into the voids among CB particles thus reducing porosity. However, reaching excessive pressing pressure after removing the load, the sample deformation takes place, leading to its stratification and the formation of overpressure cracks adversely affecting the basic operational properties of the developed material.

Basing on the received data, it has been decided to apply the pressing pressure equal to 8 MPa for further studies, as well as for the selection of the components ratio in the binder solution.

To assess the results of the composite material development for construction purposes, additional studies were conducted to determine the basic performance properties of samples produced on the basis of the raw mixture composition containing 50 wt% CB for achieving the highest compressive strength (see Table 1).

Table 1. Properties of the developed composite material

Water absorption, %	Frost resistance, cycle	Compression strength, MPa	Bending strength, MPa	Heat resistance, W/m ·°C
2.18	58	16.2	4.0	0.461

The data obtained proves that the developed composite material is characterized by sufficiently good frost resistance and low water absorption and can be recommended for outdoor construction application, and in particular for the wall cladding of buildings and structures. The strength and thermal conductivity of the developed material equal the average values for most construction materials and products and meet building regulatory requirements.

4 Conclusions

The research experiments resulted in the development of the raw mixture composition, including 50 wt% crushed brick, 19.2 wt% expanded polystyrene waste and 30.8 wt% MC. This composition allows complex utilization of two large-capacity types of waste to manufacture composite material for construction purposes. Since the material frost resistance exceeds 50 cycles, it can be used for outdoor wall cladding of buildings and structures. The mechanical strength of the developed material is relatively low, but the obtained data are sufficient when there is no high mechanical load, which practically do not occur during in the performance of facing and finishing materials and products. It should be noted that the developed material strength is superior to ceramic brick brand M150, for which the compressive strength and bending equal 15 and 2.8 MPa, respectively. The material thermal conductivity is close to the limit values for the group of conditionally efficient thermal characteristics in compliance with GOST 530-2012 ($\lambda < 0.46$ W/m ·°C), which is its advantage compared to most facing materials.

Thus, applying the developed composition of the raw material mixture we can reduce waste anthropogenic impact on the environment, expand the raw material base for the production of building materials and produce high-quality products at low energy intensity and production costs.

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Development of Facade Facing Ceramics with Self-Glazing Effect and Increased Energy Efficiency

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Abstract. The research presents the charge composition development on the basis of low-plasticity clay from the Vladimir region deposits for the production of ceramics for construction purposes. This low-plasticity clay is in low demand for ceramic production due to its poor durability, frost resistance and crack resistance resulted in products quality. To improve ceramics quality, it has been proposed to introduce trepel from the Vladimir region, boric acid and cullet into the charge. Trepel allows obtaining material fine-porous structure, which reduces thermal ceramics conductivity alongside maintaining its sufficient strength and frost resistance. The joined usage of cullet and boric acid provides liquid-phase sintering to form a vitreous phase, which serves as a binder of ceramic particles, fills large pores and voids in the material depth and provides self-glazing effect on the products surface. Simultaneously the fine-porous structure remains, since vitreous phase viscosity does not allow penetrating into small pores. As a result, the material strength increases, water absorption decreases and frost resistance increases, but self-glazing effect also allows creating a self-cleaning surface in the snow and rain, which is important for facade products. The application of the charge developed composition allows expanding the raw materials specification for the construction ceramics due to the low-plasticity clay and cullet usage for manufacturing high quality facing products that meet regulatory requirements for the outdoor facades cladding.

Keywords: Cullet · Low-plasticity clay · Energy efficiency · Self-glazing · Facing ceramics · Trepel · Boric acid

1 Introduction

Currently, three groups of construction materials are basically used for wall construction: load-bearing walls, insulation, indoor and outdoor facing. Each group performs its specific functions according to which certain requirements are to be met. Load-bearing wall materials should firstly resist high mechanical compression stress, thermal insulation materials should provide low thermal conductivity and reduce heat loss, and facing materials should resist bending stress, possess low water absorption

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and high frost resistance to protect the walls from environmental inpact. Additionally, all three groups of wall materials should meet fire and environmental safety requirements, as well as have durability, low cost and easy installation [1–3].

However, each group of building materials has certain disadvantages, which are offset by the advantages of other groups. So, materials for bearing walls and facing materials are characterized by high density, accompanied by their relatively large weight, causing the load on the foundation, and relatively high thermal conductivity, which does not allow to compline with thermal standards. Thermal insulation materials are characterized by high porosity, which reduces their mechanical strength, and as the pores are basically open, it increases water absorption, thus in turn reducing frost resistance. Besides when saturated with water it significantly increases thermal conductivity caused thermal conductivity of water filling the pores [2]. Another important factor is the effective functioning of the material, which reduces the walls thickness and as a result reduces the load on the foundation, increases inner space of the building and reduces the cost of construction work.

In this regard, the actual direction of development is the possibility to combine the advantages of all three groups of wall materials in one material simultaneously minimizing the mentioned above disadvantages. Ceramic materials characterized by strength, durability and incombustibility provide great opportunities for improvement, as well as wide possibilities for properties modifying using various functional additives, using various secondary resources for this purpose [4–6].

This research considers the possibility of producing energy-efficient facing ceramics based on the raw materials from the Vladimir region. Low-plasticity clay was used as the basic component, its reserves are sufficiently large in the region, but they are almost of no demand due to poor quality of the resulting products [7]. Therefore, the possibility of its combined application with functional additives is quite justified.

To improve the developed ceramics energy efficiency, trepel was proposed to be used in our research, as it facilitates the increase of the material porosity alongside maintaining its sufficiently high strength parameters in the production of ceramic materials [8, 9]. To reduce water absorption and increase frost resistance of the developed ceramics, boric acid and cullet are proposed to be introduced jointly, as previously it allowed the authors to obtain self-glazing effect of the facing ceramics [10–12]. The cullet was chosen as an additive forming a viterous phase, because there is huge amount of this waste in the Vladimir region (up to 10% of the total waste amount) stipulated by the activity of the local glass industry and household consumption [12–14].

2 Materials and Methods

The basic component of the charge composition is low plasticity clay from the Suvorotskoye deposit in the Vladimir region possessing the following composition (wt %): SiO_2 = 67.5; Al_2O_3 = 10.75; Fe_2O_3 = 5.85; CaO = 2.8; MgO = 1.7; K_2O = 2.4; Na_2O = 0.7. This clay refers to low plasticity type in compliance with Standard GOST 9169-75 as its plasticity index is 5.2 according to the standard method [4, 14].

Trepel fro Peksha deposit in the Vladimir region was applied as a pore-forming and active mineral additive of the following composition (wt%): SiO_2 = 74.2, Fe_2O_3 = 6.9; $A1_2O_3$ = 9.4; CaO = 2.2; MgO = 1.6. Boric acid B 2-nd grade (GOST 18704-78) with basic substance weight of 98.6% has been used as a fusing agent, its efficiency was proved by the research authors in the previously conducted experiments [10–12]. As a flux-strengthening additive window cullet of the following composition was introduced into the charge (wt%): SiO_2 = 73.5; CaO = 7.4; MgO = 1.9; Na_2O = 11.1; K_2O = 5.2; Al_2O_3 = 0.9.

The developed ceramics samples were produced in compliance with semi-dry pressing technology [4, 10]. Prior to the usage clay, trepel and cullet were dried reaching their constant mass, and then crushed with subsequent fraction selection of max 0.63 mm particle size. Then the charge components were mixed in the required experimental ratios in the dry state, and the resulting mixture was mixed with water to obtain a molding mass with a moisture content of 8 wt%. The developed ceramics samples from the molding mass were produced under the specific pressing pressure of 15 MPa and maximum firing temperature of 1050 °C. The experiments were carried out with each charge composition in parallel of a three samples batch.

The samples were tested to determine the following characteristics in compliance with the standard methods for construction materials: thermal conductivity (λ, Wt/(m·°C), compression strength (σ_{cs}, MPa), bending strength (σ_{bs}, MPa), density (ρ, kg/m^3), water absorption (W, %), open (P_{opn}, %), and total (P_{tot}, %) porosity, frost resistance (F, cycles). The developed ceramics macrostructure was studied using the microscope Micros MC-20 (MICROS Productions - und HandelsgesmbH, Austria).

3 Results

At the initial stage of the experiments, the dependences of the principle operational characteristics of the developed material upon the components ratio in the mixture were obtained. Basing on the previous experiments carried out by the research authors [4, 10] boric acid (BA) amount introduced into the charge was limited to 2.5 and 5 wt%. Lower amount of this additive affect the ceramics properties negligibly. Higher amount of BA, introduced together with the flux-strengthening additives, leads to the excess of the vitreous phase and consequently to the products shape loss and most pores filling up, thus in turn reducing the products energy efficiency and failing the research objective.

According to the data shown in Fig. 1, thermal conductivity of the developed ceramics decreases alongside the increase in trepel amount the decrease of BA amount and window cullet (CW) in the charge composition.

Such dependencies nature can be explained by the impact of each functional additive on the material structure formation. BA, being a flux, reduces the liquid-phase sintering temperature of the components and increases the amount vitreous phase formed during the firing. CW is the main source of the vitreous phase during the firing, and acts as a binder of the ceramic grains, filling large pores and voids in the material.

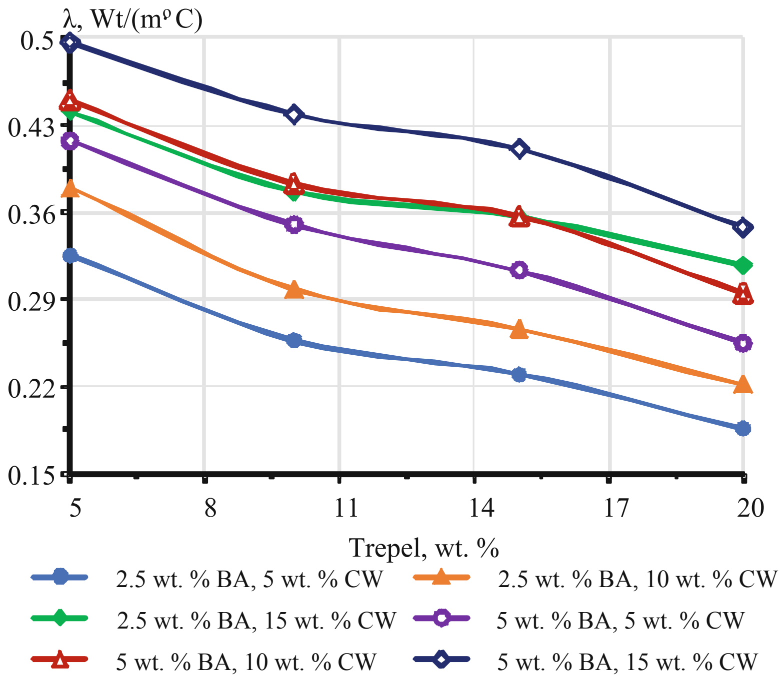

Fig. 1. Dependance of thermal conductivity on the ratio of the raw mixture components of the developed ceramics

Trepel is basically a microglobular structure of the rounded opal grains of 0.001–0.01 mm in size [15]. Consequently, each trepel particle is an agglomerate of opal grains (amorphous $SiO2 \cdot nH2O$ with iron, magnesium and calcium oxides impurities), from which, during the firing at the temperature of 450–800 °C, chemically bound water is removed, thus increasing the porosity of the material structure. At the same time, opal grains small size is known to facilitate the creation of a developed contact surface between the ceramic grains and causes the formation of a fine-porous structure at the temperature of 1050 °C [9].

Thus, trepel agglomerates form fine-porous connections between the ceramic particles, linking them in a single frame. Due to its reactivity, stipulated by the amorphous structure and small size, opal grains actively interact with the ceramic mass during firing [8], being a part of the compounds formed during firing, thus increasing the connections contact strength of the trepel agglomerates with ceramic particles and the vitreous phase. It also should be noted that the viscosity of the vitreous phase, formed from CW and BA, does not allow its penetrating into the fine-porous parts of the ceramic structure, so the vitreous phase fills only large pores.

Consequently, the trepel amount increase in the charge composition increases the overall material porosity, which in turn reduces its thermal conductivity. In turn, the increase of CW and BA leads to the filling of pores and voids in the material with the vitreous phase, increasing its thermal conductivity. However, it should be considered that on the one hand, porosity increase improves thermal characteristics of the material, and on the other – reduces its strength and increases water absorption, which in turn reduces frost resistance.

Strength decrease and water absorption increase of the material alongside the increase of trepel amount and decrease of CW and BA in the charge is confirmed by the data in Figs. 2 and 3.

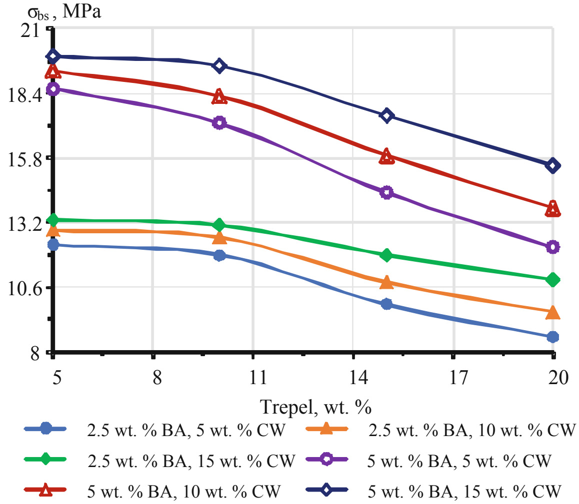

Fig. 2. Dependence of bending strength and raw mixture components ratio of the developed ceramics

In this regard, when choosing the content of charge composition components, it should be noted that trepel amount should ensure products energy efficiency, produced with the increased porosity and reduced thermal conductivity, but CW and BA amount should provide good strength and poor water absorption due to the possible glazing effect of the ceramic particles surface and agglomerates of trepel and samples surface self-glazing [10]. Vitrification and self-glazing effects for the developed compounds are proved by the data shown in Fig. 4, which demonstrate that these effects can achieve high closed porosity in the material depth with pore size about 90 microns on the surface, and pore size in the depth up to 200 microns.

Since it is supposed to apply the developed material for the production of cladding products, it should be noted that according to GOST 13996-93 requirements the bending strength of products, used for cladding facades should be minimum 16 MPa, and for cocle lining – minimum 8 MPa. Therefore, basing on Fig. 2 data, all the presented component ratios prove the possibility of producing products for cocle lining, and the use of charge compositions, containing 5 wt% of BA and trepel in an amount not exceeding 15 wt%, allows to manufacture products for facades facing. The dependency in Fig. 2 also demonstrates that the introduction of trepel of more than 20 wt% into the charge composition reduces the bending strength below the threshold of 8 MPa for compositions containing 2.5 wt% BA and less than 10 wt% CW.

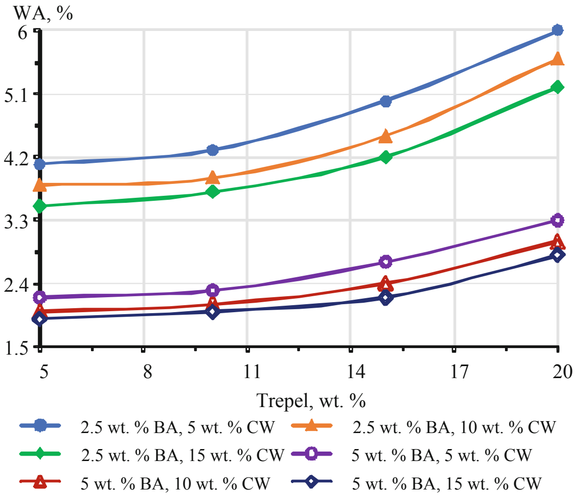

Fig. 3. Dependence of water absorption and raw mixture components ratio of the developed ceramics

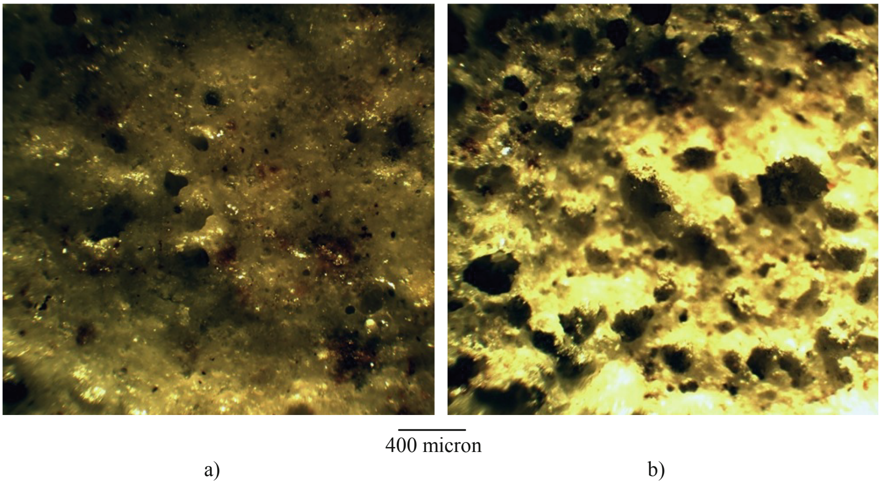

Fig. 4. Developed ceramics macrostructure on the surface (a) and in the section (b)

According to GOST 13996-93 requirements the lower limit of productwater absorption is 2%, and the upper limit is 9% for the wall products and 5% for the cocle products. Consequently Fig. 2 data shows that all the presented component ratios meet the requirements for wall products, and the charge compositions, containing 5 wt% of BA for all presented amounts of trepel, as well as 2.5 wt% of BA and trepel in an amount not exceeding 15 wt% enable to produce the material that meets the requirements for cocle products.

As the developed material should be energy efficient, it should be taken into account that GOST 530-2007 requires thermal conductivity not higher than $0.46\,W/(m \cdot ^\circ C)$, and, consequently, Fig. 1 shows that the number of CW in the charge should not exceed 15 wt%.

In compliance with the specified GOST, high energy efficiency is achieved at thermal conductivity of less than 0.2 W/(m·°C), it means that the charge composition contains 5 wt% CW, 2.5 wt% of BA and 20 wt% of trepel (Composition 1). Ceramic material samples based on this charge composition show the lowest bending strength of all the prodiced samples. The biggest bending strength of all the samples, alongside maintaining the conditional energy efficiency, belongs to the samples based on the charge composition containing 15 wt% of CW, 5 wt% of BA and 10 wt% of trepel (Composition 2). The principle operational and physical-mechanical properties have been determined for these compositions, presented in the Table 1.

Table 1. Properties of the developed ceramics

Composition	ρ, kg/m3	Popn, %	P_{tot}, %	W, %	σ_{cs}, MPa	σ_{bs}, MPa	F, cycles	λ, $Wt/(m^2 \cdot ^\circ C)$
1	1390.5	8.3	30.8	6	20.4	8.6	44	0.186
2	1917.1	3.8	17.7	2	37.5	19.5	54	0.439

According to the received data, the ceramic material based on the Composition 1 does not meet GOST 13996-93 requirements for water absorption and frost resistance for the cocle cladding products ($W > 5\%$, $F > 50$ cycles), but it is highly energy efficient and can be recommended for the production of bearing and thermal insulation layers in multilayer walls, for example, energy-efficient brick brand M200. Ceramic material based on Composition 2 meets the requirements for both wall and cocle facing products and refers to the conditionally effective thermal products ($0.36 < \lambda < 0.46\,W/(m \cdot ^\circ C)$).

4 Conclusions

The experiments results prove that energy-efficient ceramics with the particles glazing effects in the material depth and self-glazing surface can be produced on the basis of low-plasticity clay with such functional additives as CW, trepel and BA as. At the same time, Trepel acts here as a pore-forming additive and actively interacts with mineral phases during firing. So taking into account its structure and composition it is possible to produce a developed contact surface among ceramic particles, which reduces strength to a certain extent, but at the same time causes thermal conductivity decrease. BA together with CW act as a source of vitreous phase, which provides the glazing and self-glazing effect, which increase strength and reduce water absorption. Herewith large pores in the material are filled with the vitreous phase, but the fine-porous structure remain, since vitreous phase viscosity does not allow it to penetrate into the small pores.

When charge composition containing 15 wt% of CW, 5 wt% of BA and 10 wt% of trepel is used ceramic material possessing conditionally effective thermal characteristics can be obtained. Basic functional properties of the material meet the requirements for wall and cocle cladding materials.

Applying the developed charge composition we can consume low ductility clay raw materials of poor demand and dispose cullit thus reducing their accumulation rate in landfills and in the environment.

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Experimental Research of the Strength of Compressed Concrete Filled Steel Tube Elements

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Abstract. The purpose of this article is to study the effect of the compressing force eccentricity on the strength of compressed concrete filled steel tube elements of circular section, produced from high-strength concrete. The behavior of short laboratory samples with 159 mm cross-section diameter was investigated under axial and eccentrical compression in low and high eccentricity areas. Self-stressing concrete was used to produce half of the examined samples. The conducted research results indicate high utilization efficiency of the steel shell for high-strength concrete core of concrete filled steel tube elements behaving not only under centric compression but also under eccentrical compression with low eccentricities. The application of self-stressing concrete for such samples allows increasing the confining effect by approximately another 5%. To a greater extent, the presence of self-stressing concrete has increased the elastic strength limit of structures.

Keywords: Concrete filled steel tube elements · Strength · Circular section · Centric and Eccentric · Compression

1 Introduction

Compressed concrete filled steel tube elements (CCFSEs) of circular section are quite commonly used in civil practice, especially as heavy loaded columns and bridge supports [1–6]. Their most valuable property - high strength – is particularly leveraged under axial compression strain. Hence, most publications are dedicated to experimental research of short centrally compressed concrete filled steel tube elements [7–13]. It is known that as the compressing force eccentricity increases, the CCFSE strength is significantly reduced [14–20]. There is a relatively small number of studies performed on such structures. However, eccentrically compressed elements, in particular, are very common in design practice. The purpose of this article is to study the effect of the compressing force eccentricity on the strength of the laboratory samples of short CCFSEs. To improve the effectiveness, such samples were produced from high-strength

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concrete. The effect of self-stressing concrete on the improvement of performance properties of CCFSEs was examined at the same time.

2 Materials and Methods

To achieve the desired goal, experimental research of the strength of centrally and eccentrically compressed laboratory samples of CCFSEs.

Experimental samples had a cylindrical shape, 640 mm length and 159 mm diameter. Eight series of experimental samples were produced for the research. Every series was based on three twin samples. Four series of samples (N.0, N.1, N.2 and N.3 for research conducted at relative eccentricities e_o/d = 0, 0.125, 0.25 and 0.375, respectively) were produced from high-strength heavyweight concrete of class C80 and the other four series of equivalent samples (S.0, S.1, S.2 and S.3) were produced from self-stressing concrete of grade S_p2 and with the same class of compressive strength.

The following materials were used as components for producing the concrete core:

- mains water;
- portland cement M600;
- quartz sand with 2.6 mm fineness modulus;
- 5–10 mm fraction crushed basalt;
- superplasticizing admixture Sika ViscoCrete 5–600 SP;
- multi-purpose Embelit modifier.

Embelit concrete modifier represents a powdered organomineral-based multicomponent product. The main effect of producing concrete with the use of Embelit modifier is to ensure high strength when the shrinkage is compensated. The following additional effects are achieved in this case:

- reduced concrete permeability (to permeability grade W20 and above);
- improved corrosion resistance and durability of concretes;
- concrete expansion and self-stressing;
- plasticizing, stabilizing and water-retaining effect on concrete mixes;
- improved pumpability and consistence stability of concrete mixes over time.

Superplasticizing admixture Sika ViscoCrete 5–600 provides the following benefits:

- enhanced mix plasticity without affecting the strength of concrete;
- improved mix density;
- improved adhesion between concrete and metal;
- reduced concrete shrinkage.

Steel tubes with 159 × 5 mm dimensions, produced from steel class S345B were used as steel shell for all series of samples. Average yield strength of the tube steel σ_{yp} = 363 MPa.

Laboratory samples at the age of 28 days were vertically tested with a 500 ton hydraulic press at momentary compressive load. The adopted testing procedure was mainly standard. Resistive strain gauges were used to measure the strains of the steel shell. Only the adopted procedure for measuring longitudinal strains of the concrete core was original.

Normally, CCFSE researchers face the challenge of measuring concrete strains because it is not easily available. This problem was resolved in the following way. Before the beginning of the concrete forming process, 10 mm diameter holes were drilled at preliminarily marked locations of the steel shell walls. Plastic inserts and 6 mm diameter metal pins with expansion bolt screwing thread at one end and M6 metric thread at the other end were fitted through them. Plastic inserts were supporting the metal rods in such a way that they were placed 15 mm inside the concrete core and aligned relative to the hole. After the formation of the product, the pins got unscrewed because the cement paste densely wrapped around them during its setting and created something similar to a thread, which was quite solid. The plastic inserts were removed. The holes were sealed against water and the sample was taken into storage.

Steel rods pre-coated with epoxy glue were screwed into the concrete core immediately before testing. The samples were kept for one day to ensure the hardening of the epoxy glue. Then, metal strips of pre-calculated length were firmly fixed onto the pins. As a result, securely fixed mounting devices were obtained for measuring instruments. Aistov strain gauges with 0.001 mm division value were used to measure the strains. The gauge length for longitudinal strains of the concrete core was 200 mm. Deflection indicators were used to measure the bending of the sample's longitudinal axis. The compressive load was transmitted to the end surfaces of the samples through 60 mm thick steel plates. Steel bandages were attached to the end surfaces of the samples. The sample view during the test is represented in Fig. 1.

Fig. 1. General view of the sample during the eccentrical compression test

3 Results

Main test results for laboratory samples of CCFSEs are presented in Table 1. These results include the following:

- N_{el} is the load corresponding to the end of the sample's quasielastic behavior;
- N_u is the failure load;
- N_{cp} is the calculated value of the total force taken up by the concrete and the steel shell on the assumption of their behavior under uniaxial compression or tension;
- $n_{el} = N_{el}/N_u$ is the relative elastic behavior limit;
- $m_c = N_u/N_{cp}$ is the coefficient determining the influence of the confining effect – associated with the presence of the external steel shell - on the sample strength in terms of quantity.

For the purpose of better clarity, the table provides only average values of all the above-listed parameters for every series of samples. The obtained data demonstrate the display of the confining effect for all the examined samples. The highest values of m_c coefficient are observed with centrally compressed samples. As the compressive load eccentricity increases, these values are reduced. However, even at relative eccentricity e_o/d = 0.375 the confining effect is noticeable and amounts to 8÷9%.

Table 1. Main results of laboratory samples testing

Series	e_o/d	f_c, MPa	N_{el}, kN	N_{cp}, kN	N_u, kN	n_{el}	m_c
N.0	0	84.8	1616	2310	2835	0.57	1.23
S.0	0	85.3	1960	2318	2970	0.66	1.28
N.1	0.125	84.8	1000	1526	1855	0.54	1.21
S.1	0.125	85.3	1200	1532	1930	0.62	1.26
N.2	0.25	82.5	700	1180	1365	0.51	1.15
S.2	0.25	84.4	800	1194	1450	0.55	1.21
N.3	0.375	82.5	500	940	1020	0.49	1.08
S.3	0.375	84.4	550	947	1030	0.53	1.09

The presence of self-stressing concrete has improved the confining effectiveness for the samples behaving under compression with random and low eccentricities. Although the m_c coefficient growth is stable in this case, it is limited and amounts to about 4÷5%. For samples representing series S.3 and N.3, which behave under high compressive force eccentricities, the confining effect is practically the same.

To a greater extent, the presence of self-stressing concrete had an influence on the elastic strength limit. This influence was particularly noticeable with samples representing series S.0 and S.1 where the relative elastic strength limit was increased by minimum 15% when compared to samples representing series N.0 and N.1. As relative eccentricity increased, the proportion of concrete taking up the compressive stress was reduced. Therefore, the preliminary compression of the concrete core had the least effect on the behavior of examined samples. As a result, the relative elastic strength limit in samples representing series S.2 and S.3 increased only by 8% when compared to samples representing series N.2 and N.3.

The presence of self-stressing concrete had no observable influence on the nature of breakdown. Breakdown of examined samples representing all the series progressed in a plastic manner. By the time when the limit load was reached, steel shell folding (Fig. 2, a) was observed in centrally compressed samples on every side face. This was preceded by the fragmentation of the concrete core located in the area where the folds were formed, which resulted in the loss of bond between the concrete and the steel shell. Therefore, the concrete could no longer protect the steel shell walls against wrinkling. By the time of breakdown, the eccentrically compressed samples were subjected to significant bending strains that by far exceeded the strains of the corresponding reinforced concrete elements (Fig. 2, b). Slight folding appeared in the most compressed steel shell area of these samples. After the removal of the external shell, concrete fragmentation was observed in the area where the folds were formed. Concrete was scaling off in these areas under slight mechanical pressure. Cracks were observed in the tensile region of concrete samples loaded with force with relative eccentricities e_o/d = 0.25 and 0.375, which were perpendicular to their longitudinal axis. No trace of breakdown was observed in the tensile region of samples representing series N.1 and S.1.

A) B)

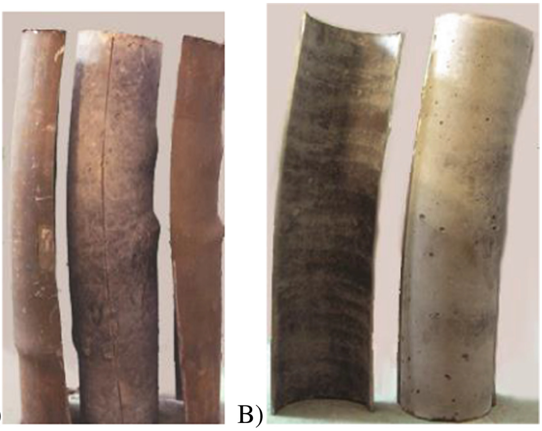

Fig. 2. (A) Nature of breakdown for centrally compressed samples. (B) Nature of breakdown for eccentrically compressed samples

4 Discussion

The conducted research showed that the efficiency of utilizing the steel shell as a confinement for high-strength concrete remained noticeable (around 10%) even at relative eccentricities e_o/d = 0.375. High levels of longitudinal strains were observed in the compressed area before the samples broke down. For example, by the time when the maximum load was reached, relative longitudinal strains of samples representing series N.0 constituted 0.8% on average and those of samples representing series S.0 constituted 0.84%, which was much higher when compared to reinforced concrete structures without confinement reinforcement. The same trend was observed during the analysis of longitudinal strains of the most compressed face of eccentrically compressed samples of different series. High levels of ultimate concrete strains make it possible to take full advantage of the strength properties of compressed reinforcement with high conventional yield strength. Rational use of high-tensile reinforcement allows obtaining considerable economic benefits. The positive effect of using self-stressing concrete can be explained in the following way. During the hardening, self-stressing concrete generated slight pre-stressing of the steel shell along the circumference. The reaction pressure applied by the steel shell transferred the stress to the concrete core even before the sample was loaded with compressive force. In other words, in this case the concrete was under volumetric compression even at low loading levels. This contributed to the increased level of intensive microcracking inside the concrete and, as a result, a significant increase in ultimate elastic strength and a moderate improvement in sample strength.

Considering the high strength and the great levels of ultimate strains of the examined samples, it can be concluded that they have higher durability when compared to conventionally used reinforced concrete or metal structures. Using CCFSEs as vertical load-bearing frame structures will significantly improve the resistance of buildings to progressive collapse. This is particularly important for construction activities performed in seismically active regions.

5 Conclusions

The conducted research results indicate high efficiency of utilizing the steel shell for high-strength concrete core of CCFSEs behaving not only under central but also under eccentrical compression with low eccentricities. For samples loaded with compressive force with small eccentricities $e_o/d = 0.25$ and below, the use of self-stressing concrete allows increasing the confining effect by approximately 5%. To a greater extent, the presence of self-stressing concrete has increased the elastic strength limit of structures. When achieving the highest load, CCFSEs produced from high-strength concrete had significant longitudinal strains. This feature of the examined samples, firstly, improves their durability and, secondly, makes it possible to effectively utilize high-tensile reinforcement inside them. Experiments with such samples having high-tensile longitudinal reinforcement are planned to be conducted in the near future.

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Exploitation Characteristics of the Constructions of Transport Buildings and Structures Under Dynamic Loads

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Abstract. The simplified method for solving the problem of oscillations of the bearing and enclosing constructions of buildings and structures under the action of vibrations propagating in ground bases during the movement of railway transport is theoretically justified. The proposed method is based on the division of the structural scheme into separate rod constructions, the calculation of which is carried out sequentially on the dynamic deviations of their supports. Vibration process excited in the grounds during the movement of transport leads to dynamic vibrations of the constructions of buildings located near transport communications, which leads to additional dynamic loading in these structures. Decrease in operational characteristics of structures is expressed in cracking and local destruction. A computational model for estimating these effects is proposed as follows: source of dynamic load (moving railway transport), load transfer medium (soil), building structure (impact receiver). When forming the design schemes, the simplifying assumption about the discretization of the design scheme based on the d'Alembert's principle is taken into account. The solution of the equations of motion is represented in the form of expansion in its own forms of vibrations. Some simplifications of the computational model have been substantiated, which allows obtaining numerical results for practical use. The presented calculation of building constructions for dynamic displacements of supports caused by dynamic impacts from traffic is a theoretical basis for taking into account such effects in the design and construction.

Keywords: Moving railway transport · Transport facilities · Dynamic effects from transport · Physical vibration model · Calculation method of dynamic impact

1 Introduction

During the exploitation of transport facilities, the deterioration of characteristics of building structures makes it difficult, and in some cases impedes the normal functioning of the building. These include a wide class of objects: buildings of railway stations, transportation hubs, depots, construction of sorting stations and other buildings intended for maintenance of transport, as well as buildings and structures located near moving vehicles [1].

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The oscillatory process, excited in the soils of the foundations during traffic, causes fluctuations in the adjacent structures of the building framework, leads to additional dynamic efforts in these structures and a violation of sanitary and hygienic standards during the operation of premises intended for passenger service [2]. Currently, these additional efforts are not taken into account, although they are often the cause of the violation of the operational suitability of buildings expressed in the appearance of cracks in the walling and supporting structures and local destruction sites [3]. In addition to direct dynamic effects on the structure, vibration loads also have an indirect effect, characterized by a deterioration of the physical and mechanical properties of the base soils, expressed in the intensification of the creep properties of the ground (the phenomenon of vibrocreep). This leads to the deterioration of the strength and deformability properties of the bases during traffic and can cause the growth of uneven sediment foundations under the surrounding structures, which also inevitably causes additional internal efforts in the building structures for which they were not originally designed. The physical model of the problem of calculating the structure of buildings with regard to the dynamic effects of traffic can be represented as follows: source of dynamic load (moving railway transport) → load transfer medium (soil) → building structure (impact receiver).

The solution of the problem of calculating the surrounding structures of the framework of transport structures on dynamic loads should be made in two main directions, because they have a direct and indirect effect. First, under the action of vibrations of bases propagating in soils, neighboring building structures are involved in the vibration process, in which, due to the inertial dynamic component, additional forces arise. Secondly, the dynamic effects propagating in the soils lead to a decrease in the strength and an increase in the deformative properties of the soils of the foundations, which is reflected in the growth of additional sediments of the foundations of buildings and structures. Since modern constructive solutions of buildings represent statically indefinable constructions in which elements with uneven precipitation, additional efforts are formed, taking this factor into account is also urgently necessary [4].

Neither the first nor the second moment is taken into account by modern methods of calculating the surrounding constructions of buildings, for which only static calculations are always carried out, which cannot reflect real work, since the dynamic features of the deformation process are completely ignored. As a rule, the dynamic effects are usually calculated, the structure that directly perceives them (the upper and lower structure of the railway track), while the influence of traffic movement on neighboring structures becomes obvious, and this effect is stronger than closer to the constructions is located the source of vibration [5].

These dynamic factors, providing additional power, lead to additional vibrations and loads in the structures for which they were not originally (still at the design stage), taken into account, often leads to deterioration and even disruption of their operational characteristics, resulting in the growth of additional uneven sediments, vibrations, cracking and even partial collapse in some areas, and most often the wall filling collapses, and some other constructions too.

2 Results Section

The development of the calculation method must begin with the determination of the dynamic loads affecting the behavior of structures, and the nature of the load must be determined so that it would be possible to simply construct the calculating apparatus. Obviously, when calculating the vibrations of building structures, it is convenient to take vertical or horizontal (or both at the same time) dynamic displacements of the foundation supports as the initial impact, since the vibration effects are transmitted and affect the surrounding constructions of buildings and structures through the ground base. The calculation of statically indefinable building structures for additional precipitation, unlike the previous one, should be stationary, and it is well known from the rules of structural mechanics. Obviously, to obtain the final internal force in the engineering method, it is necessary to carry out two calculations and the results of static calculations for uneven precipitation and dynamic for oscillations of structures, and based on the principle of independence of the forces, these forces should be summed up. These forces, obtained as a result of the engineering method of calculation, should be supplemented with stresses calculated from the results of generally accepted design measures carried out in the static calculation of structures for the effect of permanent and temporary external loads, on the basis of which the specific type of bearing and enclosing elements is formed. Thus, the final value of the resulting force on the basis of the principle of independence of the action of forces or additivity should be obtained by the following formula:

$$\sigma = \sum\nolimits_{1}^{i} \sigma_{din,i} + \sum \sigma_{stat,i} \leq R_{din}(\rho) \quad (1)$$

Here: the first term is the magnitude of the stresses obtained as a result of the calculation of the effects of vibrations of constructions, the second - is the stress value obtained as a result of the generally accepted static calculation of structures for the effect of its own weight and temporary loads, including the stresses from additional sediment; Rdin (ρ) is the strength of the material of the calculated construction with regard to its decrease as a result of fatigue taken depending on the cycle asymmetry factor at the most unfavorable combination of external loads:

$$\rho = \frac{\sigma_{min}}{\sigma_{max} = \frac{\sum_{1}^{i} \sigma_{stat,i} - \sum_{1}^{i} \sigma_{din,i}}{\sum_{1}^{i} \sigma_{stat,i} + \sum_{1}^{i} \sigma_{din,i}}} \quad (2)$$

It should be noted that the summation of the stresses in formula (1) must be performed taking into account the known coefficients of the combinations having the corresponding values for different combinations of loads. At the same time, the dynamic load from oscillations of structures and from an additional increase in precipitation due to the vibro-creeping of the bases should be attributed to long-acting in a special combination. The plus sign in expression (1) means algebraic summation if the action planes of the loads are the same and geometric—if they do not coincide, for example, its own weight (in vertical) and the structure oscillations in the plane of least rigidity (horizontal).

When forming the design schemes, the simplifying assumption about the discretization of the design scheme based on the d'Alembert's principle allows placing the concentrated masses along the weightless axis of the calculated rod. This approach allows one to simply achieve the required accuracy of the calculation, since with a certain (sufficiently large) number of masses, the result of solving a discrete dynamic problem is practically the same as a continuous solution [6]. On the other hand, the discrete technique is easy to computer simulate and allows the use of artificial mathematical techniques consisting in the application of finite element methods or finite differences and even the use of already developed software [7].

Obviously, the design scheme should be formed depending on the actual design scheme, which will be a kind of three-dimensional frame structure for which differential equilibrium equations are constructed, solved in the elastic-linear formulation using known methods used in the dynamics of structures (Fig. 1.).

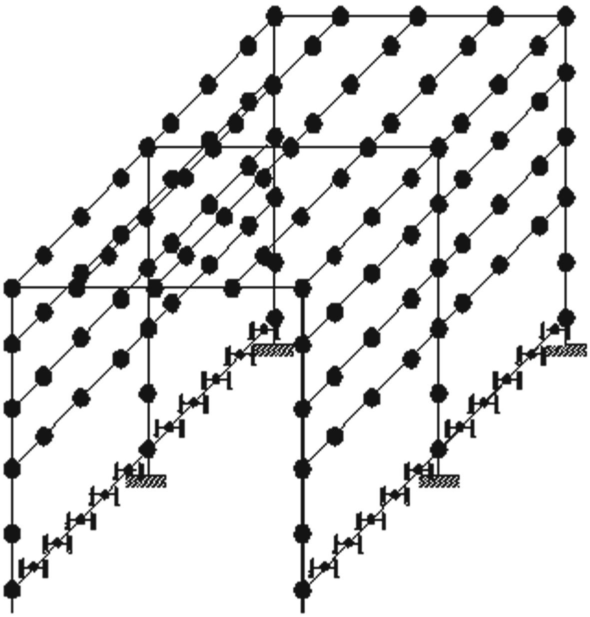

Fig. 1. Design scheme

Moreover, the number of considered frames should be formed depending on the magnitude of the ground oscillation amplitude, both in the vertical and horizontal planes, it is likely that the extreme frame spans should be taken in the oscillation zone where the amplitude of the dynamic displacements of the soil is approximately 20% of the maximum, which corresponds to the generally accepted accuracy of engineering calculations, and the following spans outside this zone, it is possible not to include into the calculation due to the insignificant forces in them arising.In this case, the system of resolving equations for the design scheme shown in Fig. 1 will be as follows:

$$\sum_{k=1}^{n} m_n \frac{d^2}{dt^2}(Z_n + \Delta) + \sum_{k=1}^{n} r_{kn} Z_n + \sum_{k=1}^{n} \beta\, r_{kn} \frac{d}{dt} Z_n = 0 \tag{3}$$

here: m_n is the mass of the corresponding section of the building construction, which should be located on the corresponding section of the frame rod; r_{kn} is the unit reaction of the superimposed virtual connection k, in which the mass m is collected from the corresponding section of the construction from the unit displacement of node n, calculated as a result of calculating the spatial statically indefinable frame; Δ is the specified displacement of the support, determined by the method described above; Z_n is the mass displacement n due to the bending of the frame rod; β is the conditional viscosity coefficient taken in accordance with the considered theory of internal resistance (damping) of the material and for the theory of frequency-independent internal friction, taken equal to:

$$\beta = \gamma / \omega \tag{4}$$

where: γ is the energy absorption coefficient of the material under consideration (in the general case it can be taken as variable and dependent on the level of the stressed state); ω - frequency of forced vibrations.

It should be noted that the system of Eq. (3) is obtained on the basis of the d'Alembert's principle which implies equality to zero (equilibrium at each considered moment) of all forces applied to each mass, the first term being the inertia forces of the considered mass, and the second and third respectively the forces of elastic resistance and damping caused by the same inertia force.

With the system of Eq. (3) in order to reduce the mathematical record and further mathematical calculations, it is more convenient to operate in the matrix form:

$$M\vec{\ddot{Z}} + M\vec{\ddot{\Delta}} + R\vec{Z} + \beta R\vec{\dot{Z}} = 0 \tag{5}$$

(here: M is the diagonal mass matrix of the system; R is the compliance matrix; Z is the mass displacement vector: Δ is the vector of a given displacement of supports that performs the role of a free member in the system instead of a dynamic force effect. Both the development and the solution of the systems of the resolving equations for such a three-dimensional model, even with synchronous displacements of the supports and even in the elastic-linear formulation, will be extremely complex. First, because even in the case of a single-span building, the number of unknown movements in system (4) can reach from several tens to hundreds, secondly, when calculating single reactions, it is necessary to perform a three-dimensional static calculation of the same scheme for single movements, and finally, in the third the calculation should be performed on the vertical and horizontal displacements of the supports and summed up the results. Therefore, it is more rational to go for an even greater simplification of the design scheme associated with the transformation of the three-dimensional frame structural scheme into separate flat frames and core elements (beams and columns), the calculation of which is further simplified. This assumption is fully justified, since the vibrations are transmitted from the foundation soils to the foundations, and from them through separate structures of the column and wall filling and roofing areas, while wall filling is difficult to attribute to the core structure, but due to the presence of window openings and it can be considered as an extended frame or beam scheme.

It is obvious that the calculation of the columns and, most sensitive to vibrations, the vertical filling should be carried out on horizontal influences, since the rigidity of the latter in the horizontal plane is much less than in the vertical one. A weightless core structure with a discrete mass arrangement along its axis is taken as the design scheme of the column, and the mass location points and their magnitude should be taken taking into account the mass of the wall filling and the foundation beams. The resolving equations should be used in the form (3). The static design scheme of the column is traditionally considered as part of a flat frame and is presented in Fig. 2, on the basis of which it is necessary to find the reactions of the system of Eq. (3) for single displacements. As an external load, when calculating the rack, unit forces applied at the points of application of masses placed on the columns will be used to plot the diagrams of unit moments in the frame for which the coefficients of the system of Eq. (3) are calculated using the Mohr – Vereshchagin integral on the basis of multiplying these diagrams. as their inverse values.

As a result of solving the system of Eq. (3), the amplitudes of displacements of the node masses of the rack are determined, by which the forces of mass inertia are calculated and the magnitude of the dynamic component of the forces acting in the cross sections of the building framework columns are found. Column nodes and adjacent wall filling areas oscillate together, so it is appropriate to assume that previously calculated synchronous dynamic translational deviations of columns in the areas of abutment of wall filling can serve as the initial load for calculating wall filling. Assuming that the wall filling sections above and below the window openings are girder structures that carry concentrated masses of the weight of the wall structure and that have hinged supports at the ends, the design scheme of which can be represented in Fig. 2.

The resolving equations for calculating sections of wall filling for oscillations at synchronous displacements of the supports will take the following for

$$m_n \frac{d^2}{dt^2}(Z_n + \Delta_{st}) + \sum_{k=1}^{n} r_{kn} Z_n + \sum_{k=1}^{n} \beta\, r_{kn} \frac{d}{dt} Z_n = 0 \tag{6}$$

where: Z_n is the displacement of the corresponding node of the beam scheme (see Fig. 2); Δ_{st} is the displacement of the section of the rack in the zone of contiguity of the calculated section of wall filling, obtained as a result of the calculation of the column.

The solution of the equations of motion (5) or (6) can be simplified if we move from the unknown to new group displacements, the shape of which coincides with the natural oscillation patterns of the given system, i.e. to seek a solution in the form of decomposition in its own forms of oscillations.

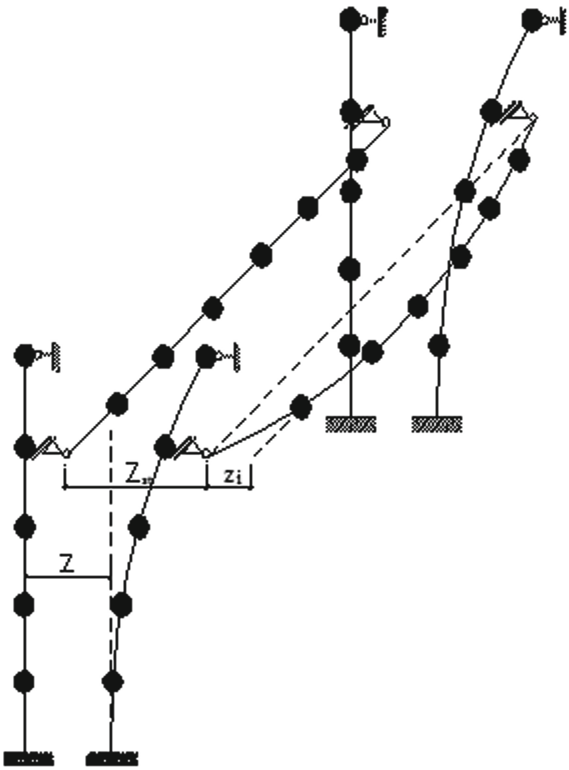

Fig. 2. The design scheme of the column and wall filling

3 Conclusions

Based on the above, the following conclusions can be made: a simplified theoretical method for calculating the problem of oscillations of the bearing and enclosing constructions of buildings and structures (foundations, columns, wall filling and foundation beams) under the influence of the vibrations of the bases propagating in the soil during railway traffic is theoretically justified. The proposed method is based on the division of the constructive scheme into separate core structures, the calculation of which is performed consistently on the dynamic deviations of their supports. The given method of calculating building structures for dynamic displacements of supports from vibration effects during traffic can serve as a theoretical basis for designing and accounting for such effects during the design and construction of transport buildings and structures.

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Transport Management, Intelligent Transport Systems

Assessment of Media-Forming Potential of the Territory in the Implementation of the Lands

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Abstract. The substantiation of the need to assess and predict changes in the medium-forming properties of individual components of the environment, as well as lands, landscapes and territories as regular combinations of a complex of natural and natural-anthropogenic geographical components, carried out in the analysis and planning of the use of natural resources, is given. In the process of developing the territory of the region, its medium-forming potential decreases significantly with the intensive development of the lands of settlements and agricultural purposes. Keywords: land management, land of settlements, agricultural land, land monitoring, medium-forming potential, territory, land.

Keywords: Land management · Lands of settlements · Land monitoring · Environment-forming potential · Territory · Lands

1 Introduction

According to the results of land monitoring, scientists noted a trend towards a decrease in the area of agricultural land and an increase in the land area of settlements and lands under other non-agricultural uses.

Historically, the main accounting elements of state land accounting are land - these are lands that are systematically used or suitable for use for specific economic purposes and differ in natural-historical characteristics. Land is divided into agricultural (arable land, fallow lands, hayfields, pastures, perennial plantings) and non-agricultural (forests, shrubs, swamps, roads, built-up areas, ravines, sands, etc.).

According to A.P. Sizov, in the analysis and planning of nature management, special attention should be paid to the medium-forming potential (MFP) of the territory [1, 2].

This concept is used in the scientific literature for the most part in relation to forest ecosystems with the highest MFP; the mechanism of ecological and economic assessment of the MFP of forest landscapes is described in detail. However, any territorial unit has a medium-forming potential, and it is of particular interest to assess the MFP of the territories of settlements, which can be carried out within the framework of various procedures, in particular, environmental arrangement - because its object is

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the formed natural and anthropogenic human environment and human life, considered as the totality of spatially interdependent and interconnected developing urban ecosystems [3].

The medium-forming potential of the territories in the broad sense is understood as the totality of all natural resources, factors and conditions of the territory that have medium-forming, environment-reproducing and environment-protective properties (including climatic, geological, hydrological, land, soil, etc.). In the process of development and development of the territory, its MFP changes, decreasing with intensive development, but increasing with the implementation of environmental measures (for example, during land reclamation and land reclamation, integrated landscaping, etc.) [4].

We give the formula for calculating the value of the MFP of the territory of settlements according to A.P. Sizov:

$$P^{mfp} = P^{sp} \times \sum\nolimits_{i=1}^{n} (K_i \times S_i) \tag{1}$$

The values of the average specific medium-forming potentials of the territory and the correction factors for the relative value of the land are summarized in Tables 1 and 2.

Table 1. Averaged specific medium-forming potentials of the territory (p^{sp})

The confinement of settlements to forest zones (The list of forest growing zones and forest regions of the Russian Federation was approved by order of the Ministry of Natural Resources of Russia dated August 18, 2014 No. 367)	p^{sp}, point/m^2
Zone of near-tundra forests and rare taiga	900
Taiga zone	500
Coniferous-deciduous forest zone	400
Forest-steppe zone	500
Steppe zone	600
Semi-desert and desert zone	550
Mountainous North Caucasus Zone	700
South Siberian mountain zone	700

Table 2. Correction factors for the relative value of the land K_i

Land	Agricultural grounds	Forest land	Forest plantations not included in the forest fund	Under the water	Building land	Under the roads	Swamps	Disturbed lands	Other lands
K_i	1.6	1.5	1.5	1.8	1.3	1	1.8	1	1

2 Study Areas and Analyses

The Tyumen region occupies most of the West Siberian Plain and actually divides the territory of Russia into two large parts: to the west - the Urals and the European part of the country, to the east - Siberia and the Far East.

The nature of the Tyumen land is rich and diverse. Various climatic zones are found here: taiga in the northern part, forest-steppe and steppe in the south. The vastness of the Tyumen region is due to the presence of several geographical zones, characterized by a variety of climatic and biomedical conditions. Each landscape (geographic) zone is characterized by its own soil and vegetation types.

But they have one thing in common: the widespread distribution of bog soils, on which bog vegetation forms [5].

In general, the climate of the region is typically continental, with short cool in the north and warm in the south in summer and severe, long, with strong winds in winter, late spring and early autumn frosts. The large extent of the territory from north to south is the reason for the pronounced zonality in the distribution of heat and moisture.

On the territory of the Tyumen region there are 1236 settlements, including 4 cities of regional subordination - Tyumen, Tobolsk, Ishim and Yalutorovsk, as well as the city of Zavodoukovsk.

The calculation formula was tested when calculating the MFP of the territory of the Tyumen region for two dates: as of 01.01.2011 and 01.01.2018. The source information is taken in open sources. As a specific medium-forming potential for the territory of the Tyumen region accepted 500 points/m^2.

The results of the calculation of the MFP are shown in Table 1.

Despite the fact that for more than 20 years in the Tyumen region, agricultural enterprises cultivated only arable land, where it is possible to get high yields without unnecessary costs, now there is a tendency to increase sown areas and the use of other agricultural land.

An analysis of the dynamics of the use of the region’s land fund (Fig. 1) shows that the area of agricultural land used in commodity production is beginning, albeit slightly, to increase.

The increased interest in the use of agricultural land is explained by the long-term target program “The main directions of the development of the agricultural complex for 2013–2020” implemented by the Department of agro-industrial complex of the Tyumen region.

From the calculated data it can be seen that the Tyumen region is a territory with a stable balance (like any large territory), therefore, the calculation of the MFP to assess its dynamics over a period of 5–15 years was not informative.

For a more detailed study and comparability of indicators of the medium-forming potential of the territory of the Tyumen region, it is proposed to calculate the specific medium-forming potential of the region, where the most significant changes in the balance of land occurred during the land reform.

During the land reform, issues of land conservation and increasing the efficiency of their use were not resolved [6].

Table 3. The distribution of land of the Tyumen region by land and the value of their environment-forming potential

Territory	As of	Total area	Agricultural land	Forest land	Forest plantations not included in the forest fund	Under the water	Building land	Under the roads	Swamps	Disturbed lands	Other lands	Total medium-forming potential, billion points	Specific medium-forming potential, point/m^2
Tyumen region	01.01.2011	16012.2	3383.5	7112.8	145	508.4	79.3	95.8	4609.2	4.6	73.6	1289.4	641.2
Tyumen region	01.01.2018	16012.2	3381.9	7112.8	144.9	508.5	80	96.1	4609.1	4.6	74.3	1289.4	638.9

Today, in the Tyumen region, large areas of agricultural land are overgrown with shrubs and small forests, swamped, eroded, devastated and degraded.

The following quantitative changes have taken place in the structure of the land fund of the region on agricultural lands.

The total area of agricultural land in the region as of 01.01.2018 is 3381.9 thousand ha (Table 3).

Most of the agricultural land - 2920.8 thousand hectares - is located in agricultural lands. In the category of reserve lands, the area of these lands is 256.5 thousand ha, in the forest fund - 111 thousand ha, in the lands of settlements – 91.2 thousand ha, in the lands of industry and other special purposes - 2 thousand ha; in specially protected areas – 0.4 thousand ha (Fig. 1).

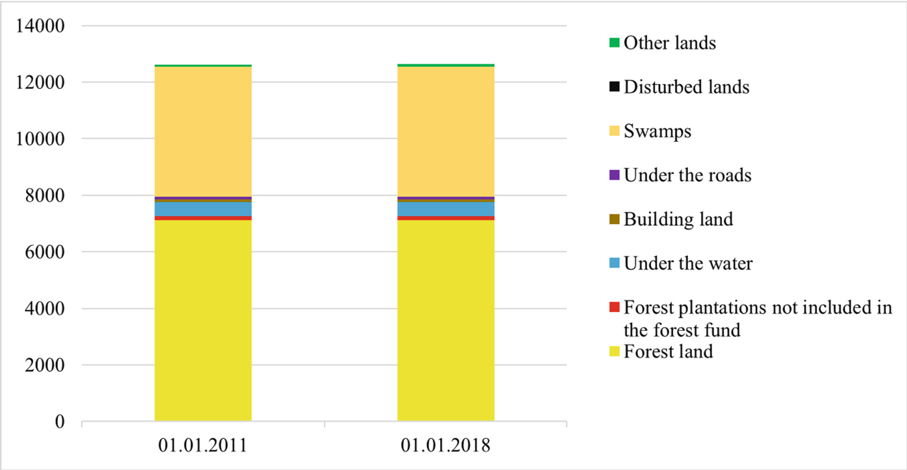

Fig. 1. The distribution of land of the Tyumen region by land, thousand hectare

The area of arable land used in 2017 in the Tyumen region decreased by almost 17.5 thousand hectares, mainly due to the transformation into a deposit in the Omutinsky, Golyshmanovsky and Nizhnetavdinsky districts. At the same time, arable land (1353 thousand ha) accounts for only 8.4% of the territory of the region and 40% of the area of farmland [7].

Fodder lands of the Tyumen region in 2017 increased 1.4 thousand hectares due to transformation from arable land in the Nizhnetavdinsky district, and as of 01.01.2018 their area amounted to 1652.5 thousand ha.

As a result of the lack of funding, the restoration of productive land, the restoration of disturbed lands, and land reclamation were practically stopped.

Land monitoring notes a tendency towards a decrease in the area of agricultural land and an increase in the land area of settlements and lands for other non-agricultural uses.

Significant structural changes have occurred in the land fund of the region over the past 20 years. In the process of redistribution of land area of settlements, increased due to the land of agricultural enterprises (Table 4) [8].

Most of the region's territory (64.1%) is occupied by forest land, agricultural land makes up 28.5%, settlements land – 1.32%, industrial land, energy, transport, communications, broadcasting, television, computer science, land for provision of space activities, land of defense, security and land of other special purposes – 0.4%, land of the water fund – 2.98%, reserve land – 2.69%, land of specially protected territories and objects – 0.01% (Fig. 2).

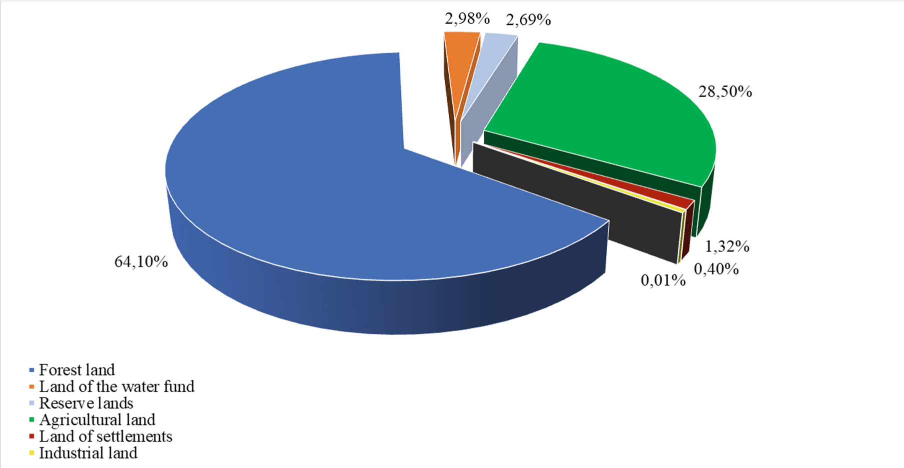

Fig. 2. Distribution of the land fund of the region by land categories as of 01.01.2018

Lands of settlements include lands used and intended for development and development of settlements. The boundaries of urban and rural settlements separate the lands of settlements from lands of other categories.

Table 4. The dynamics of the distribution of the land fund of the region in two categories of land

Name of land categories (thousand ha)	1990	2009	2010	2014	2015	2017
Agricultural land	5991.3	4549.9	4540	4547	4546.5	4565.1
Land settlements	89.9	204.1	215.1	215.2	215.5	215.8

As of 01.01.2018, the land area of settlements of the Tyumen region amounted to 215.8 thousand hectares. As a result of clarifying the boundaries of the settlement of Ishim, 0.1 thousand hectares of agricultural land were included in the city limits, mainly gardens, and 0.1 thousand hectares from industrial lands.

The land area of urban districts amounted to 81.7 thousand ha, the area of rural settlements – 134.1 thousand ha [9].

In recent years, the land fund of the region has undergone significant structural changes. In the process of redistribution of the land area of settlements, lands of the forest fund, lands of the water fund and lands of the reserve increased due to the lands of agricultural enterprises (Fig. 3).

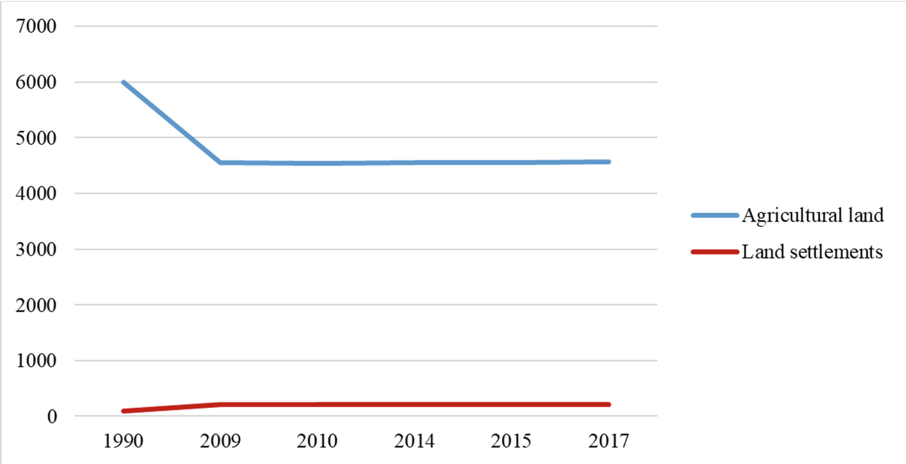

Fig. 3. The dynamics of the distribution of the land fund of the Tyumen region for the studied land categories

3 Results

As an evidence base for the trend of decreasing agricultural land, the authors propose to analyze the retrospective of the indicator of the medium-forming potential of the territory of the Tyumen region (Tables 5 and 6).

Table 5. Distribution of land of settlements and agricultural land of the Tyumen region and the value of their environment-forming potential (for 1990)

Land category	Area total thousand hectares	Total medium-forming potential, billion points	Specific medium-forming potential, point/m^2
Land settlements	89.8	583.7	650
Agricultural land	5991.3	47930.4	800

Table 6. Distribution of land of settlements and agricultural land of the Tyumen region and the value of their environment-forming potential (for the period from 2009–2017)

Land category	Area total thousand hectares	Total medium-forming potential, billion points	Specific medium-forming potential, point/m^2
Land settlements	1155.6	6927.7	599.5
Agricultural land	28739.8	181988.0	633.2

Thus, from the TFP calculations it is seen that in the process of development and development of the territory of the region, its MFP has changed significantly, decreasing during the intensive development of the lands of settlements.

To increase the environment-forming potential of agricultural lands, intensive environmental protection measures are necessary (for example, land reclamation and land reclamation, integrated landscaping, etc.).

Table 7. Distribution of land of settlements and agricultural land of the Tyumen region and the value of their environment-forming potential (for the period from 2009–2017)

Land category	Area total thousand hectares	Total medium-forming potential, billion points	Specific medium-forming potential, point/m2
Land settlements	1155.6	6927.7	500.3
Agricultural land	28739.8	181988.0	510.4

The object of the analysis of the efficiency of agricultural land use was the Malkovskoye municipal entity (hereinafter referred to as Malkovskoye municipal district) in the Tyumen municipal district, as well as the agricultural enterprise Malkovskoye Joint-Stock Company, which is located in the Tyumen Region, the village of Malkovo.

If you look at the trend of the change in the indicator of the medium-forming potential of the territory of the region as a whole, the district and the municipality, then the fact of a decrease in the above indicator is confirmed (Fig. 4).

As a local territory, we consider the company Malkovskoye Joint-Stock Company, the successor to the Malkovsky farm, founded in 1968.

According to its geographical location, the company is located in the suburbs of Tyumen, which ensures quick delivery of products. The condition of the road network of the economy is satisfactory and provides communication with points of delivery and sale of products. The Malkovskoye joint-stock company is distinguished by a high yield of grain, potatoes, cabbage, beets and carrots, which allows this agricultural enterprise to make a profit. The management structure of the joint-stock company "Malkovskoye" is an ordered set of relations between the links and employees engaged in solving production problems.

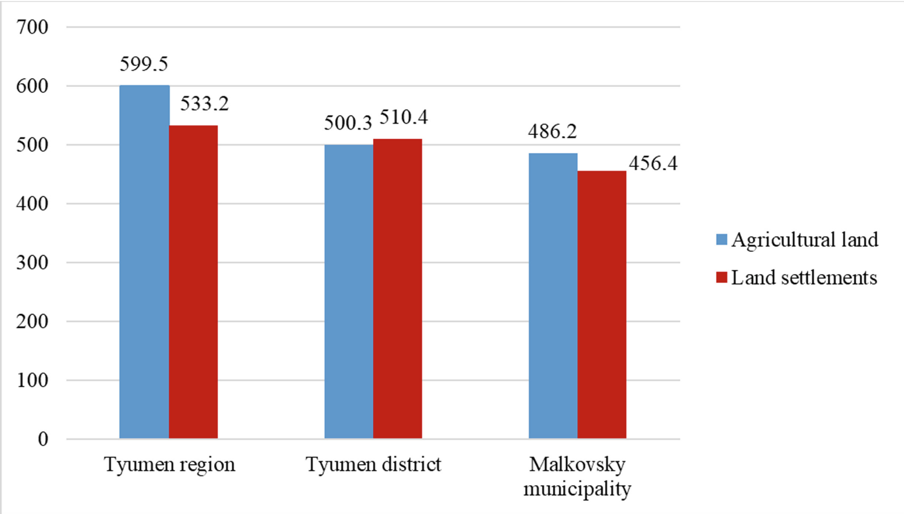

Fig. 4. Diagram of the change in the indicator of the medium-forming potential of the territory of the Tyumen region

The total agricultural land area of the enterprise of the Malkovskoye joint-stock company for 2018 is 650 hectares; the enterprise leases land plots from individuals. Land plots of the Malkovskoye joint-stock company are presented in Fig. 5.

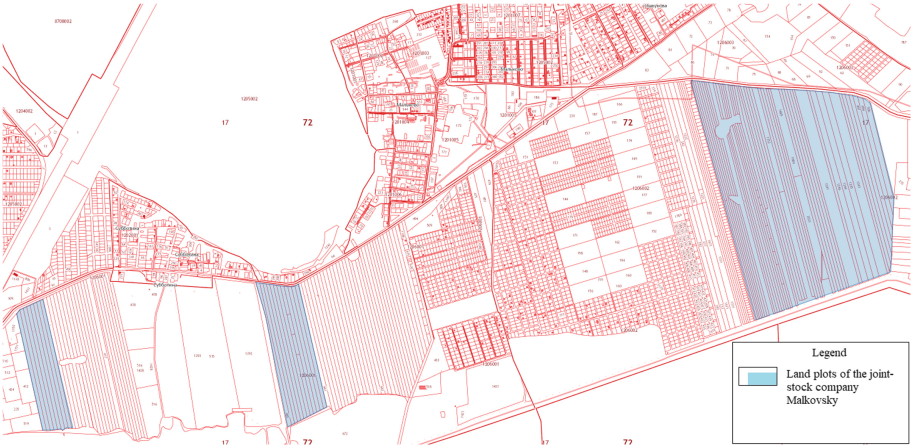

Fig. 5. The boundaries of the land plots of the joint-stock company "Malkovskoe"

This company plays a leading role in the agricultural industry and makes a significant contribution to the economy of the region. Currently, the population of the Malkovsky municipality is 2559 people, most of whom are engaged in the activities of the enterprise under study, therefore the effectiveness of this production is very important for the region and for the residents themselves.

The total area of the enterprise (ha) is presented in Table 8.

Table 8. The total land area of the joint-stock company "Malkovskoe"

Indicators	2014 г.	2015 г.	2016 г.	2017 г.	2018 г.
Total land area, ha	928	928	928	760	650
including: farmland	928	928	928	760	650
arable land	845	845	845	760	650
hayfields	83	83	83	–	–

Most of the agricultural land is arable land. This is due to the fact that the joint-stock company Malkovskoye specializes in the production of crop products.

As can be seen from Table 7, it is obvious a decrease in the total land area, including agricultural land in the joint-stock company Malkovskoye.

Table 8 presents the calculation of the indicator of the medium-forming potential of agricultural land of the Malkovskoye joint-stock company (Table 9).

Table 9. Distribution of agricultural land of the Malkovskoye joint-stock company and the value of their environment-forming potential (for the period from 2009–2017)

Land category	Area total thousand hectares	Total medium-forming potential, billion points	Specific medium-forming potential, point/m2
Agricultural land	650	18188.0	435.9

4 Discussion

Despite the efficient use of land and the stability of the economic indicators of the enterprise's products, the "shareholders", as owners of the land plots, pursue a policy of putting up land plots for sale - this is due to the desire to receive more benefits than for the lease provided by the Malkovskoye joint-stock company. The market value of the land plot is higher than the rental cost, but due to the high payment, these land plots remain in a downtime, the condition of the land for the introduction of agricultural production worsens.

The current trend leads to inefficient use of land. At the moment, the solution to the problem is to negotiate with the "shareholders" (equity holders) on the entry into the authorized capital of the company Malkovskoye joint stock company, the conclusion of long-term lease agreements.

At the level of a rural settlement, it is possible to solve local problems of land conservation and use independently, in a complete, comprehensive and reasonable way, in the interests of not only living people, but also future generations.

To date, in municipalities there is no developed and approved municipal program for the protection of unused land, which would be aimed at creating favorable conditions for the use and protection of land, ensuring the implementation of the state policy for the efficient and rational use and management of land resources in the interest of strengthening the economy of the rural settlement.

In our opinion, it is necessary to develop the Municipal Program "Protection of agricultural land in the territory of the municipal formation of the Malkovskoye Tyumen region for 2019–2021."

The objective of such a program would be to increase soil fertility, optimize soil formation processes, and create conditions for the conservation of biological diversity.

Program activities will be financed from the budget of the Malkovsky municipality. The total funding for the Program in 2019–2021 is 200 thousand rubles.

Activities for the implementation of the Program for subprograms, years, volumes and sources of financing are given in Table 10.

The volume of budgetary funds are predictive in nature and are subject to annual refinement in the prescribed manner when forming the corresponding budgets.

The monitoring of the implementation of the Program will be carried out by the Administration of the Malkovskoye municipal formation.

Table 10. System of land conservation program measures on the territory of the municipality Malkovskoye

Consecutive number	Name of event	Performers	Timing	The amount of financial resources from the budget of the Malkovsky rural settlement, thousand rubles			
				2019 year	2020 year	2021 year	Total
1	Control over the use of agricultural land in accordance with the intended purpose	Administration of the municipality Malkovskoye	2019–2021 year	0	0	0	0
2	Monitoring the legality of the grounds for the use of agricultural land in the territory of a settlement			0	0	0	0
3	Identification of unused agricultural land in the territory of the settlement			0	0	0	0
4	Identification of factors of unauthorized occupation of agricultural land			0	0	0	0
5	Identification of agricultural land use factors leading to a significant environmental degradation			0	0	0	0
6	Identification of factors of poisoning, pollution, damage or destruction of the fertile soil layer of agricultural land			100	50	50	200

5 Conclusions

As a result of the implementation of the Program activities, it will be ensured:

– improvement of land quality characteristics;
– efficient use of land;
– protection and restoration of land fertility;
– protection of agricultural land from wind and water erosion, waterlogging, waterlogging, desiccation, overgrowing by trees and shrubs, weeds, from pests, from pollution and littering of industrial and consumption waste.

Irrational use of land, consumer and mismanagement towards it lead to disruption of its functions, a decrease in natural properties. Land protection can only be effective when rational land use is ensured.

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Urban Transport and Logistics Infrastructure as an Element of Economic Security in the Region

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Abstract. The paper discusses the main problems and areas of improvement of the transport and logistics infrastructure of the city of Moscow, in order to increase the economic security of the region and increase its socio-economic development. The aim of the study was to assess the level of development of the transport and logistics system of the city of Moscow, as an element of the economic security of the region to identify ways to form new transport routes that ensure comfortable movement of citizens in the directions they need. To achieve this goal, it was necessary to conduct a sociological research with the use of various tools to identify problem areas in the urban transport and logistics infrastructure. In the framework of the study, the following research methods were used: expert estimates, analytical methods, a comparison method, statistical and quantitative methods, as well as questionnaire methods. As a result of the study, project ways to solve the identified problems of the development of the transport and logistics infrastructure in the region proposed, aimed at improving the efficiency, effectiveness and economic security of the transport and logistics system in Moscow. The possibility of implementing transport and logistics projects on the territory of Moscow will reduce the negative impact of various environmental factors related to the problems of the transport and logistics system. Keyword. transport and logistics infrastructure, economic security of the region, transportation, social survey, competitiveness of manufacturing enterprises, monitoring of public portals, urban routes, business environment.

Keywords: Transport and logistics infrastructure · Economic security of the region · Transportation · Social survey · Competitiveness of manufacturing enterprises · Monitoring of public portals · Urban routes · Business environment

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1 Introduction

At present, the pace of life of a society is so high and dynamic that people have a need for a large number of different routes that urban transport would take in a constant mode. First, it is connect with the active construction of new buildings, residential complexes, as well as production facilities [1–4].

The level of development of transport infrastructure has a significant impact on the state of the economy and society as a whole, and also increases the level of economic security of the region [5–8].

According to the results of a comparative statistical cross-country analysis, a significant relationship was found between the level of development of transport infrastructure and GDP per capita - as one of the most representative indicators of socio-economic development [4, 5], which contributes to the economic security of the region.

The development of the transport and logistics infrastructure of the city is directly related to the level of socio-economic development of the city, which can ultimately ensure the development of the business environment, increase the quality of life of the population, increase the competitiveness of industrial enterprises and increase the economic security of the region as a whole [3, 6, 9]. It should also be note that the achievement of target indicators of the strategy for the development of transport infrastructure is impossible without the formation and development of its new facilities and the solution of a number of other problems that may hinder its improvement [10–14].

According to the results of an entrepreneurial assessment of the development of transport infrastructure, it was reveal that the development of road infrastructure is moving more extensively, and its quality level and safety is still low and leaves much to be desired [15–19].

The level of development of the transport and logistics infrastructure of the city is directly related to the socio-economic development of the city [8], which can ultimately ensure the development of the business environment, increase the quality of life of the population, increase the competitiveness of manufacturing enterprises and increase the economic security of the region as a whole [21, 22].

Especially important in the development of transportation in the Russian Federation is to increase the speed of transport communication [9], given the large size, the territory of Moscow, which are constantly expanding.

The transport sector is a vital artery that ensures the economic security of each individual region and the state as a whole, as it ensures the viability and interaction of participants in all business processes and business structures [4, 5, 10, 11]. Ensuring the economic security of the region and its stable functioning, especially development is impossible without the effective functioning of the transport system. Improving the transport and logistics infrastructure will contribute to improving economic security and economic growth in the region [15, 18, 26].

2 Study Methodology

The development of the theory and practice of the transport and logistics infrastructure is devoted to the work of such authors as Ballis, J. Golias, Bilegan, I. C., Kakhrimanova D.G., P.V. Kurenkov, B.M. Lapidus, D.A. Macheret, O. D. Pokrovskaya, V.A. Persianov, A.V. Ryshkov, Thor-Erik Sandberg Hanssen, N.P. Tereshina. Many works are devoted to the issues of development and ensuring economic security, including the works of the following scientists: V. Kossov, M. Crui, D. Galai, R. Mark, B. Flivborg, Rotengatter, N. Kapustina, R. Fedosova, Z. Mehokh, Yu. Sokolov, Ivan Burcar Dunović, Rafaela Alfalla-Luque, Robert W. Poole, Jr. and Peter Samuel.

The development of urban transport and logistics infrastructure must necessarily be carried out in accordance with the principle of consumer orientation and meet the needs of the population in the urban transport and logistics infrastructure to the maximum [7, 8, 14, 23].

For this reason, the purpose of the study is to assess the level of development of the transport and logistics system of the city of Moscow, as an element of the economic security of the region, and to identify ways to form new transport routes ensuring comfortable movement of citizens in the directions they need.

In the process of research, the following research methods used: expert assessments, computational and analytical methods, comparison method, statistical and quantitative methods, and questionnaire methods [22, 26].

The study conducted in the following steps:

1. Identification of potentially interested social groups.
2. Monitoring of public portals to identify problem areas in the transport and logistics urban routes of Moscow.
3. Development of a socially oriented questionnaire for ranking social groups and identifying problem areas in the transport and logistics city routes of Moscow.
4. Conducting a social survey of the population using the developed questionnaire.
5. Identification of problem areas, based on the results obtained from social surveys.
6. Development of measures for the development of transport infrastructure in the identified problem areas.

The hypothesis of the study is that the main problem of the transport and logistics system of the city of Moscow are transport and logistics routes in new residential and industrial areas of the city.

3 Assessment and Results

Potential stakeholders in the development of transport infrastructure are the population of the city of Moscow and the Moscow region, as well as guests of the capital. The main users of the transport infrastructure are the working population, including students and schoolchildren.

Monitoring of public portals to identify problem areas in transport and logistics urban routes in Moscow suggested that the most problematic are transport and logistics routes in new residential and industrial areas of the city.

The developed socially-oriented questionnaire for ranking social groups and identifying problem areas in transport and logistics city routes in Moscow contains questions regarding the preferred mode of transport, reasons for using transport and logistics city routes, the frequency of using city transport, and ways to pay for transport services.

Citizens of different age groups from 16 to 63 years attended the survey (Fig. 1). All of them are active and able-bodied population.

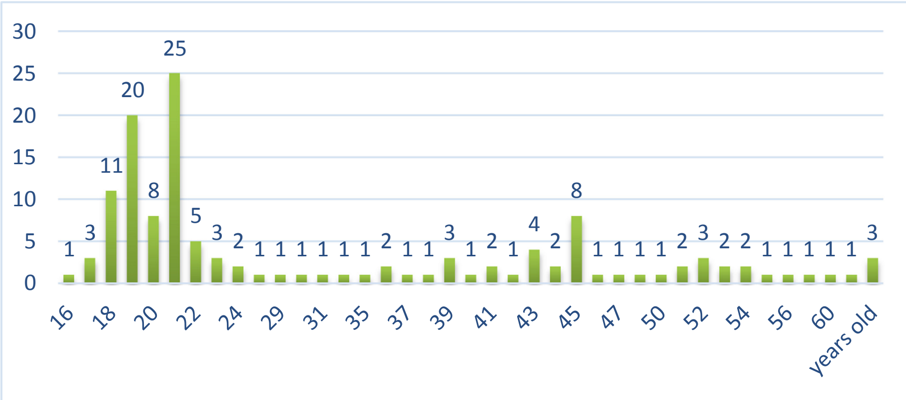

Fig. 1. Age groups of citizens who took part in a social survey.

Having studied the age structure of Moscow residents who took part in a social survey to assess the development of transport and logistics infrastructure, it is worth noting that more than 50% of the participants are people under the age of 22 years. The remaining 46.1% are people aged 22 to 63 years.

The most preferred mode of transport for the population of Moscow was the metro. It used by 55.7% of respondents. In second place is a bus - 37.4%, and in third place is personal transport. Personal transport used by 35.9% of respondents (Fig. 2).

Having considered the reasons for using the urban transport and logistics infrastructure, it is worth noting that the respondents use transport for various purposes. So, for travel to the place of study, transport and logistics routes used by 56.8% of respondents, 50.8% of respondents use public transport in order to travel to the place of work. Some respondents use urban transport routes in order to get to the place of walking - 25.8% (Fig. 3).

Residents of all districts of Moscow took part in the survey; the structure of participants by districts of Moscow is present in Table 1.

The survey was attend by residents of all districts of Moscow. After examining the structure of the respondents in the district of residence, it is worth noting that the residents of the Southern District had the greatest interest in the survey, the Western District ranked second, and the Moscow Region had the least interest. The reason for the least interest of citizens of the Central District of Moscow to the survey being conduct to

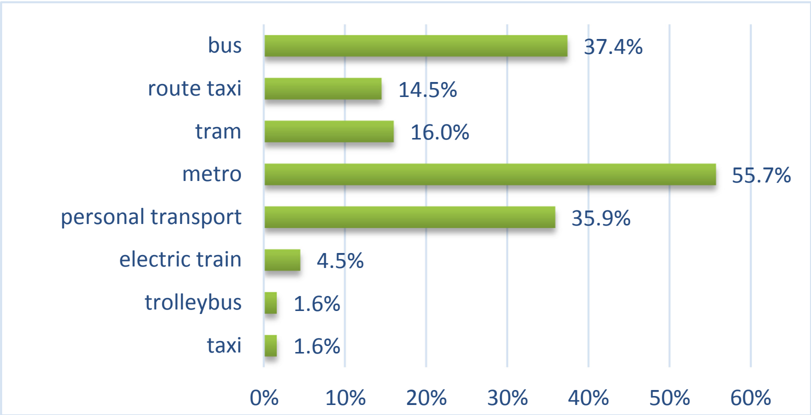

Fig. 2. Most preferred mode of transport

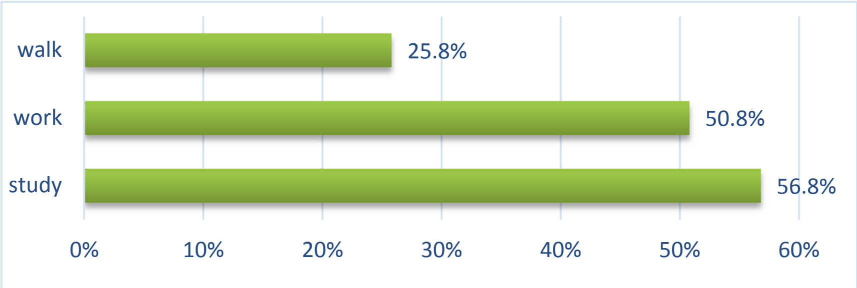

Fig. 3. Reasons for using urban transport and logistics infrastructure

Table 1. Structure of respondents in districts of Moscow

District of Moscow	Share of survey participants, %
South	30.1
West	17.3
East	18.0
North	21.1
Central	13.5
Total	100.0

assess the level of development of the city's transport system is most likely the high level of development of the transport and logistics infrastructure of this district.

To the question of satisfaction of the population with the transport and logistics system of Moscow, 63.2% of respondents answered that they were satisfied with the transport and logistics infrastructure of the region, and 36.8% answered that they were not satisfied with the work of the city transport and logistics system.

Currently, due to the growing level of digitalization of the economic sector and the increasing role of computer technologies in transport, the development of various forms of payment in order to improve the quality of service, which allows us to speed up and optimize business processes in transport, a survey has been conduct on the subject of preferred forms of payment for transport [17, 25].

The results of a survey assessing the preferred forms of payment for travel on public transport are present in Fig. 4 in the form of a diagram.

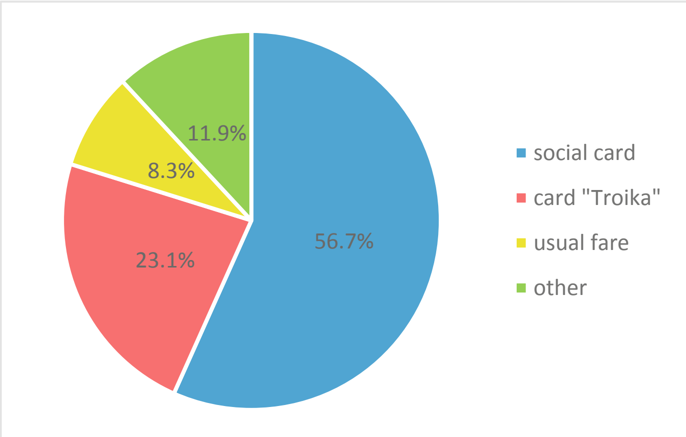

Fig. 4. Preferred forms of payment for public transportation in Moscow

Based on the survey on the preferred form of payment, it found that the majority of respondents pay for travel on the social card. Students, pensioners, large families, etc. use social cards in Moscow. Since more than 50% of respondents are people under the age of 22, respectively, they are students and pay the fare by social card.

It is also worth noting that 68% of women and 32% of men respectively took part in the survey.

With the help of the conducted sociological research, a problem identified related to the underdeveloped transport system of urban transport in the areas of construction of new residential complexes and production facilities, which confirmed the hypothesis put forward by the study. People living in these complexes, complaining about the fact that it becomes difficult to get to a place of work, study or recreation without the presence of personal transport. The use of personal transport is also difficult due to the heavy traffic arteries in the metropolis. According to a sociological survey, 60% of respondents are not satisfied with the existing transport network. In order to level a wave of discontent, a project should be launch, aimed at developing optimal urban transport routes that will connect new residential complexes with the city's infrastructure.

The objectives of the proposed project are: the creation of new suburban routes in Moscow for the smooth operation of transport, improving the efficiency of transport infrastructure use and improving the performance indicators of transport infrastructure use. The final product of the project expected to form new transport routes, providing comfortable movement of citizens in the directions they need.

The urgency of this project will consist in the fact that in its implementation the mobility of the population will increase. According to the survey, about 80% of respondents are people of working age, as a result, the construction of new routes will contribute to the influx of new labor resources and the activation of those already involved, by reducing the time spent on the way and increase comfort. The main advantage of this project is its flexibility, namely when attracting investors, it is possible to simulate routing based on the location of commercial organizations interested in construction. The enlarged project work plan includes the development of the concept of transport systems, the identification of potentially interested structures, the algorithm for creating transport routes and the launch of the project.

The main idea of the project is, first, to lay new routes when designing new buildings and they will connect these buildings with the infrastructure of the city. It is also necessary in the shortest time to the already existing residential complexes to carry out optimal transport routes.

A brief description of the project to improve the urban transport and logistics infrastructure, its objectives and product are present in Table 2.

Table 2. Description of the project to improve the urban transport and logistics infrastructure

The project name	Improving urban transport and logistics infrastructure
The problem that the project aims to solve	Lack of (optimal) transport routes to new residential complexes and production facilities
Project goals	Creating new routes in the suburbs of Moscow for the smooth operation of transport Improving the efficiency of use of transport infrastructure Improving the efficiency of transport infrastructure use
Improving the efficiency of use of transport infrastructure	New transport routes, providing comfortable movement of citizens in the directions they need

In order to improve the implementation of the project to improve the transport and logistics infrastructure of Moscow, it is also worth increasing attention to attracting and encouraging private investment in the construction and reconstruction of transport infrastructure facilities.

4 Conclusions

As a result of the study, it was revealed that potentially interested parties in the development of transport infrastructure are the population of the city of Moscow and the Moscow region, as well as guests of the capital. The main users of the transport infrastructure are the working population, including students and schoolchildren.

Monitoring of public portals to identify problem areas in transport and logistics urban routes in Moscow suggested that the most problematic are transport and logistics routes in new residential and industrial areas of the city.

The developed socially-oriented questionnaire for ranking social groups and identifying problem areas in the transport and logistics city routes in Moscow allowed determining the type of preferred transport, the reasons for using transport and logistics city routes, the frequency of using urban transport, and the preferred methods of payment for transport services.

The study made it possible to identify current problems of the transport and logistics infrastructure of the city of Moscow, as the main element of the economic security of the region, and to identify ways to develop city logistics. With the successful implementation of the proposed ways to solve problems associated with the movement of people from new areas to the city and back will be eliminate. Because of these activities will increase passenger traffic on the plying transport lines. This will give a positive response for the city's logistics in general, which will be effective for the entire infrastructure of the city and suburban routes.

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Comparative Risk Analysis of Using the Markings for Ground and Raised Pedestrian Crossings

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Abstract. The quality of road construction and ensuring road safety is one of the most important tasks today. One of the tools for solving this problem is risk-oriented approach. For the first time, the authors presented a comparative analysis of using the markings for ground and raised pedestrian crossings, taking into account the permissible risk of a breakdown of the car's chassis and the value of the permissible risk of deterioration in the conditions of the driver and passengers when the car is moving along the indicated crossings with permissible speeds. From the results obtained above it follows that the use of the ground pedestrian crossing with an average marking line height of 6.0 mm, a weighted average marking line length from 4.0 m to 6.0 m, and a car speed at the crossing of 60 km/h (as regulated by road traffic code in the city limit) is considered permissible. The risk of breakdown of the car's chassis at the speeds indicated in Russian State Standard GOST R 52605-2006 may remain acceptable (1×10^{-3}) if the weighted average length of the raised pedestrian crossing also increases. Such pedestrian crossings are acceptable, for example, in large metropolitan areas.

Keywords: Pedestrian crossings · Markings for ground · Quality of road construction · Road construction · Road safety

1 Introduction

Marking holds a special place among the technical means of traffic organization. Its main difference is the duration of presence in the driver's viewing area. This feature allows using marking not only to control traffic flows, but also to regulate other road users. Marking lines, depending on the type, color and location, have different semantic meanings, can be used both independently and in combination with traffic lights, road signs in order to regulate the movement of vehicles and pedestrians [1–7].

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Marking lines should be clearly distinguishable both day and night. They should have high wear resistance, durability, fairly rough surface, and high light resistance during rain and snowfall.

It is obvious that the problems of pedestrians cannot be resolved separately from transport problems in general, but the approach to solving them should be based on the equality of the rights of road users - both drivers and pedestrians for safe and, if possible, comfortable movement on roads and city streets. Compromises are often necessary, but when proposing a solution to a problem, one must remember that human life and health should always be at the top of the priorities [8–16].

In the paper, we consider two types of the pedestrian crossing marking.

1. Ground pedestrian crossing marked with its road signs "Pedestrian crossing" according to Russian State Standard GOST 32945 and (or) horizontal road marking according to Russian State Standard GOST 32953 "Zebra".
2. Raised pedestrian crossing - type of technical means of traffic organization, which is a structure in the form of an elevation on the carriageway, installed or arranged on the carriageway with the aim of forcibly limiting the speed of vehicles established by road signs or traffic rules of the member states of the Eurasian Economic Union. (P 3.12 GOST 32944-2014 Public roads. Pedestrian crossings. Classification. General requirements) (see. Figs. 1 and 2).

In Moscow, the installation of such raised pedestrian crossings made of rubber plates has started. It is believed that drivers are more likely to slow down when they approach such crossing that allows pedestrians to feel safer. However, at what speed is it possible to drive cars along this raised pedestrian crossing and not get damaged chassis, as well as ensuring a comfortable condition for drivers and passengers?

Fig. 1. Raised pedestrian crossing in Moscow (a)

Fig. 2. Raised pedestrian crossing in Moscow (b)

2 Research Methods

Tolerances for these parameters of raised pedestrian crossings can be determined by the value of the allowable risk of damage to the chassis of the car and the value of the allowable risk of deterioration of the condition of the driver and passengers when the car is moving at a permissible speed that is set immediately before this crossing. From the standpoint of risk theory, that means the following:

– the permissible probability (permissible risk) of a breakdown of the car's chassis when passing through a raised pedestrian crossing should not exceed one accident out of 10,000 cases of vehicles moving along a crossing at a permissible speed;
– the admissible probability (permissible risk) of an accident due to a deterioration in the driver's condition due to dangerous vibrations and vehicle vibration should not exceed one accident out of 10,000 cases of vehicles moving along a crossing at a permissible speed.

Nowadays, due to the beginning of the introduction of a risk-oriented approach, including in the road industry, probabilistic and theoretical approach to assessing technical and environmental risk, developed by the scientific school of Professor Stolyarov V.V., has gained relevance and significance. It is based on the probabilistic nature of the studied parameters, as applied to road facilities [1–6].

In this paper, we consider the effects of the marking of the ground pedestrian crossing (1.14.1 and 1.14.2) and raised pedestrian crossing on the condition of the driver and passenger when passing through it by means of risk assessment of damage to the car's chassis, and the deterioration of the condition of the driver and passengers due to imperfections of pedestrian crossing parameters.

Let us determine the risk of the parameters of the ground pedestrian crossing (1.14.1 and 1.14.2) and raised pedestrian crossing normalized in the current Russian State Standards GOST and SP.

3 Research Results

1. The risk of the parameters of the ground pedestrian crossing normalized in the current Russian State Standards GOST and SP (1.14.1 and 1.14.2).

Note that the ground pedestrian crossing, as a horizontal marking, should not protrude more than 6 mm above the surface on which it is applied, including the height of the marking ledges with a profile surface and in the case of applying a new horizontal marking on top of the old one (P 5.1.7 GOST 32953-2014 INTERSTATE STANDARD Public roads ROAD MARKING Technical requirements).

Therefore, in order to determine the risk of the parameters of the ground pedestrian crossing (1.14.1 and 1.14.2) normalized in the current Russian State Standards GOST and SP in accordance with the three-level system of technical regulation: the actual parameters of the ground pedestrian crossing are measured; the measured parameters are compared with the normalized parameters of the crossing, and the procedure for assessing the normalized risk of an accident at a permissible speed of the vehicle at the equipped ground pedestrian crossing is performed using the formula

$$r = 0,5 - \Phi\left(\frac{\ell g\ (h_{CR}/h_0)}{\sqrt{\ell g^2 m_{CR} + \ell g^2 m_0}}\right) \tag{1}$$

where

h_{CR} – critical height of the marking line of the ground pedestrian crossing, at the appearance of which the risk of breakdown of the car's chassis at the estimated speed is 50% ($r = 0.5$), mm;

h_0 – modal height of the measured marking lines, mm;

m_{CR} – distribution parameter of the critical heights of the marking lines, mm;

m_0– distribution parameter of the actual heights of the marking lines, mm.

The estimated parameters of the formula (1) are determined by the dependencies:

$$h_{cr} = 1620 \cdot g \cdot \left(\frac{K_{st} \cdot \ell_{w.a.}}{V_p}\right)^2 \tag{2}$$

$$h_0 = 10^{\lg h_{av} - \lg^2 \sigma_h} \tag{3}$$

$$m_{cr} = 10^{1 - \frac{\lg V_p^2}{5}} \tag{4}$$

$$m_0 = 1 + \lg^2 \sigma_h \tag{5}$$

In formulas (2)–(5):

h_{cr} - the height of the marking line of the ground pedestrian crossing, which is critical for the permissible speed (V), mm;

g - gravitational acceleration, m/s^2;

K_{st} - coefficient taking into account the stiffness of the springs, pneumatics and shock absorbers. Assumed that $K_{st} = 0.9$;

$\ell_{w.a.}$ - weighted average along the track marking line length, m;

V_p - the permissible speed on a given surface, at which a check (assessment) of the risk of breakdown of the car's chassis is made, km/h;

h_{av} - the average heights of the marking lines, mm;

σ_h - the standard deviation of the heights of the marking lines, mm.

In our case, the ground pedestrian crossing (1.14.1 and 1.14.2) has the following parameters: the average height of the marking line is 6.0 mm (see above), the parameter $\sigma_h = 6.00 \times 0.05 = 0.3$ mm, the weighted average length of the marking line is considered from 4.0 m to 6.0 m. The permissible car speed at the equipped ground pedestrian crossing in accordance with the road traffic code (city limit) is 60 km/h.

The risk calculation of the parameters of the ground pedestrian crossing (1.14.1 and 1.14.2) normalized in the current Russian State Standards GOST and SP are presented in Table 1.

Table 1. The risk of the parameters of the ground pedestrian crossing (1.14.1 and 1.14.2) normalized in the current Russian State Standards GOST and SP

K_{st}	l_{wa}, m	V, km/h	h_{av}, mm	σ_h, mm	h_{cr}, mm	h_0, mm	m_{cr}, mm	m_0, mm	r
0.9	4	60	6	0.3	57.21	3.20	1.944	1.273	0.00002275
0.9	5	60	6	0.3	89.39	3.20	1.944	1.273	0.00000125
0.9	6	60	6	0.3	128.73	3.20	1.944	1.273	0.00000009
0.9	7	60	6	0.3	175.21	3.20	1.944	1.273	0.00000001

Conclusion: With these parameters of the ground pedestrian crossing (the average height of the marking line is 6.0 mm, the weighted average length of the marking line is considered from 4.0 m to 6.0 m), the risk of breakdown of the car's chassis and deterioration of the driver's condition due to dangerous vibrations and vibration of a car moving at a permissible speed of 60 km/h according to road traffic code in the city limit is less than the permissible value $1 \cdot 10^{-4}$. Therefore, when accepting the road for operation, such parameters of the ground pedestrian crossing will be considered acceptable.

2. The risk of the raised pedestrian crossing parameters normalized in the current Russian State Standards GOST and SP.

To determine the parameters of the raised pedestrian crossing, we will rely on Russian State Standard GOST R 52605-2006 Technical means of traffic management. ARTIFICIAL IRRIGULARITIES: the average height of the marking line is 70.0 mm, $\sigma_h = 70.00 \times 0.05 = 3.5$ mm, weighted average length of the marking line is considered: 3.5 m at 20 km/h, 4.5 m at 30 km/h, 6.75 m at 40 km/h. The permissible car speeds along the equipped raised pedestrian crossing were also taken in accordance with Russian State Standard GOST R 52605-2006, depending on the marking line length.

It should be noted that the raised pedestrian crossings are used, as a rule, in areas with high accident rates on existing roads. Therefore, each of these tolerances should not exceed the value 1×10^{-3} for existing roads.

The risk calculation of the parameters of the raised pedestrian crossing normalized in the current Russian State Standard GOST is presented in Table 2.

Table 2. The risk of the parameters of the raised pedestrian crossing normalized in the current Russian State Standard GOST

K_{st}	l_{wa}, m	V, km/h	h_{av}, mm	σ_h, mm	h_{cr}, mm	h_0, mm	m_{cr}, mm	m_0, mm	r
0.9	3.5	20	70	3.5	394.23	35.41	3.017	1.296	0.0168
0.9	4.5	30	70	3.5	289.64	35.41	2.565	1.296	0.0157
0.9	6.75	40	70	3.5	366.57	35.41	2.287	1.296	0.0035

Conclusion: With these parameters of the raised pedestrian crossing:

- the average height of the pedestrian crossing equal to 70.0 mm, the weighted average length of the pedestrian crossing 3.5 m, the speed of 20 km/h, the risk of breakdown of the car's chassis and deterioration of the driver's condition due to dangerous vibrations and vibration of the car moving along the crossing is equal to 16.8×10^{-3}, i.e. 17 out of 1000 cars will get into accidents due to a breakdown of the chassis;
- the average height of the pedestrian crossing equal to 70.0 mm, the weighted average length of the pedestrian crossing 4.5 m, the speed of 30 km/h, the risk of breakdown of the car's chassis and deterioration of the driver's condition due to dangerous vibrations and vibration of the car moving along the crossing is equal to 15.7×10^{-3}, i.e. 16 out of 1000 cars will get into an accident due to a breakdown of the chassis;
- the average height of the pedestrian crossing equal to 70.0 mm, the weighted average length of the pedestrian crossing 6.75 m, the speed of 40 km/h, the risk of breakdown of the car's chassis and deterioration of the driver's condition due to dangerous vibrations and vibration of the car moving along the crossing is equal to 3×10^{-3}, i.e. 3 cars out of 1000 will get into an accident due to a breakdown of the chassis.

Therefore, it is necessary to determine the permissible speed of the vehicle along the raised pedestrian crossing according to the permissible risk for existing roads 1×10^{-3}. The calculation results are presented in Table 3.

Conclusion: the permissible car speed along the raised pedestrian crossing according to the permissible risk for existing roads 1×10^{-3} is:

- at a height of 70 mm, the marking line length of 3.5 m–5 km/h;
- at a height of 70 mm, the marking line length of 4.5 m–10 km/h;
- at a height of 70 mm, the marking line length of 6.75 m–30 km/h.

Table 3. Determination of the permissible vehicle speed for the raised pedestrian crossing with parameters

K_{st}	l_{wa}, m	V, km/h	h_{av}, mm	σ_h, mm	h_{cr}, mm	h_0, mm	m_{cr}, mm	m_0, mm	r
Height 70 mm, marking line length 3.5 m									
0.9	3.5	20	70	3.5	394.23	35.41	3.017	1.296	0.017
0.9	3.5	15	70	3.5	700.85	35.41	3.385	1.296	0.008
0.9	3.5	10	70	3.5	1576.9	35.41	3.981	1.296	0.003
0.9	3.5	**5**	70	3.5	6307.61	35.41	5.253	1.296	**0.001**
Height 70 mm, marking line length 4.5 m									
0.9	4.5	30	70	3.5	289.64	35.41	2.565	1.296	0.016
0.9	4.5	25	70	3.5	417.07	35.41	2.759	1.296	0.009
0.9	4.5	20	70	3.5	651.68	35.41	3.017	1.296	0.005
0.9	4.5	15	70	3.5	1158.54	35.41	3.385	1.296	0.003
0.9	4.5	**10**	70	3.5	2606.72	35.41	3.981	1.296	**0.001**
Height 70 mm, marking line length 6.75 m									
0.9	6.75	40	70	3.5	366.57	35.41	2.287	1.296	0.004
0.9	6.75	**30**	70	3.5	651.68	35.41	2.565	1.296	**0.001**

4 Discussion of the Results

From the results obtained above it follows that the use of the ground pedestrian crossing (1.14.1 and 1.14.2) with an average marking line height of 6.0 mm, a weighted average marking line length from 4.0 m to 6.0 m, and a car speed at the crossing of 60 km/h (as regulated by road traffic code in the city limit) is considered permissible.

In the case of installing raised pedestrian crossings, it is recommended to establish the above restrictions on the car speed, specifically: at a height of 70 mm, a marking line length of 3.5 m, it should be not 20 km/h, but 5 km/h; with a height of 70 mm, a marking line length of 4.5 m, it should be not 30 km/h, but 10 km/h, and at a height of 70 mm, a marking line length of 6.75 m, it should be not 40 km/h, but 30 km/h. In this case, the risk of breakdown of the car's chassis and deterioration of the driver's condition due to dangerous vibrations and vibration of the car moving along the crossing will be acceptable and will be 1×10^{-3}, i.e. 1 car out of 1000 will get into an accident due to a breakdown of the chassis.

Analyzing the algorithm described above, it is clear that the risk of breakdown of the car's chassis at the speeds indicated in Russian State Standard GOST R 52605-2006 may remain acceptable (1×10^{-3}) if the weighted average length of the raised pedestrian crossing also increases. Such pedestrian crossings are acceptable, for example, in large metropolitan areas.

These decisions comply with the requirements of Law No. 184 "On Technical Regulation" (risk management by reducing to acceptable values) and Decree of the Government of the Russian Federation No. 806 of 17.08.2016 on the application of a risk-oriented approach [7].

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Features of Personnel Reproduction in the Transport Industry

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Abstract. The article investigates the problem of personnel reproduction in the transport industry. The aim is to determine the special aspects of staffing in transport in terms of changing educational paradigms. The methodology of the present study is based on the competence approach (V. I. Baydenko, I.A. Zimnjaja), facilitation approach (K. Rogers), K. Marx's theory of labor value, the theory of labor behavior (F. Taylor, F. Hertzberg) and the doctrine of human needs (E. Mayo, A. Maslow.) Classical methods contributed to the achievement of this aim: analysis and synthesis. The analysis was applied to: statistics on institutions of higher education, literature on Pedagogy, Psychology, Labor Economics and literature on various modes of transport. The experience of transport systems in Russia, Germany and France was analyzed. The author stated the reasons for the specificity of education in transport universities and identified educational institutions that are a source of personnel for the transport industry. In order to identify the need for specialists in the Federal districts, the University was determined to belong to a certain subject of the Russian Federation, and the provision of each with transport infrastructure was studied. The Web portal hh.ru with data for workplaces was surveyed; jobs relating to the category of "Transport" were identified, as well as the number of CVs per one vacancy in the same group. In conclusion, the author identified the features of personnel reproduction in the transport industry.

Keywords: Personnel · Human resources · Transport · Reproduction · Training · Competence approach · Resume · Vacancy

1 Introduction

Since the end of the last century, the entire Russian economy has been subject to structural transformations. The transport system was involved in the processes associated with the technical and technological reconstruction [1].

The introduction of more technologically advanced systems in operation required new knowledge and skills, which is associated with the acquisition of new professional competencies [2]. The transport industry is one of the most dynamic in terms of technology [3], which requires continuity in the educational process. The change of educational paradigms from knowledge to competence has predetermined the change

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of approach to the process of knowledge extraction. In light of the new requirements of the labor market, employees with a universal set of competencies are required, allowing expanding the range of responsibilities as much as possible. However, the transport industry, despite the high speed of reforms is one of the specific industries in terms of training. The knowledge transferred to students should be applied, as transport security can be considered one of the key aspects of national security.

The theory of generations, developed by William Strauss and Neil Howe, clearly shows how the modern worker's portrait has changed. Indelible changes will occur with the next generation Z, which will enter the phase of reproductive age in just a few years. Labor functions in transport are also changing due to digitalization, which forces the labor market to react accordingly.

These circumstances predetermined the aim of the article, which is to define the special aspects of personnel reproduction in the transport industry.

2 Research Methods

The traditional practice of teaching, adopted in the classical version is to introduce students to the systematic experience of social practice of the society, that is, the leading role is given to theoretical knowledge [4].

However, the transport industry is focused on embedding theoretical knowledge in the space-time context. This allows the student to understand the nature of the work, as well as to identify the possibility of integration of General subjects in the processes that take place in the transport. For many students, the incorrectly submitted learning process is the reason for the fall of interest in the chosen profession.

As a result of dominating an "abstract method of school" there was a noticeable separation of training from practical life that in transport branch is inadmissible. Only by means of "active" and "biased" activity, the development of social experience, the development of mental functions and abilities of the person are carried out.

Issues of teaching technology at some time were paid some amounts of attention. The historical stages of learning technologies development are as follows:

- 1975–1990 General Interest in the Concept of Technology and the Formation of a Systematic View of the Forms and Methods of Teaching in the Relationship of Means with Content;
- 1970–1985 Development of Technologies Focused on the Formation of System Knowledge;
- Between 1970 and 1985 the Development of Technologies Aimed at Activation of Cognitive Activity;
- 1975–1990 Development of Technologies Focused on the Activity Approach in Training;
- Development of Technologies Focused on Formation of Activity of the Person in Educational Process.

To grow the personality of a specialist, it is necessary to transform cognitive activity into professional activity with a change of needs and motives, goals, means and results.

3 Research Results

As the experience of countries with market economies shows, the availability of highly skilled workers is the basis for survival in competition. World experience shows that the success of the company requires a strong personnel policy based on a solid scientific basis.

The geographical position of the country plays a significant role in the pulse formation for the training of highly qualified transport personnel. For example, one of the reasons for the establishment of the Aviation Institute, the Department of Railway Transport and, accordingly, the Faculty of Transport Engineering, together with four specialized departments of Vilnius Gediminas Technical University (Lithuania), was the fact that Lithuania acquired the status of a transit country due to the intersection of the II and IX transport corridors. The authors [5] note the contribution of the University to the development of the transport industry – for the period from 2012 to 2015 – thanks to painstaking scientific work, three Doctoral Dissertations in the field of transport engineering were defended; it emphasizes the need to include the scientific sector in the process of building human resources.

Colleagues [6] from Frankfurt am Main (Germany), where the Darmstadt University of Technology is located, also note the opportunities of the scientific sector for the efficient and intelligent use of the existing transport infrastructure. Scientists at the University tend to combine existing competencies for the development of integrated transport systems. However, the current challenges in the transport industry have become more complex and require an interdisciplinary approach, and the scale of infrastructure projects reveals the need to include practitioners responsible for their operation, as new technologies must be brought to a broad and safe application in real economic conditions. This is possible only through the continuous interaction of transport, science and government institutions. This format allows Darmstadt University of Technology to include students in real projects at the research stage, which brings them closer to the needs of the employer.

In total, there are 17 transport universities in Russia (Table 1), of which 24% of all head universities are in the Central and Siberian Federal districts, 18% - in the North-Western and Volga Federal districts, 6% - in the Urals, South and far East. There are only branches in the North Caucasus Federal district. There are no main universities of transport orientation (Fig. 1). Universities that produce specialists for work on the railway are represented in each of the Federal districts, with the exception of the North Caucasus.

Such remoteness of the location of universities is explained by geographical latitude of Russia. At the same time, European colleagues [7] also note this feature of the formation of the educational framework – the University of the Basque Country in San Sebastian (Spain) is the only public University in the Basque Country, and its three campuses are located in different provinces, which creates difficulties with the choice of transport. The lack of alternative transport (as in the Northern parts of Russia) often forces to use their own cars, which creates even more problems within the transport industry, affecting not only safety, the environment, but also on human resources.

Table 1. Transport Universities in Russia

Aviation	Water	Railway	Vehicles
Moscow Aviation Institute (National Research University) (MAI): a Stupinskyi branch;	the State University of Maritime and River Fleet named after Admiral Makarov - a Voronezh branch; - a Kotlas branch; - a Moscow branch	Samara State University of Railway Engineering: - a Nizhny Novgorod branch; - a Orenburg branch; - a Saratov branch	Siberian State Automobile and Road University (SibADI)
Moscow State Technical University of Civil Aviation	Siberian State University of Water Transport: - a branch of Omsk; - a Yakutsk branch	Irkutsk State University of Railway Engineering: - a branch Krasnoyarsk; - a branch of Chita; - an Ulan-Ude branch	Moscow Automobile and Road State Technical University (MADI): - a branch of Makhachkala; - a Cheboksary branch; a branch of Bronnitsy; - a branch of the Lermontov
Kazan National Research Technical University. A. N. Tupolev-KAI	St. Petersburg State Marine Technical University	Omsk State University of Railway Engineering	
	Volzhskyi State University of Water Transport: - a Kazan branch; - a Perm branch; - an Astrakhan branch.	Ural State University of Railway Engineering: - a Chelyabinsk branch; - a Perm branch	
		St. Petersburg State University of Railways of Emperor Alexander I: - a Yaroslavl branch; - a Ryazan branch	
		Russian University of Transport (MIIT)	
		Rostov State University of Railway Engineering	
		Far Eastern State Transportation University (FESTU)	

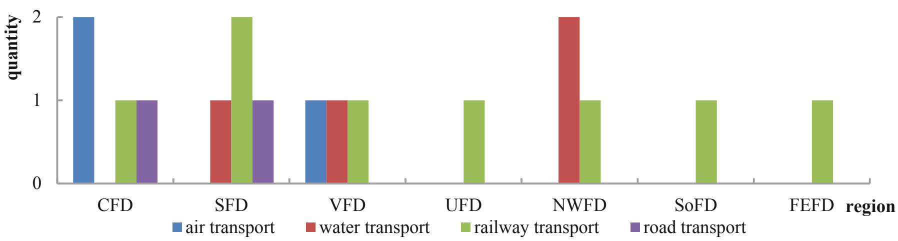

Fig. 1. Number of higher education institutions by transport sector (CFD - Central Federal District; SFD - Siberian Federal District; VFD - Volga Federal District; UFD - Ural Federal District; NWFD - Northwestern Federal District; SoFD - Southern Federal District; FEFD - Far Eastern Federal District)

Average monthly wages by kinds of economic activities in accordance with the national classification of economic activities (ОКВЭД2) at the end of 2018 made 47,474, compared with the average value in 2018 43,724 and 43,967 Rubles compared with 39,167 Rubles in 2017 (Fig. 2).

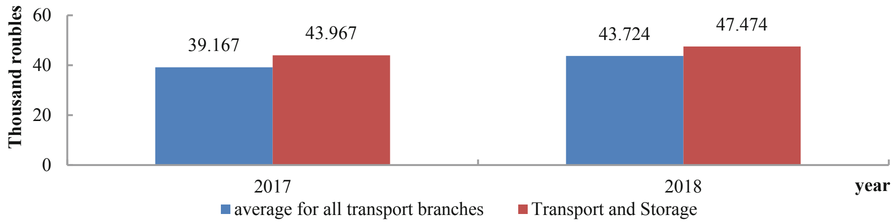

Fig. 2. Average monthly wages by industry and transport

The higher average level of wages in the field of transport among the residents of Russia is characterized by an increased number of applicants for positions related to transport. Western colleagues [8] state the correlation between transport infrastructure and employment in the regions. However, this dependence is very different by means of transport. For example, the employment rate is less sensitive to the rail network and more sensitive to the availability of highways, while the proximity of the international airport significantly increases the likelihood of employment growth.

The study analyzed data from the website https://hh.ru - one of the largest portals in the world in the search for work and employees. The information received on the number of resumes and vacancies available to the portal in economic specialties and areas of training was converted into a tabular form for the purpose of subsequent

Table 2. ABC analysis by number of vacancies

Name	Number of vacancies, units	Share, %	The cumulative share, %	Group
Driver	26110	20.90	20.90	A
Storekeeper, warehouse worker	43474	34.80	55.69	A
Autotransportations	16660	13.33	69.03	A
Logistics, traffic superintendant	17156	13.73	82.76	A
Expeditor	6031	4.83	87.59	B
Entry level, little experience	5502	4.40	91.99	B
FTA	2284	1.83	95.12	C
Sea/river transport	2224	1.78	98.01	C
Rail traffic	1629	1.30	93.30	C
Air transportation, civil aviation, business aviation	1490	1.19	99.20	C
Container transportation	1378	1.10	96.23	C
Customs clearance	809	0.65	99.85	C
Pipeline transport	192	0.15	100.00	C
Total	124939	100.00		

ABC analysis. As 15.09.2019 on the website hh.ru there are listed 124939 jobs in the category professional areas “Transport”. The results of the analysis on the number of vacancies are presented in Table 2.

The number of employers’ vacancies confirming the need for employees to work in the railway transport amounted to slightly more than 1% of the total. Similar value in the number of vacancies was placed in the field of sea and river transport-just over 3%. The most popular were specialists in road transport – more than 33% of all resumes placed belong to this category. About 4% of all applicants, employers are ready to accept immediately after graduation – for them vacancies are placed in the category “Entry level/ little experience”.

At the same time, the number of people who posted on the portal summary in the area “Transport” made 1489417. Of these, 305,961 resumes or 21% of the total were submitted in the category “road transport”. The Rail category contained 3,270 summaries or 2%.

Among the professions of air transport there were taken into account resumes in the aggregate summary as a whole for air transport, civil aviation and business aviation. The total number of resumes in these categories was 31095, which is a percentage of 2%. Candidates in the field of water transport are less represented – in the category of sea and river transport, slightly less than 2% of the total number of applicants is placed, which in absolute terms is 260 resumes (Table 3).

Table 3. ABC analysis by number of resumes

Name	Number of resumes, units	Share, %	The cumulative share, %	Group
Storekeeper, warehouse worker	354605	23.81	23.81	A
Driver	314565	21.12	44.93	A
Autotransportations	305961	20.54	65.47	A
Logistics, traffic superintendant	204641	13.74	79.21	A
Expeditor	156142	10.48	89.69	B
FTA	32832	2.20	91.90	B
Rail traffic	32270	2.17	94.06	B
Air transportation, civil aviation, business aviation	31095	2.09	96.15	C
Customs clearance	19646	1.32	97.47	C
Container transportation	13240	0.89	98.36	C
Sea/river transport	12563	0.84	99.20	C
Entry level, little experience	8467	0.57	99.77	C
Pipeline transport	3390	0.23	100.00	C
Total	1489417	100		

From the data obtained, it can be concluded that only every 8 resumes are provided with vacancies. In the context of each specialty analysis is given in Table 4.

The total number of jobs posted in the category “Transport” is 124,939, while the number of resumes in the same category 1,489,417. Thus, about 12 people apply for one vacancy in Russia, which indicates the current shortage of vacancies in the labor market in the transport industry. A small percentage of resumes are not taken into account in the calculations, since one candidate can post resumes for different positions (according to the author's observations, this proportion ranges from 5 to 10%).

The most favorable situation was in the category of employees without experience- the excess of resume over vacancies is 1.5 times. Sea and river transportation also demonstrate the correctness of the formation of personnel - in accordance with the needs of the market. The smallest gap between industries is observed here. The number of potential employees exceeds the number of possible places by a little more than five times. It should be concluded that graduates of water transport universities:

– find jobs fast. The total number of vacancies in the category "Transport" - only 2%, which significantly reduces the horizons of choice;
– are arranged in the place of practice, for this reason, the resume does not fall into the portal;
– the specificity of education does not allow to change the employer, and therefore the turnover rate at the enterprises of the water transport industry is low compared to other modes of transport [7].

Table 4. Share of vacancies secured by resumes

Name	Number of vacancies, units	Number of resumes, units	Number of resumes per vacancy
Driver	26110	314565	12
Storekeeper, warehouse worker	43474	354605	8
Autotransportations	16660	305961	18
Logistics, traffic superintendant	17156	204641	12
Expeditor	6031	156142	26
Entry level, little experience	5502	8467	2
FTA	2284	32832	14
Sea/river transport	2224	12563	6
Rail traffic	1629	32270	20
Air transportation, civil aviation, business aviation	1490	31095	21
Container transportation	1378	13240	10
Customs clearance	809	19646	24
Pipeline transport	192	3390	18
Total	124939	1489417	12

Railway transport in Russia is represented by the monopolistic structure of the Russian Railways (RZD) holding. The average age of employees of the Russian Railways holding is 39 years. The share of employees with higher education is increasing annually and currently stands at more than 30% (Fig. 3).

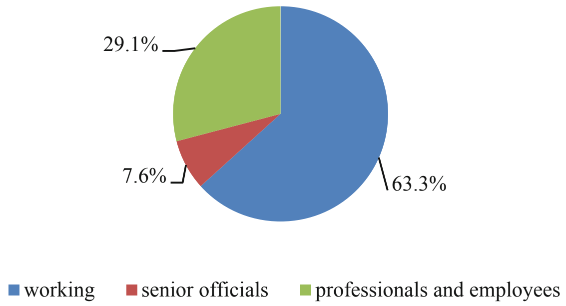

Fig. 3. Distribution of employees with higher education by category [8].

More than 25% have experience of more than 10 years, which is determined by the uniqueness and narrow specialization of railway workers' jobs and determines the special importance of specific human capital, the need for long-term labor relations for its formation and development [9].

4 Discussion of Results

Modern methods of teaching in transport universities should be aimed at:

- humanization of education and individualization of training;
- formation of general and psychological culture of participants of educational process;
- professionalism of the personality and activity of teachers.

Humanization - an appeal to the personality and individuality of the student, the creation of conditions for the most complete realization. It is assumed that the student of transport universities in addition to the intellectual level should have Gnostic, design, constructive, communicative abilities and self-organization. For students of transport universities, this causes some difficulty, because if they pass Psychology, it is superficial. Teachers of special transport disciplines are often graduates of the same transport universities, purposefully not studying Psychology and Pedagogy [10].

Individualization involves taking into account the individual psychological characteristics of students and their inclinations to professional activity, the fullest disclosure of their potential and personality as a whole [1].

Graduates of transport universities have to adapt more to the requirements of the modern labor market [11]. Even 20 years ago, humanity could not imagine that today unmanned vehicles would drive on public roads, and now it is becoming an objective reality. The rate at which the technological structure of society is changing is much faster than the rate of change and restructuring of basic educational technologies. American scientists believe that professional knowledge annually becomes obsolete by 15–20% depending on the rate of development of the industry [9]. Many countries devote a significant proportion of their total budget expenditure to continuing education programmes. In France - a Law on education, continuing professional training and retraining was adopted in 1971. In Sweden - the Law on the restructuring of the education system in 1975, which is based on the idea of continuous education. In the United States - the Continuing Education Act was passed in 1976 [9].

In France, each firm must spend at least 1.5% of the SN Fund on staff training and education. Otherwise, enterprises are fined and unused funds are taken to a centralized employee training fund [9].

At the same time, if we consider the key principles of personnel development in transport enterprises, they are the same for all countries of the world (Fig. 4).

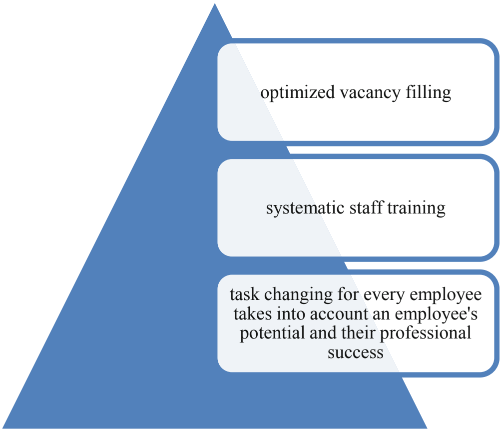

Fig. 4. Principles of personnel development at transport enterprises [9]

It should be borne in mind that the training of existing employees must also be carried out in a continuous mode, because the current staff, especially employees who are involved in the movement of rolling stock hourly responsible for hundreds of lives: whether it's a train, a plane or a cruise ship [9]. Therefore, special attention at transport enterprises should be paid to measures for regular improvement of existing skills (Fig. 5).

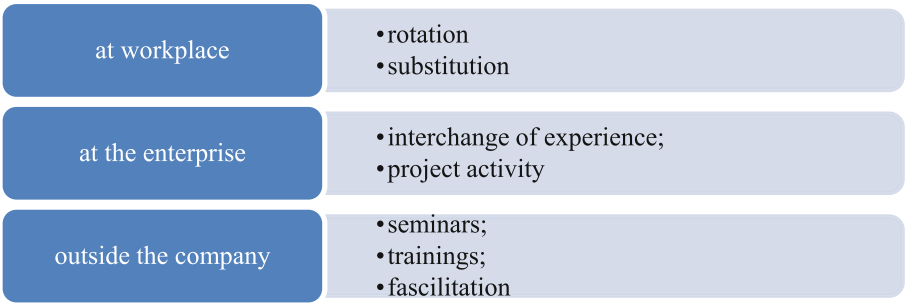

Fig. 5. Professional development activities at transport enterprises, [9].

It is important to remember that any employee of the transport industry, regardless of the position, whether it is a manager, logistician, accountant or captain of the vessel should have an idea about the key structural elements of transport:

- passenger traffic;
- freight traffic;
- rolling stock;
- ways of communication.

In the post-graduate period updating of knowledge on these elements is more expedient to carry out within professional development. Summarizing the above, we can highlight the main features inherent in the reproduction of personnel in transport:

- transport companies operate in conditions of high competitiveness and rapidly changing technologies;
- participants of the transport services market are organizations that devote a large amount of budget to professional development and training of personnel, especially for professions related to the movement of rolling stock;
- professions related to the movement of rolling stock imply the presence of competencies associated with the ability to independently solve personnel, technical and technological problems that affect the final economic result;
- issues of retention of qualified personnel in the transport industry are becoming crucial in the implementation of the strategies of each mode of transport, transport strategy in general and regional development strategies;
- training of employees in the field of transport requires a focus on the applied nature, with a shift in emphasis towards practical activities (laboratory work, excursions, facilitation, business games. simulation programs, etc.);
- the implementation of basic educational programs should be carried out in accordance with the requests of employers-transport companies;
- intensive updating of fixed assets entails an increase in requirements for the level of training of personnel serving modern equipment and technology.

5 Conclusion

The changed economic conditions and Russia’s integration into the world economic system determine the objective process of complicating the management of transport enterprises. This justifies the need for appropriate training. Labor relations in the transport industry are one of the most important areas, because the quality of transport services depends on the degree of satisfaction of the transport company’s employee with his own position in the company. The issues of improving the quality of transport services are laid down in the Transport strategy of the Russian Federation until 2030 as target indicators, which itself speaks of the importance of this indicator.

The complexity of achieving the target indicator is proved in other studies of the author, but the variability of the problem solution allows to focus not only on the educational component in the system of personnel reproduction, but also on post-university education, the responsibility for which at the time of awarding the diploma of higher education passes from the university to the employer and the graduate.

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Fuzzy Set Theory for Planning the Operation of a Motor Transport Enterprise

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Abstract. The emphasis is placed on the uncertainty of demand in the planning of the volume of transportation of goods in intercity traffic for motor transport enterprises, requiring managers to make scientifically sound management decisions aimed at fulfilling the terms of the contracts. The aim of the study is to develop a scientific and methodological approach to planning the volume of cargo transportation in intercity traffic by rolling stock of a motor transport enterprise. In the proposed approach, a synthesis of scientific methods of the fuzzy set theory and the classical theory of probability is implemented, which allows planning the volume of transportation of goods in intercity traffic for a motor transport enterprise, taking into account the fuzzy volume of transportation under contracts, rolling stock sizes and quarters. For practical implementation, a method has been developed that is implemented using the created mathematical model for planning the volume of cargo transportation in intercity traffic. Using the developed method, the volumes of transportation of food products from Omsk in the Western and Eastern directions were planned. Using the theory of fuzzy sets for planning, it will be possible to estimate the volume of cargo transportation according to a certain technological scheme in accordance with the performance of rolling stock by standard sizes, which should be taken into account when managing the resources and capacity of motor transport enterprises for the current period.

Keywords: Motor transport enterprise · Current planning · Fuzzy set theory · Rolling stock sizes

1 Introduction

Nowadays, the current planning of the motor transport enterprise (MTE) is an integral part of activities aimed at fulfilling the terms of contracts and making a profit. Violation of contractual obligations reduces the reliability of the carrier and leads to non-returnable loss of the client [1]. Customers prefer to interact with regular carriers who are ready to work all year round, not even with a single tariff for the transportation of goods. The practice of MTE operation has shown that contracts are concluded for a year. This is mutually beneficial for both freight customers and MTE. Today, the qualitative composition of freight road transport is improving, and the times when carriers preferred to buy used imported equipment are becoming a thing of the past. Today, according to

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some estimates, the country has about five million units of trucks of various sizes, corresponding to the demand for transportation of goods. According to statistics presented on the official website of KamAZ LLC, the share of KamAZ vehicles in the segment of main tractors increased to 19% in 2018. In this segment, KamAZ is represented by KamAZ-5490 truck tractors (4 × 2 wheel arrangement), KamAZ-65209 (6 × 2 wheel arrangement), and KamAZ-6460 (6 × 4 wheel arrangement). The value of the demand for the transportation of goods in intercity traffic, as a rule, is fixed in contracts with already known MTE customers and is carried out by specific standard sizes of rolling stock [2]. The head of the MTE can determine the demand in the range of approximate numbers of traffic under the contracts, which will be presented by the customer for next year. Using this information, the manager can establish a range of approximate numbers of the volume of cargo transported, which can be performed with a specific standard size of rolling stock under a specific contract. It is possible to model the reasoning of the leader using the theory of fuzzy sets [3].

Today, domestic and foreign scientists have developed approaches that use the methods of the fuzzy set theory to take into account the uncertainty of demand in the practice of transport enterprises in solving problems arising in operational planning [4–6], strategic planning, when choosing vehicles, in adjusting the volumetric performance indicators of participants in international supply chains [7], as well as in forecasting; when planning the relationship of technological processes of cargo transportation by rail and road transport, sea and road transport [8–11]. The fuzzy logic apparatus is the basis for the implementation of various technical solutions aimed at the introduction of automated traffic control systems based on the new generation of road controllers [12]. The conflict between municipal authorities and passengers was proposed to be solved using the game-theoretic model [13]. The analysis of scientific works did not allow identifying examples of solving the problems of the current planning of the MTE operation for which, as fuzzy sets, the volumes of cargo transportation in intercity traffic under contracts and standard sizes of rolling stock are examined taking into account the seasonal changes in the needs for these transportations.

Examples of using the theory of fuzzy sets for operational planning are presented when choosing delivery routes in the conditions of uncertainty. The sets of typical states of the system are presented in the form of graph nodes, and the transitions between these nodes correspond to the fuzzy situational network control decisions using the example of the delivery of goods by the Neva-Line logistics company from the container site of the seaport and Pulkovo cargo terminal to a warehouse, central office and four stores. Sun, Liang, Li, Zhang, [4] solved the problem of routing freight transportation at the operational level in an extensive multimodal transport network, which consists of scheduled rail transport and flexible road transport. The theory of fuzzy sets was used for modeling in which fuzzy requirements were presented in the form of trapezoidal fuzzy numbers. To quantify the impact of demand uncertainty on the routing problem, sensitivity analysis and fuzzy modeling were combined [4]. In [5], fuzzy numbers of container transportation times were used to solve the routing problem at the operational level in a multimodal network of automobile and railway transport. Janic [6] used fuzzy numbers of costs and lead times of possible intermodal container shipping from Canada to Mexico for operational route planning. Situational advisory systems with fuzzy logic of the class "situation - management strategy - action" for mathematical modeling of the adaptive system of logistic management of metal flows were studied. Effective management of the transport system for the delivery of metal products was ensured due to the capabilities of the proposed approach, which took into account the uncertainties and fuzziness of the environment, reflected the coordination of the work of individual links and elements at the stages of the transport process for the delivery of metal in real time. An algorithm was developed using fuzzy clustering to solve operational planning tasks to determine the size and range of vehicle loads and assign routes to them, at which the total costs of the enterprise to satisfy all incoming requests will be minimal. The algorithms developed in the GIS environment and computational optimization programs in various information systems were presented, which allow obtaining effective solutions, while taking into account the needs and capabilities of the user. For the operational planning of the work of vehicles in the transportation of raw materials, a complex hierarchical three-level structure was considered: suppliers of raw materials—MTE—processing enterprise. For each level of the system, operational goals were determined, and for the selection and distribution of MTE vehicles for technological operations, a fuzzy form of expression of the goal of the participants in the transport process was taken into account.

It was proposed to apply the methods of the fuzzy set theory to select the best option for the development strategy of the enterprise. Analytical tables of strategic factors influencing the functioning of the enterprise in an uncertain and constantly changing environment have been developed. The analytical tables were processed using the methods of fuzzy set theory using the desirability function. The theory of fuzzy sets was used to identify the level of adaptability of a freight carrier to a variable nature of demand. As a result of the studies, diagnostic methods were systematized, and their significance was assessed using the criteria: accuracy, laboriousness, objectivity, efficiency.

To justify the appropriateness of the use of trucks, a fuzzy set of car models was studied in the market of motor vehicles, which can be used in specific operating conditions. The argument to the membership function characterized the operation parameters of trucks. To solve the problem of choosing a transport in the framework of organizing a complete supply chain of dried fruits to the Ukrainian market from different regions of the world, the mathematical apparatus of fuzzy logic was used.

Fuzzy-regression models that allow converting non-numeric variables into fuzzy sets with membership functions of a triangular and trapezoid type were developed to predict the time and cost of freight transportation. A combined fuzzy-plural and hierarchical analysis was used to develop a methodology for assessing the effectiveness of supply chain management of raw materials for forecasting the work of textile and sewing enterprises.

In [8, 9], the problem of choosing the location of warehouses for the effective interaction of cargo transportation by rail and road was solved. In [8], a multicriteria decision-making model was used, which is based on a combination of compromise programming techniques with the theory of fuzzy numbers. In [9], a host tag algorithm was proposed for the solution for a fuzzy shortest path with uncertainty of the length of the ride with the load. Wang, Yang, Yang, Gao [10] developed an algorithm in which they used the genetic search method to plan technological processes of an inter-modal road-rail transport system with fuzzy parameters of demand, cost and time. In [11], a mathematical model was proposed to determine the optimal schedule of rolling stock in the European Gateway Services (EGS) intermodal container transport network. The transit time and the possibility of using subcontracted transport were considered as fuzzy sets. In [14], issues of estimating the parameters of algorithms for diagnosing automobile systems are considered. The rationale for the need to implement measures to ensure man-machine compatibility at the design stage of equipment is given. A model for evaluating the parameters of the algorithms for diagnosing automobile systems based on the use of a fuzzy logic apparatus has been developed. The parameters of real processes are used as initial data.

The variety of problems that arise in the practice of transport, for which the theory of fuzzy sets was applied, confirms the relevance of the study, and also allows complementing the research with an author's vision of the application of the theory of fuzzy sets to the current planning of the work of a freight truck company, depending on the uncertainty of demand for transportation of goods.

2 Research Methods

A fuzzy set will be a pair (Q_{MTEt}, $\mu_{Qi,t}(Q_{MTEt})$), where Q_{MTEt} is the universal set of values for the volume of goods transported in long-distance traffic, which can be mastered by MTE under all contracts for each quarter, $\mu_{Qi,t}(Q_{MTEt})$ is a membership function of a fuzzy set, defined on the set of values of the volume of cargo transportation under a specific contract for each quarter ($Q_{i,t}$) on the interval [0,1]. Values $Q_{i,t}$ are trapezoidal fuzzy numbers of (*L*-*R*) -type. The universal set will be determined on the range of the maximum and minimum performance of rolling stock of all sizes, established with a confidence probability of 0.95 according to the results of studies of the influence of the length of the ride with the load in the long-distance traffic and the mass of the load on the functioning of the MTE. As the next universal set, the volume of transportation of goods under contracts and quarters will be considered. The membership function of a fuzzy set will be the degree of belonging to this set of values of the volume of goods transported by rolling stock sizes, which can be performed under contracts at the considered time stage ($Q_{j,i,t}$). The membership function of a fuzzy set is defined on the set $Q_{j,i,t}$ and takes values on the interval [0,1]. To implement the proposed scientific and methodological approach, a direct method of constructing a function will be used, in which the values $Q_{j,i,t}$ are set for each value of the universe. The values of the traffic volume of each standard size in the contract are trapezoidal fuzzy numbers of (*L*-*R*) -type.

The left indicator of the volume fuzziness of cargo transportation for the rolling stock of each standard size $\left(\underline{Q_{j,t}} - Q_{\alpha j,t}\right)$ cannot be less than the minimum output value, which is established with a confidence probability of 0.95 [15, 16]. The right indicator of the volume fuzziness of cargo transportation for the rolling stock of each standard size $\left(\overline{Q_{j,t}} + Q_{\beta j,t}\right)$ cannot be more than the maximum output value, which is established with a confidence probability of 0.95. The values of fuzzy volumes of cargo transportation on the left and right edges will take into account the possible number of months of work in each quarter. The volume of goods transported by rolling stock sizes for each quarter is a fuzzy variable that has a trapezoid membership function obtained by summing fuzzy numbers of (*L-R*) -type.

The proposed scientific and methodological approach to the current planning of the MTE operation allowed the author of this paper to develop a methodology for planning the volume of transportation of goods in intercity traffic, taking into account the fuzzy volume of transport under contracts, which is implemented in the following stages.

Stage 1. Input of initial data. The initial data of the methodology include: the number of contracts, sizes and quarters for current planning.

Stage 2. Formation of information on the performance of MTE rolling stock by sizes and quarters. At this stage, information is being generated on the performance of MTE rolling stock by standard sizes for each quarter and on the performance of MTE rolling stock by quarters. To obtain information, we use the results of studies to establish the dependences of the production of rolling stock of each size on the length of the trip with the load and the mass of the shipment with a confidence probability of 0.95 [15, 16]. Information on the performance of ATP rolling stock by standard sizes for each quarter is formed taking into account the possible number of months of operation of a particular standard size in this quarter. To generate information on the performance for each quarter, summation of the rolling stock performance of all sizes is performed.

Stage 3. Determination of the membership function of the fuzzy set of the volume of cargo transportation under the contracts for each quarter. The membership function is formed on the universal set of values of the volume of cargo transportation in intercity traffic, which can be mastered in each quarter (formula (1)).

$$\mu_{Qi,t}(Q_{MTEt}) = \begin{cases} 0, & \text{when } Q_{MTEt} < (\underline{Q_{i,t}} - Q_{\alpha i,t}); \\ \frac{Q_{MTEt} - (\underline{Q_{i,t}} - Q_{\alpha i,t})}{\underline{Q_{i,t}} - (\underline{Q_{i,t}} - Q_{\alpha i,t})}, & \text{when } (\underline{Q_{i,t}} - Q_{\alpha i,t}) \le Q_{MTEt} \le \underline{Q_{i,t}}; \\ 1, & \text{when } \underline{Q_{i,t}} < Q_{MTEt} < \overline{Q_{i,t}}; \\ \frac{(\overline{Q_{i,t}} + Q_{\beta i,t}) - Q_{MTEt}}{(\overline{Q_{i,t}} + Q_{\beta i,t}) - \overline{Q_{i,t}}}, & \text{when } \overline{Q_{i,t}} \le Q_{MTEt} \le (\overline{Q_{i,t}} + Q_{\beta i,t}); \\ 0, & \text{when } Q_{MTEt} > (\overline{Q_{i,t}} + Q_{\beta i,t}), \end{cases} \quad i = \overline{1, I},\ t = \overline{0, 4} \tag{1}$$

where Q_{MTEt} – the volume of cargo transportation that can be mastered by the MTE at the t-th time step of calculation, t; $\mu_{Qi,t}(Q_{MTEt})$ - membership function of a fuzzy set; $Q_{i,t}$ - fuzzy numbers of the volume of transportation of goods under the i-th contract at the t-th time step of the calculation, t; $\underline{Q_{i,t}}$, $\overline{Q_{i,t}}$- the volume of cargo transportation under the i-th contract at the t-th time step of the calculation, providing a maximum membership function, on the left and right sides, respectively, t; $(\underline{Q_{i,t}} - Q_{\alpha i,t})$, $(\overline{Q_{i,t}} + Q_{\beta i,t})$- respectively, the left and right indicator of the fuzziness of the volume of cargo transportation under the i-th contract at the t-th time step of the calculation, t;

Stage 4. Verification of the condition (formula (2)).

$$\sum_{j=1}^{J}\left(Q_{Mj,t\min}\cdot D_{j,t}\right)\leq Q_{MTEt}\leq\sum_{j=1}^{J}\left(Q_{Mj,t\max}\cdot D_{j,t}\right),\quad t=\overline{0,4}\qquad(2)$$

where $Q_{Mj,t\max}$, $Q_{Mj,t\min}$ – respectively, the maximum and minimum values of the rolling stock performance of the *j*-th standard size, established with a confidence probability of 0.95 and adopted at the *t*-th time step of the calculation, t; $D_{j,t}$ - the possible number of months of operation of rolling stock of the *j*-th standard size at the *t*-th time step of the calculation, units.

If the condition is met, then go to step 5, otherwise return to step 3.

Stage 5. Determining the membership function of a fuzzy set of freight volumes by rolling stock sizes and contracts for each quarter. The membership function is determined on the universal set of values for the volume of cargo transported under contracts for each quarter. Estimated values of the volume of freight for each standard size of rolling stock are established under contracts.

Stage 6. Verification of the condition (formula (3)).

$$\left(\overline{Q_{j,t}}+Q_{\beta j,t}\right)\leq\left(Q_{Mj,t\min}\cdot D_{j,t}\right)\leq\left(\underline{Q_{j,t}}-Q_{\alpha j,t}\right),\quad j=\overline{1,J},\quad t=\overline{0,4}\qquad(3)$$

where $\left(\underline{Q_{j,t}}-Q_{\alpha j,t}\right)$, $\left(\overline{Q_{j,t}}+Q_{\beta j,t}\right)$ – respectively, the left and right indicators of the fuzzy volume of transportation of goods of rolling stock of the *j*-th standard size at the *t*-th time step of the calculation, t;If the condition is met, go to step 7. Otherwise, go to step 5.

Stage 7. Determination of the fuzzy variable volume of cargo transportation for the MTE rolling stock by standard sizes for quarters and a year. It is carried out by summing the values of fuzzy sets of volumes of cargo transportation by all standard sizes in a quarter, and then by summing the values of fuzzy sets of volumes of cargo transportation in all quarters.

Stage 8. Making a managerial decision on the use of the obtained estimates of the volume of cargo transportation for current planning. This stage is implemented by the manager, who decides on the use of the obtained values of the volume of cargo transported by the standard sizes of the MTE rolling stock, quarterly and yearly contracts for the current planning of indicators of the processes of cargo transportation in intercity traffic and ensuring the technically sound condition of the rolling stock.

3 Research Results

For the practical implementation of the methodology, a computer program “Planning the work of a motor transport enterprise, taking into account the fuzzy volume of freight traffic in intercity traffic under contracts” was proposed. The computer program is intended for the automated planning of the operation of a cargo MTE by determining the membership functions of a fuzzy set of freight volumes by rolling stock sizes and contracts for each quarter of the year. It can be used in the MTE carrying out the transportation of goods in intercity traffic; in the research activities of the transport industry; for the learning process. Type of computer: IBM PC-compatible. Programming language: C#. Type and version of the operating system: Microsoft Windows 10. The program provides the following functions:

1. Determines the left and right indicators of the fuzziness of the volume of transportation of goods of rolling stock of each standard size under the contracts and quarters of the year.
2. Forms combinations of standard sizes of rolling stock under contracts if a fuzzy volume of transportation of goods of rolling stock corresponds to standard sizes, performance of rolling stock of these standard sizes, established with a confidence probability of 0.95.
3. Forms combinations of agreements by quarter, subject to the fuzzy volume of cargo transportation under these agreements, and the performance of rolling stock by standard sizes for the quarter.

Using a computer program will allow practitioners to plan the volume of transportation of goods by rolling stock in intercity traffic for assessing the production capabilities of transport enterprises for each rolling stock size, by quarters and year.

When using the software product, motor transport companies can plan activities within the framework of fulfilling the conditions of contracts for the transportation of goods in intercity traffic with the aim of implementing strategic indicators of the Transport Strategy of the Russian Federation.

System requirements for the developed program "Planning the work of a motor transport enterprise, taking into account the fuzzy volume of transportation of goods in intercity traffic under contracts":

1. Intel Celeron G1820 MHz processor.
2. Microsoft Windows 10 operating system.
3. 4-speed device for reading CDs or DVDs.
4. Mouse.

Working with modules combines a number of steps for entering initial information and obtaining results on indices of fuzzy volume of transportation of goods of rolling stock of each standard size under contracts and quarters of the year. It is possible to print the results. The procedure for working with modules is selected by the user, at each stage of work you can return to the main window and select another module. The "Instruction" module contains information about the modules, initial information for the program and the results.

Basic program operations: loading saved parameters from the database, reading parameters, calculating results using formulas, saving parameters.

The computer program includes the following modules: "Instruction", "Data Entry", "Standard Sizes Contracts". The developed technique with the help of a computer program was tested at the MTE. The volumes of food transportation in the East and West directions from the city of Omsk were determined for the following standard sizes of rolling stock: MAZ - 5440 + MAZ - 975830-3021 (20 t);

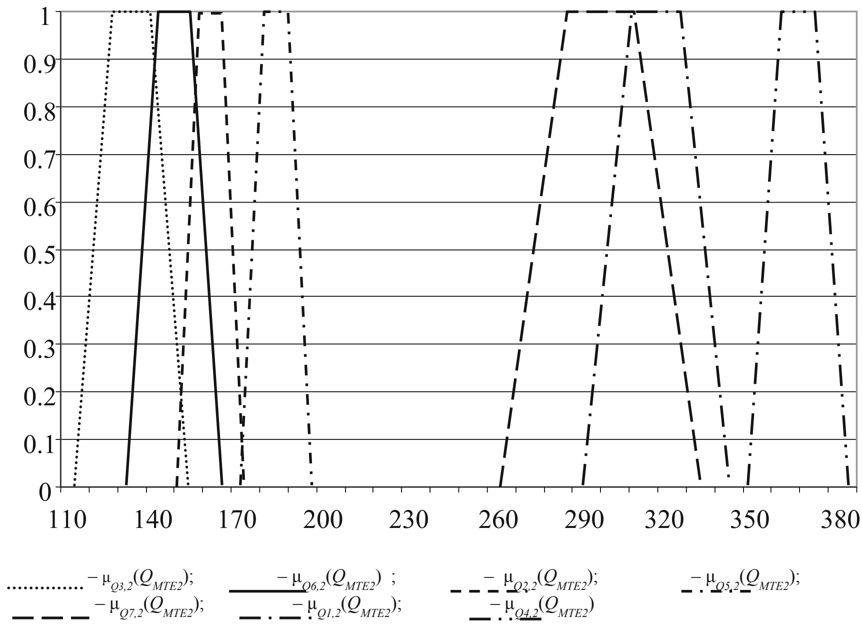

Fig. 1. Membership functions of fuzzy sets of freight volumes under contracts μ_{Qi2} (Q_{MTE2}) for the second quarter

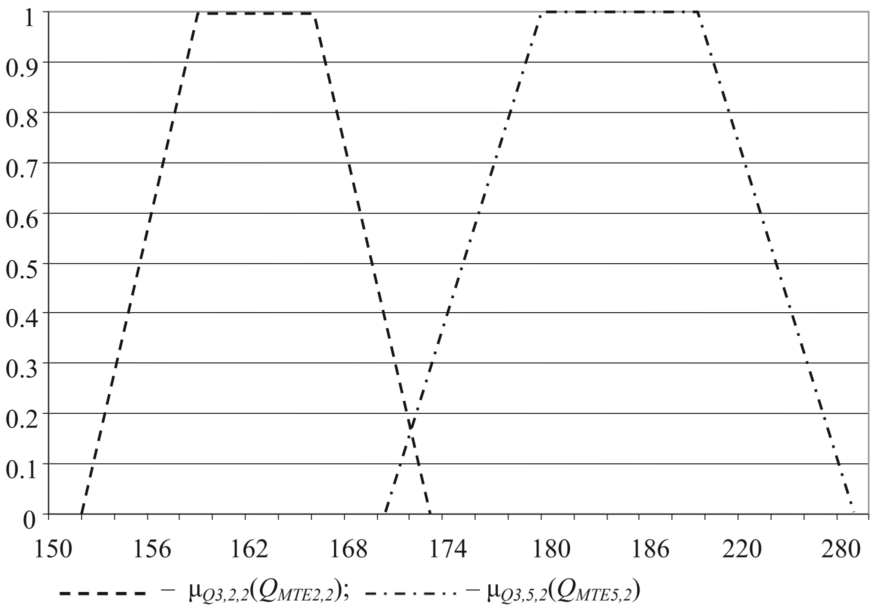

Fig. 2. Membership functions of fuzzy sets of freight volumes for the third rolling stock standard size under the second and fifth contracts for the second quarter

Kamaz 5490 + Krone SDP 24 (30 t); MAZ - 54323 + Fruehauf-T34C1RA (25 t); Kamaz 5490 + Schmitz SKO SDP 24 (32 t); DAF 105 FX + Schmitz - SKO 24/L - 13.4 FP 60 cool (24 t).

As a result, fuzzy sets of traffic volumes were obtained, which are graphically presented in Figs. 1 and 2.

4 Discussion

First developed scientific and methodological approach to current planning made it possible to propose a methodology for the practice of MTE operation, aimed at determining a fuzzy set of traffic volumes for each contract, which can be performed with a specific standard size of rolling stock for the quarter and year. Using the mathematical modeling created by the author, it became possible to form combinations of rolling stock sizes under contracts in accordance with a fuzzy volume of rolling stock transportation by standard sizes and the performance of rolling stock of these sizes, established with a confidence probability of 0.95; to form combinations of contracts by quarters if the fuzzy traffic volume under these agreements corresponds to the performance of rolling stock by standard sizes in this quarter. Estimates of the volumes of cargo transportation established as a result of the application of the developed methodology are the initial value for planning indicators of the process of transportation of goods in intercity traffic and ensuring the technically sound condition of rolling stock in the practice of MTE operation under the conditions of contracts in order to implement strategic indicators of the Transport Strategy of the Russian Federation, aimed at economic development of the country.

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Modeling as a Source of Innovation in Design Railway

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Abstract. Nowadays in the field of railway lines designing and construction it is forbidden by normative base to combine transition curves in plane and vertical curves in profile. The purpose of the research is to prove groundlessness and inadmissibility of this prohibition by means of the analysis in the program complex "Universal Mechanism". Consider more rational design a railways in using biclotoide curves, combine transition curves in plane and vertical curves in profile. It is necessary to consider abolition of the requirement about presence "clean" circular curve between transition curves by biclotoide curves. This analysis confirms the admissibility of such a combination. Accordingly, the combination of transition curves in plane and vertical curves in profile leads to reducing of interaction forces in the "wheel-rail" system, increasing of the motion smoothness, improving of the track stability.

Keywords: Track · Curve · Biclotoide · Fracture profile · Impulse of force · Interaction force · Acceleration · Smoothness and stability track · Designs standards

1 Introduction

Design of Railways is not complete without using technical rules and regulations.

The purpose of the research is to prove groundlessness and inadmissibility of combine of the transition curves in plane and vertical curves in profile in designing of rail way lines by means of the analysis in the program complex "Universal Mechanism".

The value of building's norms and regulations are reduced to main requirements and recommendations:

1. regarding the dimensions of the approach of buildings, rolling stock, scaffolding and over;
2. providing the required power of the railway: accommodation separate points, the length of receiving-departure tracks and their lot of stations;
3. provision of permissible dynamic interaction between a trains on the track.

This requirements and recommendations are addicted to alleged speed trains.

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These rules and regulations are corrected once in 10–15 years. The alternative is a computer simulation, which can be shown by example of innovation for design curved section of track.

The studies show replacing of circular curve in the plan on biclotoide curve a possible. This shown by the using the program "Universal mechanism" (UM) [1, 2].

2 Basic Design Problems of Curves of Railway Tracks

The biclotoide curve is two transition curves without circular curve. So that the average radius of biclotoides mates is bigger two times more than the circular curve [3]. In this regard track shifts inwards and the length of railway path becomes less on 1.5–2% of. In this connection Smoothness of the train, stability of the path increases due lowering of interaction forces between wheel and rail.

There were repeatedly conducted researches of the interaction "wheel and rail" by the movement of trains by "classical" curves and biclotoide in the "UM" [4]. There were conducted comparison of transverse, longitudinal and vertical forces. The compression had shown that the average values of the shear forces arising from movement by biclotoide curves were smaller by 30–50% than by the movement of trains by "classical" curves. Analysis of the total forces was executed by the formula:

$$F = \sqrt{F_v^2 + F_{lt}^2 + F_{ln}^2} \tag{1}$$

F_v, F_{lt}, F_{ln} – it's vertical, lateral and longitudinal forces.

The cost of maintaining a railway track is inversely proportional to the square of the radius of the circular curve. This circular curve replaces is biclotoide:

$$\frac{1}{R_{av}^2} = \frac{1}{4R^2} \tag{2}$$

R_{av} – average radius;
R – radius circular curve.

This proves but the costs on the use biclotoide curve decrease by 4 times then in the "classical" curve.

But, the normative documentation of railways design and high-speed highway doesn't allow combine transition curves in plan with vertical curves in profile.

First of all, this is due to the fact that the surveyors have difficulties with the breakdown of such a "spatial" curve, and the operators of railway track have problems with its content. It's very important problem for design of high-speed highway and this problem can lead to a significant amount of work (for example, the height of the embankment over 25 m in sections on the track Moscow – Kazan). In this connection, the requirements of special technical conditions (STC) on the mandatory mismatch of fractures of the profile and the plan do not correspond to the current formation of technological processes [5].

If the transition curve takes a cubic parabola, which coincides with the vertical curve, and its beginning is put to zero point of coordinates, the parametric equations of the "total" spatial curve (see Fig. 1) will have the form:

$$y = \frac{s^3}{6Rl}; \tag{3}$$

$$x = s; \tag{4}$$

$$z = R_v\left(1 - cos\frac{s \pm \delta}{R_B}\right); \tag{5}$$

where x; y – plan coordinates of any point of the resulting spatial curve;

z – the vertical coordinate of any point of the resulting spatial curve;
s – is the distance from the beginning of the transition curve, length l, to the point under consideration ("linear coordinate»);

$$0 \leq s \leq l \tag{6}$$

R_v – radius of the vertical curve, m;
δ – distance from the beginning of the transition curve to the beginning of the vertical curve;

As already mentioned, the curves was simulated in the software complex "UM" to purpose the design capability definitions combing biclotoide and vertical curves and without combing.

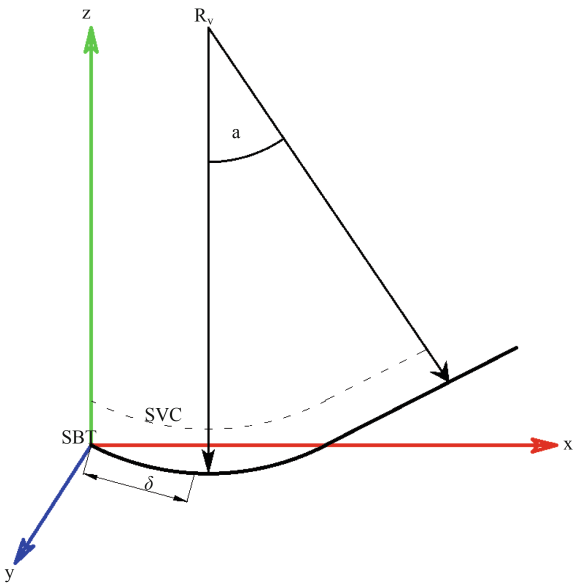

Fig. 1. Space curve

As initial data for modeling were accepted:

- Freight train of 80 cars, which has speed of 70 km/h;
- Passenger train with 16-car traction s, which has speeds of 200 and 400 km/h. The total forces (transverse, longitudinal and vertical) have analyzed between the wheel and the rail by the simulation. The following options were considered:

- "Classic" design - the vertical circular curve is designed outside the transition curves;
- The vertical curve is coincident with the transition curve;
- Vertical curve is coincident with biclotoide in the plan. There are shown the values of the "total" force between the wheel and the rail in the considered variants in Fig. 2:

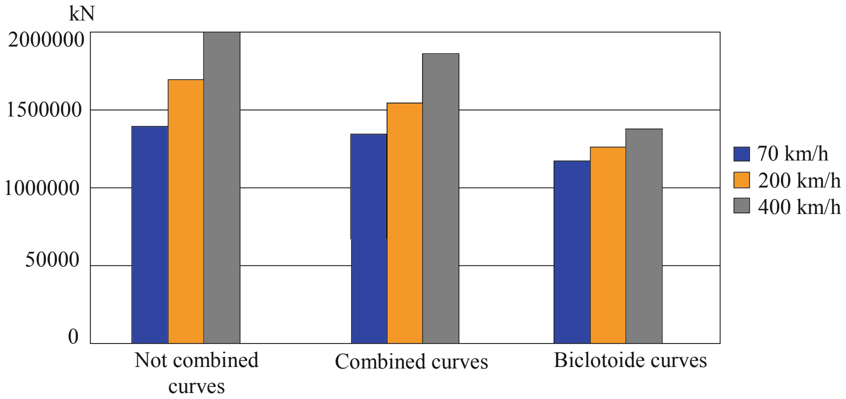

Fig. 2. Comparative analysis of total forces

3 Modeling of Combine Transition Curves in Plane and Vertical Curves in Profile

There is evident that forces by the "classic" design are more than the forces by the combination of vertical curve with a transition at V = 70 km/h to 4%; V = 200 ÷ 400 km/h to 5 ÷ 7%, as compared to biclotoide in terms at V = 70 km/h to 9%; V = 200 ÷ 400 km/h to 15 ÷ 20%.

When the passenger train is moving in a curve, the outstanding acceleration - an-is of great importance for the comfort of passengers. On the basis of experimental researches, it is found that the outstanding acceleration up to 0.8 m/s^2 is tolerated to passengers satisfactorily by prolonged repeated exposure. If this value is increased to 1 m/s^2, the comfort of the trip will not be disturbed while reducing the exposure time.

In confirmation of this, it is worth noting that the permissible outstanding acceleration in the curve is 0.799 m/s^2 on the HSR in Spain, the Madrid – Seville section where the maximum speed is 300 km/h [6].

On the Sverdlovsk railway train "Lastochka" has a maximum speed of 120 km/h [7], the maximum don't extinguish acceleration (a_{ea}) for a given train is allowed $a_{ea}^{max} \leq 0.9\,\mathrm{m/s^2}$, while as experience shows the comfort of the journey for the passenger doesn't fall.

For comparison, on passenger aircraft, the permissible acceleration, which acts on the passenger, is equal to (1,5 ÷ 2) g, or 14.7 ÷ 19.6 $\mathrm{m/s^2}$. Here g is the acceleration of gravity [8].

These arguments may be used for design of high-speed highway with using of combined biclotoide curve in plan with vertical curve in the profile.

It is necessary to take into account the total acceleration a $\mathrm{m/s^2}$, when the train moves by curve whose curvature coincides both in plan and profile (spatial curve). The total acceleration a $\mathrm{m/s^2}$ is defined similarly to formula (1), but by the relation to accelerations.

Vertical – a_v, and the longitudinal acceleration – a_{ln} are usually defined by the terms of comfort:

$a_v \leq 0.4\,\frac{\mathrm{m}}{\mathrm{s}^2}$; $a_{ln} \leq 1.2\,\frac{\mathrm{m}}{\mathrm{s}^2}$, by $a_H = 0.7\,\frac{\mathrm{m}}{\mathrm{s}^2}$, total acceleration for these conditions $a = 1.35\,\frac{\mathrm{m}}{\mathrm{s}^2}$.

The degree of physiological impact of acceleration on a person is affected by time, direction and frequency.

The concept of "force impulse" P is introduced

$$P = M \cdot a_H \cdot t \quad (7)$$

here: M – mass of body;

t – the duration of the acceleration a_H.

The research has shown [9, 10] that force impulse is $P_{400} < P_{200}$ by the movement of the train by way long 1 km to speed of 400 km/h and $a_{ea}^{max} = 1.0\,m/s^2$, P_{200} where the force impulse when $a_{ea}^{max} = 0.6\,m/s^2$, and a speed of 200 km/h. Thus, the force impulse is less than the speed is higher, by the movement of trains by same path length, i.e., it is possible to allow a greater amount of outstanding acceleration. At least, it can be increased to $1.0\,m/s^2$, and after a volumetric research it can be increased to a greater value.

4 Conclusion

1. It is possible to greater using of bichloride design in curved sections of the road;
2. Analysis in program complex "Universal Mechanism" showed, than the combination of biclotoide and vertical curves for curved sections of the track leads to

   – the reducing of interaction forces in the system "wheel-rail";
   – the increasing of smoothness of motion;
   – the improving of the stability of the track.

   This combination proves that the requirements of the Special technical conditions are unreasonable and inadmissible for such a combination.

3. It is necessary to increase the maximum allowable value of the outstanding acceleration to $1.0\,m/s^2$ according the results of our researches.
4. It is necessary to replace some of the limitations and requirements of the design standards by the computer simulation of possible situations. For example, there is possible to define the forces of interaction “wheel-rail” in the design of the profile and plan by the computer simulation.

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Coordination of Parameters of Transportation System Elements

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Abstract. Rationalization of transportation objects is one of the main challenges in the sphere of operations control. The analysis of the currently used optimization techniques showed that they don't always provide economically efficient decisions, e.g., the simulation descent can't guarantee a converge to a global optimum. In order to increase the precision of solutions aimed at improving the design and technological processes of transportation systems a comprehensive study of optimization via simulation literature was carried out. The survey showed that hybrid optimization techniques provide good results and prove to be less time and labor consuming compared to other optimization via simulation methods. As a result, the paper shows an application of hybrid optimization technique in simulation framework on example of chemical and metallurgical enterprise.

Keywords: Simulation · Optimization · Hybrid approach · Coordination of parameters · Transportation system

1 Introduction

Nowadays, a problem of economic efficiency enhancement of railway transport enterprises is becoming more and more relevant. The solution of this problem is closely connected with the determination of correct parameters of station facilities with the impermissibility of excessive and insufficient capacity. Inaccuracies in calculations, in their turn, can lead to huge economic losses from the excess or insufficiency of the capacity of railway transport enterprises.

According to relevance mentioned above in recent years scientist are increasingly turning to a problem of calculating and evaluating capacity of transportation objects [1–3]. They propose different approaches and software programs in order to improve the accuracy of capacity determination. All the known methods for capacity calculation can be divided into following sets: analytical determinate, graphical, analytical probabilistic, simulation modeling and synthetic that are the combination of the previous methods [4].

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Good and comprehensive surveys on capacity calculation methods one can find in [3, 5, 6]. The analysis of advantages and disadvantages of all existing methods shows that the most suitable method for studying transportation objects is the simulation modeling as only it can provide reliable results for the evaluation of the station under consideration [6].

Despite the status of the most accurate and reliable simulation has a number of very important drawbacks:

- creation of a model requires high labor and time resources;
- models of stations are unique because every object has its own unique peculiarities of structure and technological process;
- complexity of optimization.

As it is noted above, experiments with the model are quite time-consuming, require significant computer time, and the functional is usually given in the space of large dimension, so a full search of options is impossible. Therefore, it is necessary to implement some experiments planning procedures in order to repeatedly narrow the set of options and accelerate the recursion of the optimization process.

To avoid a complete search of options a special method of accelerating the optimization process, the so-called «simulation descent», was introduced in [7]. The motion on the result set, in other words the sequence of simulation experiments, forms the simulation descent. It necessary to create a model in such a way that the optimizing objective will be proportional to the total amount of delays.

The optimization is based on random realizations. The results of each experiment depend not only on model parameters but also on random processes. Studies proved that optimization based on random realizations converges to the same result as the optimization based on mathematical expectations. Therefore, the simulation descent uses the optimization based on random realization. Iterations stop after reaching the acceptable total delay in the model. The author of this method points out that in every system there is a delay level that is impossible to reduce and this will be considered as the optimum.

The proposed approach allows reducing the set of options and, consequently, computer time necessary to conduct experiments. Moreover, it enables the determination of some optimal result. However, there are studies [8, 9] showing that gradient-based methods and the simulation descent in particular can't guarantee a converge to a global optimum.

This means that the currently used method doesn't always provide economically efficient decisions. Therefore, the purpose of the study is to develop a methodology for more precise determination of structure elements parameters via simulation.

2 Materials and Methods

As it is mentioned in the introduction, the simulation modeling has a number of drawbacks, e.g. the complexity of finding the global optimum, which affect it is necessary to eliminate or reduce. This problem has been a topic in simulation textbooks and survey papers for many years [10, 11], but efficient and at the same reliable methods still haven't been created. But there is a number of methods that provide good enough solutions depending on the set of input parameters Ψ. If the set Ψ is finite and small, statistical methods (e.g. ranking and selection or multiple comparison) are appropriate. If the set Ψ is infinite or large only ordinal optimization, random and hybrid search methods can be adapted for the simulation environment.

2.1 Small or Finite Parameter Spaces

In finite case, when the solution set is small and fixed, the main purpose is to understand how to allocate the simulation experiments among the feasible solutions. There is no focus on «search», as the pool of alternatives is fixed; each simulation run is used to infer the best.

The optimization that is desired may differ depending on the situation, and could involve:

1. The search for the best solution from a fixed set of alternative solutions;
2. The comparison of output performance measures of each solution to a known standard value or control;
3. The pairwise comparison between all solutions.

The 1-st point is referred to as ranking and selection problem. The 2-nd and the 3-rd points are addressed on multiple comparison procedures [12].

Ranking and selection procedures apply to problems with a relatively small number of potential alternatives. The ranking and selection procedures consider the feasible solutions as categorical, meaning that there is no attempt to exploit relationships among the solutions [13]. These methods have the ability to treat the optimization problem as a multi-criteria decision problem. When it is necessary to select the best system design, the indifference zone ranking technique may be applied. When the goal is to select a subset of system designs that contains the best design, the subset selection technique may be employed. In either case, the techniques guarantee correct and precise results with a pre-specified probability. Nevertheless, the ranking and selection approach has a number of disadvantages. Firstly, it requires high computational time and is rather costly. Secondly, it works only with discrete variables. Finally, ranking and selection wastes effort and computational time due to checking every feasible solution in the solution space.

Like ranking and selection, multiple comparison procedures attempt to identify the optimal parameter values over the finite set of alternatives. Three main classes of multiple comparison procedures are used in practice: pairwise multiple comparisons, multiple comparisons with the best, multiple comparisons with a control. The most popular among them is multiple comparisons with the best. It provides inference about the relative performance of all alternatives tested. Such inference is critical when the performance is not the only criterion for decision making.

Multiple comparison approach considers the optimization problem as a statistical inference problem and, in contrast to the ranking and selection procedures, don't guarantee a decision. It is the major disadvantage of such procedures.

2.2 Large/Infinite Parameter Spaces

To address discrete optimization via simulation problems with a large or infinite number of potential solutions, procedures that have a search component are required. Almost all the algorithms that are applicable to the continuous optimization via simulation case are, with suitable modifications, can be employed for the case with infinite solution spaces. These include ordinal optimization, random and hybrid search methods.

Random search methods are presented by techniques such as tabu search, simulated annealing and genetic algorithms. Most of these algorithms guarantee global or local convergence [14].

Ordinal optimization was firstly introduced by Ho in 1992, developed and treated in the study [15]. It proposes «soft optimization» for discrete optimization via simulation problems when the solution space is too large for ranking and selection methods. It means that the ordinal optimization puts the emphasis on finding good solutions, rather than trying to get the global best solution. By doing this, ordinal optimization reduces the search process from sampling over a very large space of alternatives to sampling over a smaller, more manageable set of satisfactory solutions. So, the task is to find a good solution with some guarantees on quality (called alignment probability). Here, the emphasis is made on sampling over a selected subset of the alternatives and assessing them to determine the best. The main task is to choose this subset such that it contains a subset of appropriate solutions. The quality or satisfaction level of this selected subset can be quantified. A comparison of subset selection rules is presented in [16] and the multi-objective case is treated in [17]. To sum up, the main advantage of the ordinal optimization is the exponential reduction in computational burden due to softening the optimization objective and accepting good suboptimal solutions. The major disadvantage is that this approach doesn't determine the absolute objective values of each solution.

Simulated annealing is a probabilistic search method analogues to the physical annealing process in which the material is cooled very slowly so that it achieves a minimum energy state. Implementation of simulated annealing algorithms require selection of parameters such as the starting and final temperatures, the rate of cooling, and number of iterations at each temperature. Simulated annealing is able to come out from areas of local optima and, therefore, keeps track of the best objective value overall. Regardless the fact that simulated annealing was originally created for optimizing deterministic functions, the algorithm has been extended to stochastic simulation conditions [18, 19]. The simplicity of employing simulated annealing procedures is high and, therefore it remains a popular technique used by several commercial simulation optimization packages and a good building block for hybrid methods. Nevertheless, it is necessary to pay attention to proper selection of seed solution or current state starting point.

Tabu search uses special memory (short-term and long-term) to avoid the stuck in the local optima and to guide the search towards optimal or near optimal solutions by exploring promising regions of the search space. Tabu search is based on a modified neighborhood search procedure that uses adaptive memory to keep track of relevant solution history, together with strategies for exploiting this memory [20]. Tabu search procedures deal well with solution spaces characterized by local optima, but, unfortunately, they are not developed for discrete optimization via simulation [21].

Genetic algorithms simulate the evolutionary behavior of organisms to create subsequent generations that guide the search towards the very best solution. They borrow the concepts of genetic evolution, specifically selection, crossingover, and mutation. In general, all genetic algorithms work on the basis of initial information, which is the population of alternative solutions. The population consists of elements called chromosomes. In each generation of genetic algorithm new chromosomes are created by applying selection, mutation and crossingover functions. The selection process is based on assessing the objective (or fitness) function of each chromosome and selecting the chromosomes in accordance to their fitness values. The offspring chromosomes are then created using crossingover and mutation algorithms. The crossingover and mutation algorithms ensure that a diversity of solutions is maintained. Genetic algorithms are popular because of their simplicity and are used in many simulation optimization software packages. But such algorithms can be hard to analyze and design depending on the complexity of the system being simulated.

To compute good solutions quickly, it is often better to improve after some global search the best solutions locally without considering the rest of the search space. This indicates that a combination of different methods or the decomposition of the optimization process in phases is the best way to optimize stochastic simulation models.

Andradottir and Prudius in [22] point out the importance of synthetic approach to optimization via simulation. They proposed 3-stage optimization that includes balancing exploration, exploitation, and assessment within the framework of simulation optimization, and then presented a random search approach designed to achieve such a balance called BEESE (balanced explorative and exploitative search with estimation) [22]. The authors developed two algorithms: the R-BEESE and A-BEESE having different switch rules between phases. The R-BEESE algorithm switches between global search and local search randomly and the A-BEESE does so adaptively. Each of the algorithms has also the assessment component ensuring the determination of the best estimated performance. The authors in [22] provide numerical results of BEESE implementation and prove that their method converges almost surely to global optimum. The only peculiarity of the approach is that it is addressed on continuous simulation optimization problems.

One more example of hybrid methods is presented in [23]. In this paper, the authors used the existing algorithms in the research literature to combine them together in order to get more precise results. The study provided in [23, 24] shows that the algorithm, called Industrial Strength COMPASS, has nice convergence and statistical properties. The proposed technique consists of three stages: global search (exploration), local search (exploitation) and clean up. The global stage explores the whole space of feasible solutions and determines a small number of good solution seeds. The local stage takes the seed and defines a local optimum. The clean-up stage finds the best from potential solutions identified in the local stage and evaluates its value.

In order to determine the parameters of transport systems the technique has to tackle discrete solution space with high performance and should be low time and labour consuming. Only hybrid algorithm that combines niching genetic algorithm and COMPASS local search procedure can satisfy all the requirements.

3 Results of the Research

In order to confirm the efficiency of the approach proposed to determine the railway system structure elements parameters the paper provides the calculation of a transportation system that belongs to large chemical and metallurgical enterprise. Supporting calculations are carried out in the simulation software system ISTRA, that proved to be a reliable tool for careful simulation of railway logistic objects [25, 26], with the application of hybrid optimization procedure. To reach the goals of the study we considered the transportation system of the plant taking into account a connecting station (Fig. 1). The enterprise is planning to increase the production volumes and, therefore, the task is to determine whether its transportation system is capable to process all perspective traffic volumes (Table 1). If the capacity of the transportation system is insufficient, it is necessary to define the design and technological process that will satisfy all the requirements on performance.

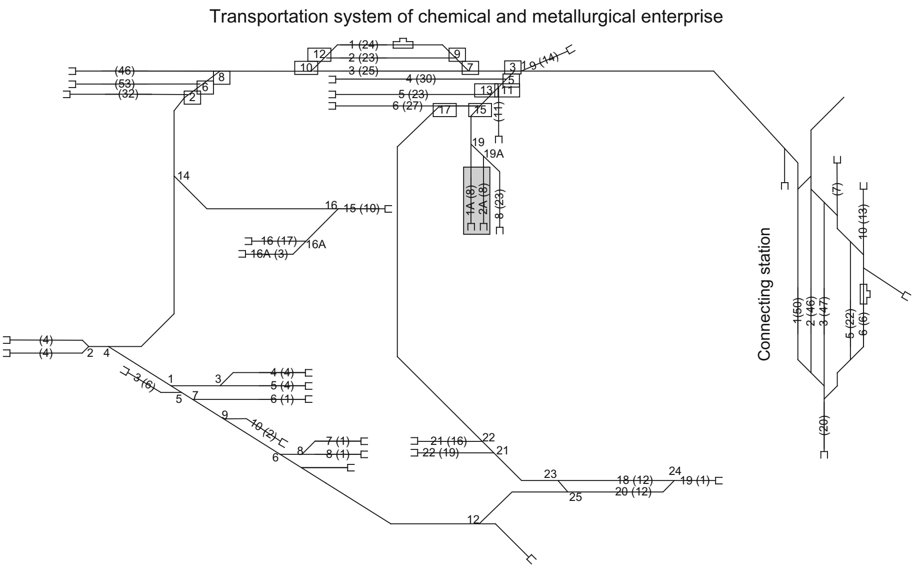

Fig. 1. Track layout of the transportation system belonging to the chemical and metallurgical enterprise

Experiments with the model of the transportation system showed that it can process the existing traffic volumes, but the existing capacity is not enough to handle the perspective. In order to find rational solutions on design and technological process the 3-phase optimization procedure was applied. The application of 3-phase optimization algorithm that includes global, local and clean-up phases allowed determining the possible solutions. On the first phase presenting the global search niching genetic algorithm samples the search space and defines promising seeds for check-up on the next phase (Fig. 2).

Table 1. Perspective railway traffic volumes of the chemical and metallurgical enterprise

Freight types	Perspective volumes				
	Tons/year	Tons/car	Cars/year	Cars/month	Cars/day
Copper concentrate	640000	69	9275	843	**28**
Limestone	25473	68	375	34	**1**
Quartzites	122894	66	1862	169	**6**
Sulphide concentrate	22800	66	345	31	**1**
Construction sands	179760	70	2568	214	**7**
Dust	2100	70	30	3	**1**
Slag	0	0	0	0	**0**
Sulphuric acid	640000	63	10159	924	**30**
Total			24614	2218	**74**

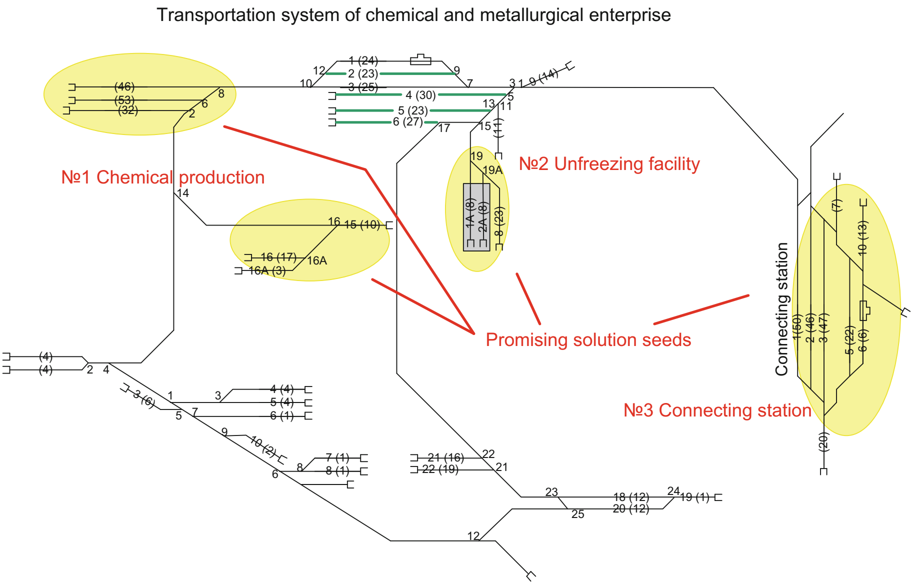

Fig. 2. Possible directions of improving the efficiency of the transportation system design

The second phase of the optimization via simulation algorithm calculates the local optima of the promising seeds. Using the results of calculations it is necessary to develop the transportation system design and its technological process according to constraints imposed by construction possibilities and safety requirements. Taking into account all constraints the second phase results are presented on Fig. 3.

In order to find the best solution the 3-rd phase represents a feasibility study that calculates the economic efficiency of the proposed solutions. In the considered case it is rational to use such an indicator of comparative economic efficiency as «Reduced

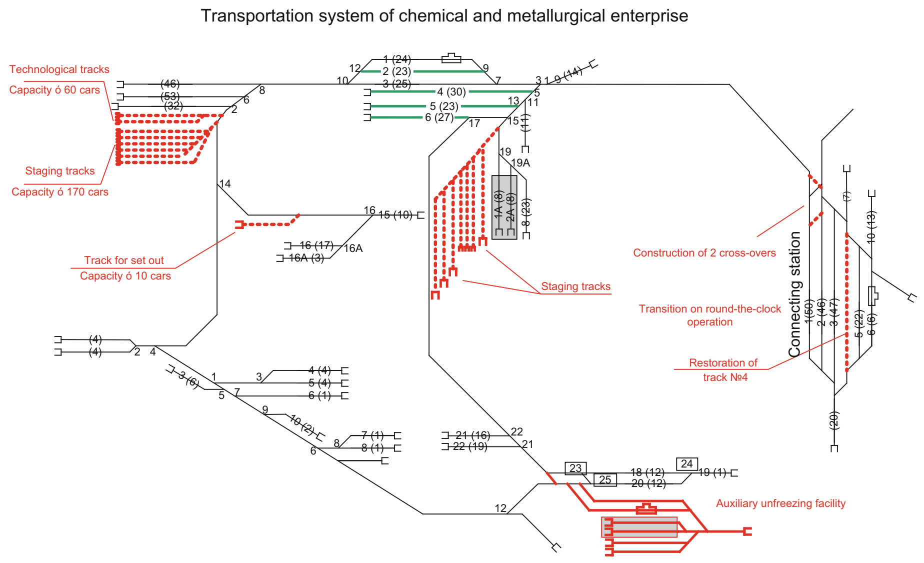

Fig. 3. Results obtained with the use of the second phase of the optimization procedure

construction and operating costs» . The most cost-effective option is the one that has the lowest value of reduced construction and operating costs:

$$C_{rc} = \sum_{t=0}^{T} \frac{I_t}{(1+E)^t} + (1 - \gamma) \sum_{t=0}^{T} \frac{O_t}{(1+E)^t} \quad (1)$$

where T is the time horizon; t – calculation step; I_t – investment costs of the period t; E – discount rate; γ – the share of tax deductions in the increase of the surplus product; O_t – operating costs of the period t.

4 Discussing the Results

The analysis of the currently used optimization techniques showed that they don't always provide economically efficient decisions, e.g., the simulation descent can't guarantee a converge to a global optimum. In order to increase the precision of solutions aimed at improving the design and technological processes of transportation systems a comprehensive study of optimization via simulation literature was carried out. As a result, to improve the efficiency of ISTRA simulation system a 3-phase (global search phase, local search phase and clean-up phase) hybrid optimization technique was selected. Global phase allows fast determining promising solution seeds with the use of niching genetic algorithm. Then these seeds are directed to the second phase where the Compass algorithm defines the local optima. The third phase represents the feasibility study where the perspective solutions from the second stage are compared by criterion of «Reduced construction and operating costs» . The most optimal solution is the one that has the lowest value of reduced construction and operating costs.

5 Conclusions

Drawbacks of the existing methods for support the decision making determined the necessity to apply new more precise methods of optimization via simulation. The most suitable for discrete-event simulation are hybrid approaches that enable multiple-phase optimization. The use of the proposed approach that combines reliable optimization methods that guarantee a converge to an optimum will allow determining more precise results on transportation system design and technology and, therefore, more rational in terms of economic efficiency.

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Integral Evaluation of Business Success: Methodology and Case of Russian SME

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Abstract. The paper proposes an original methodological approach to evaluation of business success and application of this approach for case of small and medium-sized enterprises in Russia. The sequence of calculation of the integrated business success rating is defined and based on the understanding of the company success as its "viability", expressed by the simultaneous ability to grow, to make profit, to be more successful that its business environment. The proposed method is based on accounting data, available in information databases and allows evaluating business success rating for any company in any sample, including statement of the success level of enterprise. The results of applying the proposed method have as independent practical importance in the evaluation of the enterprise's success, and can be used in further study of the success factors of enterprises, especially for small and medium businesses, and to identify best practices for ensuring the priority development of national economies.

Keywords: Business success · Small and medium business · The methodology of economic measurement

1 Introduction

For any scientific project one of the most important issues is the choice of methodology. The problem of the methodology is complicated by the need to develop a way to measure the changing social reality. In each specific research is required to choose an adequate method and adapt it to the available data. Universal methods do not exist. This is a particularly acute problem for microeconomic studies, in the center of which is often the enterprise. Many aspects of the enterprises activity do not have proper methods of evaluation. Conclusions about these aspects are drawn on the basis of rather primitive calculatory procedures, or on the basis of methods developed at other times and for other sets of enterprises. Until now, Altman's method of estimating the probability of bankruptcy is used [1, 2], which coefficients have been evaluated for specific sample in the past.

The method of success evaluation is extremely important both for the public authorities in the development of business support programs, and for the businessmen themselves and their associations for estimating the company activities in dynamics by means of aggregative indicators.

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The purpose of the paper is to develop criteria and system of indicators for measuring the success of enterprises. For goal achievement it is offered to solve a number of tasks:

1. define the "business success" and formulate its criterion;
2. determine the aspects of enterprise activity, which are necessary to evaluate the business success;
3. select the specific indicators to measure the business success;
4. develop the method of integral evaluation of the business success;
5. test the developed methodology on data of Russian small and medium-sized enterprises.

2 Literature Review

The concept of business success is used and developed by Pfann et al. [3], Stonkutė and Vveinhardt [4], Berger-Walliser et al. [5], Brown [6], but there are no techniques for business success evaluating as a concept. The existing approaches for success evaluation can be divided into three groups. The first one includes the success evaluation techniques that are applicable also to the national economy [7]. This approach is developed also by research team lead by Barkhatov [8, 9] for the purposes of the specific applied researches. It can be considered in the development of the offered method, but it is difficult to rely on them directly because of the different objects of an assessment and different tasks given during their development. The second group of methods is based on understanding of success as company's profitability [6]. This is quite simple approach, but it is clearly incomplete: for businessmen profitability is not always the measure of success. These techniques could be easily added to the approaches used in the third group, and based on understanding of success as "survivability" [3]. However, the main problem of all existing methods is in their fragmentariness.

The majority of scientists and analysts agreed with the approach to the assessment of the company according to the scheme: financial stability - liquidity - business activity - profitability. However, there are many other aspects of the enterprise operation, which can and should be evaluated using the original methods, including not requiring additional data besides the existing standard of accounting reports. Inspiring by innovative scientific approach by Popov and his colleagues [10–13], where developed new methodological approaches to economic measurements in different areas of economy.

3 Methodology

A new methodology will be based on the following principles:

- the principle of unambiguity: the method should be based on a clear and unambiguous and pre-formulated understanding of success as the characteristics of the company;
- the principle of completeness: the result of the procedure should be a number or small set of numbers, which analysis will allow to make a conclusion about whether the company is successful;
- the principle of simplicity: the application of the method shall not be complicated by carrying out additional researches except the analysis of the commonly accepted forms of accounting records of the company and its business environment.

The methodology must be unambiguous, simple, give a precise answer to the question about the success of a particular company. Partly this work is inspired by Hubbard's book "How to Measure Anything" [14], which addresses the problem of valuation of intangible assets, information and other difficult-to-measure things. Business success is also a concept with which constantly deal executives, managers, government officials, and which in this case is not unique and not easily measurable. On the basis of the analysis of economic, philosophical, sociological and psychological literature the definition of success of small and medium business (the company's success) has been formulated as its capability to exist indefinitely long, showing necessary activity and achieving goals [15, 16]. Success of the company can be both objective and subjective characteristic. It becomes objective only through its actualization in time. If the company "was, is and will be", it means it is successful. The subjective aspect of the success is seen through the evaluation of managerial decisions which promote the growth of success, which is manifested in the ability to generate profits, conquer new markets and strengthen existing (to grow quantitatively), to reach the intended by the head goals (for example, occupy a more favorable position in the value added creation chains), bring satisfaction (to be better than the competitors). The presented approach allows also formulating a criterion of company success.

To be considered successful, it is enough for a company to make profit, to grow, to achieve the intended purpose and bring satisfaction. These are sufficient conditions of success. If the company at the same time both does not grow, and does not make profit, and does not achieve its goals, and also does not bring satisfaction (things are worse than the competitors have), there is a reasonable doubt about its success. Its sale, closing or reorganization will be the result of the owners' decision about the failure of the company. If it does not occur, then the company is successful. For this reason, as a criterion of success is offered its "existential capacity". This existential capacity is manifested in three aspects of the company: profitability, growth and achieving the goals that are measured both in absolute expression and relative to its competitors (the second method of assessment is more preferable).

The ability to achieve the intended goals – is an extremely subjective and individual characteristic for each enterprise, in the diagnostics of success of the particular company for identification of this capability it is possible to use the questioning data of the head. However, in case of express diagnostics or in case of external evaluation, which is based on observable financial and production indicators, it is not possible to identify this ability. Therefore, let's focus on two aspects of success: the ability to grow and the ability to generate profit. The general requirements to the result of the developed methodology are formulated on the basis of the above-defined criteria and principles set out above. First, the result shall be expressed by a number and allow to draw the qualitative conclusion about the success of the company (successfully, not entirely successfully, failed, etc.); Secondly, the result shall reflect the maximum possible number of the enterprise success characteristics: the ability to grow, the ability to make a profit, the actual "existential capacity", as well as the ability to be a better one among business environment and thirdly, the result should take into account the importance of each characteristic for small and medium businesses. Such requirements can satisfy the integral indicator, the values of which are formed based on different sides of the company activity, expressed by the different initial indicators and calculated directly on the basis of data from accounting records. Thus, the method shall assume the choice of initial indicators of the success assessment of small and medium businesses, a certain way of bringing these indicators in a comparable form and construction on their basis of the integral indicator, taking into account the importance of different aspects of success.

Based on the principle of simplicity, every aspect of success can be expressed by the minimum number of indicators which are present at accounting reports of the company and that would allow to estimate success from outside. It is also important to emphasize that in case of an assessment of company's success it is necessary to consider its results in comparison with its business environment. For an assessment of the ability to grow it is logical to use the index of growth rate. Its positive values will indicate the presence of growth, negative - the lack of it. It is necessary to decide, the growth rate of which index should be used. There are few options: the asset (capital) value, the size of the shareholders' equity and the size of the sales revenue. The first index shows the scale of the company, the second - its financial core refined from borrowed sources of finance, and the sales revenue represents the company's activities. Asset growth is an ambiguous indicator of success, as it can be easily achieved by the growth of debt (loan capital). The growth of the shareholders' equity to the greater extent reflects the success; however, it occurs for two reasons – either the new in-payments of the owners, or emergence of undistributed profit. The first one hardly testifies to the success and the latter is closely linked to the ability of the company to generate profit, i.e. linked to the second aspect. Therefore, the use of the shareholders' equity is not quite correct for the characteristic of the company's growth. The sales revenue is better for our purpose. Thus, the first initial success index is the growth rate of sales revenue:

$$BS_1 = \frac{TR - TR^{-1}}{TR^{-1}} \tag{1}$$

where: TR^{-1} – previous year sales revenue

TR – current year sales revenue.

To assess the ability to make a profit it is necessary to use the relative indexes (profitability indexes). However, there are a lot of such indexes, and the choice of a specific indicator is an uncommon task. Most often in the evaluation of company's activity such indexes as return on assets, profitability of shareholders' equity and return on sales are used. Other indicators of profitability (return on costs, return on labor and return on debt) are used much less often. Besides, various authors suggest calculating profitability both on gross, and on a net profit. In this case, it is more convenient to operate on the contrary. The shareholders' equity in the financial reports of small and medium enterprises is still a big abstraction. Often, due to the accumulated losses in the past years its size is negative or close to 0. In this case, it becomes meaningless to calculate profitability of the shareholders' equity – it will have a sign, opposite with profit, or unreasonably high. Return on assets in case of medium and (especially) small business is quite often distorted by the fact that businessmen use property and other material possessions which belongs to them in productive activity, without reflecting it in balance. Sometimes several legal entities are established, one of which disposes of the property, while the other operates and is liable to the creditors. However for the "normal" entity which is not using such schemes, the return on assets is a very important indicator of success, it allows estimating efficiency of the capital distribution in the course of economic activity. In addition, it can be used to compare the success of companies of different branches - if the capital gives the best return, then the business is more successful, regardless of the reason this return appears. The sales proceeds, on the basis of which the return on sales is calculated – the most objective indicator of medium and small enterprises' activities, it characterizes the result of activity of the enterprise in achieving its goals. However its values greatly vary depending on a field of activity, therefore on the basis of only this indicator to compare success of the enterprises, not engaged in the same activities, is not quite correct. For example, the return on sales in the trade, ceteris paribus, will be significantly lower than in the manufacturing sector. Thus, in assessing the success should be used two indicators of profitability - return on assets and return on sales.

Choosing between the net and gross profit as a profitability indicator numerator, it is offered to stop on net for the following reasons. The net profit is a finite financial result, its presence or growth testifies to success of the company while the gross profit shows the success of the actual production and sales processes. Behind the brackets there are financial management, exchange differences and other important moments for evaluating the success of the enterprise. Thus, the second and third initial index of success – return on assets and return on sales, calculated according to net profit:

$$BS_2 = \frac{E}{S} \tag{2}$$

Where E – net profit of the company for the current period
S – sales revenue of the company for the current period

$$BS_3 = \frac{E}{A} \tag{3}$$

Where A – assets of the company to the end of the current period.

The developed method is intended primarily for subsequent identification of success factors, that is for the retrospective analysis, but not for forecasting or identification of business success at a given time. For this reason it is important to reflect in its results all important characteristics of success taking into account their comparative importance, but not to try to obtain mathematical accuracy in calculation of numerical value of success. Especially, as the aspiration to accuracy in calculations on the basis of booking data steadily faces a problem of accuracy of data itself, adequate reflection in the forms of reporting of a real situation at the company.

It is possible to unite the three offered indexes into a single indicator of success, using techniques that are often used in the decision making models – rating method. For our purpose it is sufficient to use ten-point scale. Taking into account various importance of different components of success (see in [15, 16]) it is reasonable "to assign" 6 points to an assessment of a capability to make profit (three points for each profitability indicator in the method), 3 points - for the assessment of the ability to grow, the remaining 1 point - for the assessment of the ability to exist for a long time (Fig. 1). Depending on a ratio of individual values of each initial indicators of the enterprise's success and values of the same indicator characterizing all sample, the number of points can vary from 0 to 3.

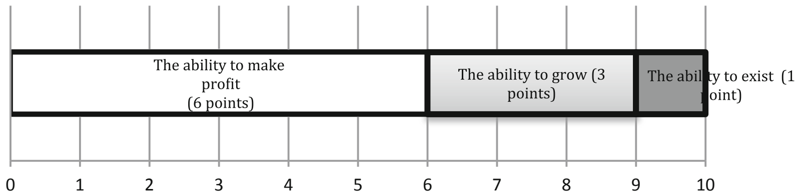

Fig. 1. The structure of the integral rating of business success

For the accounting in the method of the enterprise's business environment its specific characteristics which will be correlated to the corresponding values for the company are necessary. The basic characteristics of any set, giving its initial idea, are the characteristics of central tendency (average values) and variation indicators (standard deviation). By calculating and combining them, it is possible to define the gradation for specific success indicator in the scale of ordinal values. For example, if $\overline{BS}$ is the average value of the success indicator and σ_{BS} - the standard deviation of the same indicator, then it is possible to create the following table to transfer the initial values into points (Table 1). In total, this system has four gradations from 0 to 4, and the boundary ranges of individual values are determined by the average value and the root-mean-square (standard) deviation from this average value (an alternative (and quite legitimate) way to determine the limits of the range is the use of quartiles, but in practice to calculate the mean and the standard deviation is still easier). Thus, if the enterprise's index accepts the less value of sales revenue growth rate (BS_1), than on average the values in sample deviate from the average value (i.e., than $\left(\overline{BS_1} - \sigma_{BS_1}\right)$),

Table 1. Transfer of the comparison result of individual values of success index BS_1 into points

The range of BS_1 values	Qualitative description of index values	R_1
$BS_1 < \left(\overline{\boldsymbol{BS}_1} - \boldsymbol{\sigma}_{\boldsymbol{BS}_1}\right)$	The enterprise is unsuccessful	0
$\left(\overline{\boldsymbol{BS}_1} - \boldsymbol{\sigma}_{\boldsymbol{BS}_1}\right) \leq BS_1 < \overline{\boldsymbol{BS}_1}$	The enterprise is not quite successful	1
$\overline{\boldsymbol{BS}_1} \leq \boldsymbol{BS}_1 < \left(\overline{\boldsymbol{BS} + \boldsymbol{\sigma}_{\boldsymbol{BS}_1}}\right)$	The enterprise is successful	2
$\boldsymbol{BS}_1 > \left(\overline{\boldsymbol{BS}_1 + \boldsymbol{\sigma}_{\boldsymbol{BS}_1}}\right)$	The enterprise is extremely successful	3

then such value is estimated at 0 points if it is more, than $\left(\overline{BS_1} - \sigma_{BS_1}\right)$, but less than the average value in sample then 1 point, etc.

The approach is logical: the company is recognized unsuccessful, only if it not just has worse value of success indicator, than on average in sample (there can be more than a half of such enterprises in all sample, and it is possible to call them "not quite successful"), but also has less than the average value more than on a standard deviation from it in sample (if distribution of the enterprises in sample obeys the normal distribution law, then it is about 15,9% of the bad-working companies). The table for transfer into points will look similarly for all initial indicators of success.

It is also important to understand and take into account in the procedure, that the success of the enterprise is evaluated cumulatively; the heads' perception of the success is characterized by certain inertia. In other words, if the company has been successful in the last year and the year before, then some deterioration in the current year will be considered more as an unfortunate exception of the rule, than as a new tendency. And the perception of success will be more optimistic, than in case of a negative back story. Of course, the "weight" of past achievements in the evaluation of the success has to be lower than the current. For inclusion in the methodology of an assessment of a cumulative factor it is possible to use calculation of the weighted average point value of each success indicator. The period in two years (in the assessment of success of 2015 the result of the company operation in 2013 and 2014 is considered) can be considered as the sufficient depth in accounting of a time factor. In the methodology it is offered to use the following simple way to do that:

$$\hat{R}_1^t = 8/7\left(1/2R_1^t + 1/4R_1^{t-1} + 1/8R_1^{t-2}\right) \tag{4}$$

Where $\hat{R}_1^t$- point evaluation of success on the first indicator in a year t based on the result of the firm activity in the previous two years on the first initial indicator (sales growth rate).

$R_1^t, R_1^{t-1}, R_1^{t-2}$ - point evaluation of success on the first indicator in years *t, t−1, t−2* respectively;

$\hat{R}_1^t$ changes as well as R_1^t- from 0 to 3, but allows to give more exact assessment of success. For example, if in 2012 and in 2013 the success on the first indicator was determined by the value of R equal to 2, and in 2014 has increased to 3, then value of $\hat{R}_1^{2014}$ will be equal to $8/7(1/2 \cdot 3 + 1/4 \cdot 2 + 1/8 \cdot 2) = 2,71$, that is, a little less than 3 (such value would be if for all three years the success would be estimated by value 3 on the first indicator). In the process of further verification of the proposed method the adjustment of the weighting coefficients values or the change of time periods number taken into account is possible. The indicator values of $\hat{R}_2^t$ and $\hat{R}_3^t$ can be calculated similarly. For the accounting of time factor of the Russian firms' existence it is offered to use the indicator with the minimum value of 0 and maximum of 1:

$$R_4^t = \frac{N}{N_{max}} = \frac{t - T_{est.}}{t - 1991} \tag{5}$$

Where t – the current year;

N – the number of years of the firm's existence;

N_{max} – the greatest possible number of years of the firm's existence in Russia (1991)

$T_{est.}$ – the year of the firm's establishment.

Thus, if the firm was established in 1991, then for this firm the value of this success component (R_4) will be equal to $R_4 = \frac{t-1991}{t-1991} = 1$ and if in 2005, then the value of R_4 will depends on the current year – in 2013 the corresponding value will be equal to $R_4 = \frac{2014-2005}{2014-1991} = \frac{9}{23} = 0,391$. Overall assessment of success in points will be determined by the sum of all components of success:

$$RBS^t = \hat{R}_1^t + \hat{R}_2^t + \hat{R}_3^t + \hat{R}_4^t \tag{6}$$

This indicator (rating of business success) varies on a scale from 0 to 10, at the same time higher value of RBS characterizes more successful enterprise.

4 Apply the Method: Case of Russian SME

4.1 Description of Data

The developed method is applied to evaluation of success of small and medium-sized businesses in Russia in 2012–15, carried out on the basis of accounting data of enterprises, which was provided by the First Independent Rating Agency (FIRA) [17]. In total, data on revenue, net profit, assets value, registration date, types of activity, the region in which activities are performed on 11442 companies which in 2009–2015 provided accounting data were obtained. The sample included the companies which in 2015 matched the criterion of belonging to SME – total revenue – from 400 million to 1 billion rubles.

In accordance with the proposed methodology for evaluation of business success, the calculation of the three initial indicators of business success was carried out, i.e. the growth rate of sales revenue, return on sales and return on assets. The sample was cleared of "emissions" on each of these indicators for every year in order to obtain reliable statistically significant results. For the indicator "the growth rate of sales revenue" the range of permissible values included from −0,80 (i.e. reducing revenue no more than 5 times) to 5 (i.e. the growth of not more than 5 times per year). This is a quite flexible restriction allowing leaving in the sample the companies that made a breakthrough as well as the ones that significantly slowed down their activities. For the indicator "return on sales" in the sample were included the observations in which the values were in the range from −0, 5 to 1 (i.e., net loss didn't exceed a half of revenue, and the net profit wasn't more than revenue). This restriction was also quite flexible. For the indicator "return on assets" the range of permissible values was from-3 to 5, which means the net losses which don't exceed 3 magnitudes of total assets and the profit which doesn't exceed fivefold the asset value. As a result in calculations and the analysis the data of 9557 enterprises were used.

4.2 Sample Characteristics

Statistical characteristics of the sample of the three initial coefficients (BS_1, BS_2, BS_3) are provided in Table 2. Distributions on each of the three indicators in 2015 are shown in Figs. 2, 3 and 4. The histograms of distribution are constructed with the Free Online Statistics Software [7]. Noteworthy fact is that in the sample saved substantial variation of signs that explained the broad boundaries of acceptable values. Also it was necessary to calculate the values of boundaries of the ranges for each indicator reflecting different degree of success of companies that was made on the basis of correlation of the weighted average value and a standard deviation in the sample on each indicator. The level of return on sales changed insignificantly, and the level of return on assets decreased slightly (from 5.4 to 4.7%). It means that criteria of enterprise success, according to the offered technique, also underwent significant changes.

Table 2. Sample characteristics

Characteristics	BS_1			BS_2			BS_3		
	2013	2014	2015	2013	2014	2015	2013	2014	2015
Average value ($\boldsymbol{BS_l}$)	0.04	0.05	−0.00	0.034	0.033	0.040	0.047	0.042	0.047
Standard deviation (σ_{BS_i})	0.47	0.47	0.49	0.087	0.099	0.104	0.165	0.179	0.165
$\overline{\boldsymbol{BS}}_l - \boldsymbol{\sigma}_{\boldsymbol{BS}_i}$	−0.43	−0.43	−0.49	−0.096	−0.118	−0.117	−0.054	−0.072	−0.060
$\overline{\boldsymbol{BS}}_l - \boldsymbol{\sigma}_{\boldsymbol{BS}_i}$	0.51	0.52	0.49	0.164	0.183	0.197	0.147	0.156	0.155

4.3 Calculation of RBS for Russian SME's

Part of the computational table with data on 5 (from 9557) companies is presented in Tables 3, 4 and 5, and the calculated values of the integrated business success rating (RBS) in Tables 6 (selected companies) and 7 (generalized values).

The peculiarity of the proposed method is that it allows evaluating the success of the company in the given frames of references in concrete historical conditions. Therefore it is impossible to compare average success by years, but possible to compare the average value of each year, with average values for certain groups of enterprises. The ratio of these indicators of success will allow carrying out the high-quality and deep analysis of the developed tendencies. Distribution of RBS values by years on the companies is provided in Fig. 5.

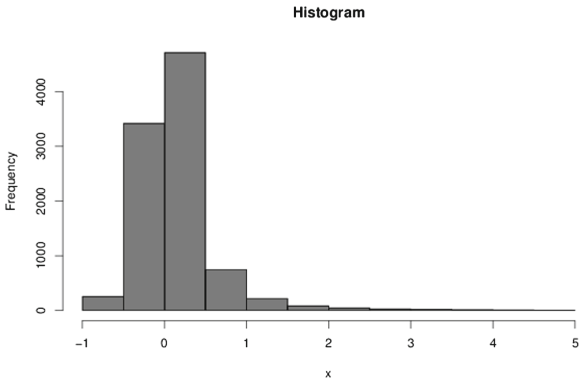

Fig. 2. Distribution of BS_1 in 2015

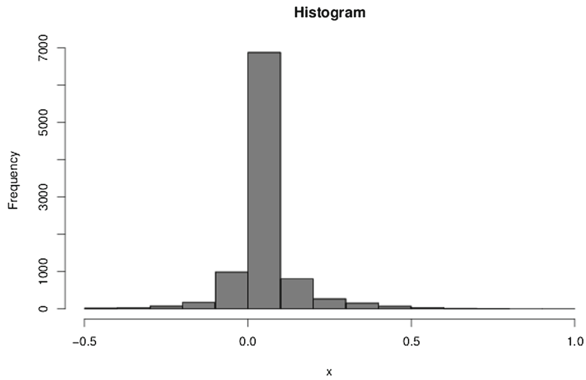

Fig. 3. Distribution of BS_2 in 2015

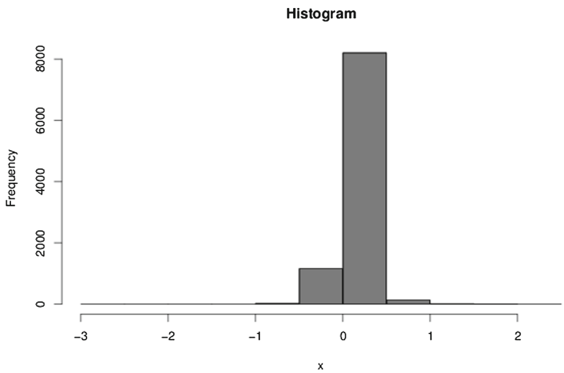

Fig. 4. Distribution of BS_3 in 2015

Table 3. Calculation example of BS_1

Company name	Gross Revenue, thousands RUR				BS_1		
	2012	2013	2013	2014	2013	2014	2015
EAST Ostankino	597,272	692,887	795,389	865,662	0.16	0.15	0.09
Voronezh-Agroprodukt	94,676	111,034	371,995	450,371	0.17	2.35	0.21
Technology BT	896,900	638,861	556,254	636,810	−0.29	−0.13	0.14
TRANSINVEST	12,686	47,424	203,703	464,438	2.74	3.30	1.28
Azon+	259,623	391,069	399,143	412,223	0.51	0.02	0.03

Table 4. Calculation example of BS_2

Company name	Net Profit, thousands RUR			BS_2		
	2013	2014	2014	2013	2014	2015
EAST Ostankino	73	188	16	0.000	0.000	0.000
Voronezh-Agroprodukt	21	129	514	0.000	0.000	0.001
Technology BT	247	140	−857	0.000	0.000	−0.001
TRANSINVEST	−6 676	7 298	4 567	−0.141	0.036	0.010
Azon+	1 986	20 107	5 997	0.005	0.050	0.015

Table 5. Calculation example of BS_3

Company name	Assets, thousands RUR			BS_3		
	2013	2014	2015	2013	2014	2015
EAST Ostankino	23 089	23 248	22 833	0.003	0.008	0.001
Voronezh-Agroprodukt	11 461	10 575	22 644	0.002	0.012	0.023
Technology BT	203 431	133 144	13 331	0.001	0.001	−0.064
TRANSINVEST	14 834	67 402	12 198	−0.450	0.108	0.374
Azon+	28 519	41 652	21 954	0.070	0.483	0.273

The measured indicator has the determined fixed statistical properties, making it a convenient tool for studying the success of small and medium-sized businesses. In the paper [15, 16] it was proposed to allocate three types of success of the companies - the success of the leader (RBS value greater than 7), a successful enterprise (RBS value from 4 to 7) and unsuccessful enterprise (RBS value is less than 4. Using this typology, we can trace the dynamics of the business success as the properties of the entire sample. For calculations on the same sample RBS for 2012–14, it is possible to note a significant reduction (from 23.4% to 20.4%) of a share of unsuccessful enterprises (2012 to 2015), as well as increase successful ones (from 66.9% to 68.2%) and leaders of success (from 9.6% to 11, 4%). Such changes suggest improving the stability of the entire population of small and medium-sized enterprises, a shift in the distribution towards larger mass of successful enterprises that are considered successful among the others.

Table 6. Calculation example of RBS

Company name	R_1 (2013–2014–2015)	$\hat{R}_1^{2015}$	R_2 (2013–2014–2015)	$\hat{R}_2^{2015}$	R_3 (2013–2014–2015)	$\hat{R}_3^{2015}$	R_4^{2015}	RBS 2015
EAST Ostankino	2–2–2	2.00	1–1–1	1.00	1–1 –1	1.00	0.29	4.29
Voronezh-Agroprodukt	2–3–2	2.29	1–1–1	1.00	1–1–1	1.00	0.29	4.58
Technology BT	1–1–2	1.57	1–1–1	1.00	1–1–0	0.43	0.25	3.25
TRANSINVEST	2–3–2	3.00	0–2–1	1.14	0–2–3	2.29	0.38	4.80
Azon+	2–1–2	1.71	1–2–1	1.29	2–3–3	2.86	0.54	6.40

Table 7. Generalized values of RBS for sample data, 2015

Characteristics	Values
Average value	5.11
Standard deviation	1.36
First quartile (Q_1)	4.13
Median (Q_2)	4.79
Thrid quartile (Q_3)	6.02

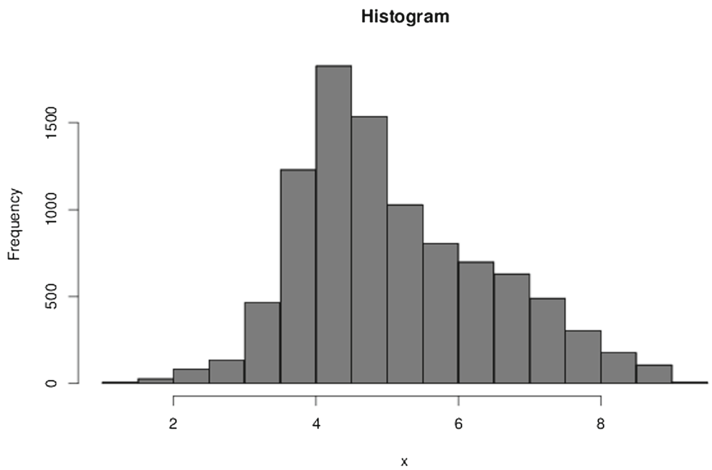

Fig. 5. Distribution of RBS in 2015

In addition it should be noted that 346 enterprises from the sample (3.6%) throughout all considered period (2012–15) were in group of leaders of success. These are the enterprises whose positive experience needs to be researched first of all. 500 enterprises (5.2%) during considered period were unsuccessful. Thus, there is rather insignificant quantity of "hopelessly" unsuccessful enterprises in sample, indicating that the ongoing struggle of the unsuccessful entities for the "place in the sun", that the status of "unsuccessful" - not the sentence, and a period of low growth and low profitability often followed by a period of sustained growth and high profits. Migration of the enterprises from one group on success in another is of interest: how many the unsuccessful companies could become successful and vice versa. Annually 8–10% of the companies change their status. At the same time in 2015 nearly 2% more of unsuccessful companies became successful, than vice versa (9.8% vs. 7.9%)

5 Conclusion

The research has allowed developing the original method of success assessment, considering the specifics of small and medium businesses. The methodology takes into account all the key aspects of the success that can be evaluated according to open data - the ability to grow, the ability to make profit, the ability to be better than business environment and the ability to exist for a long time. The methodology is based on the integrated approach. As a result was received the integrated indicator which allows drawing a conclusion on whether the particular enterprise is successful. The research results can be used in assessment of enterprises' success on industries, on regions and in general across Russia. The conclusion about the success of particular enterprise drawn on the basis of the methodology can become a basis for research of the factors determining its success, a success variation on industries and regions of Russia, as well as the success dynamics of the particular company.

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Trends in the Development of Corporate Ethics in the Company "DHL" and JSC "Russian Railways" in the Current Socio-Economic Conditions

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Abstract. The scientific article is devoted to the development of corporate ethics in the largest domestic and foreign companies. Compliance with the norms of corporate ethics contributes to the moral cohesion of the workforce, awareness of responsibility for the results of work, willingness to sacrifice personal interests for the sake of the common cause and, as a result, the stable development of the company, which is proved by the comparative analysis conducted by the authors. It is note that the analysis of corporate ethics in the context of labor relations is a new direction in economic science. The object of the study was the Russian JSC "Russian Railways". The basic ethical principles that guide the company "RZD" are list. The interrelation between the values of the brand "Russian Railways" and the competencies of their employees. The system of motivation in the DHL Company is present. The internal communications of the Moscow representative office of DHL and the system of internal communications of Russian Railways are investigate. The comparative analysis is carry out and features of system of internal and external communications in the DHL and JSC Russian Railways are reveal. It is conclude that in any national corporate ethics objective and subjective factors are closely intertwine, universal features are combine with the national characteristics of the system of labor relations and the specifics of the regional mentality, the industry of the company.

Keywords: Corporate ethics · Socio-economic conditions · Transport

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1 Introduction

For modern companies have become relevant to the development and adoption by all members of the workforce of a certain set of ethical standards that could work to achieve their goals. This would make it possible to deal with internal conflicts, staff turnover, and weak labor discipline in the absence of motivation to work, violation of basic justice in the distribution of profits, disclosure of trade secrets and betrayal of common interests. Compliance with the norms of corporate ethics contributes to the moral cohesion of the workforce, awareness of responsibility for the results of work, willingness to sacrifice personal interests for the sake of the common cause and, as a result, the stable development of the company. Under the influence of corporate ethics, the activities of employees are organize not so much based on orders and compromises, but at the expense of internal consistency of aspirations. The company, built on the unity of the worldview and values of its members, becomes the most harmonious and dynamic form of the business community [1].

Compliance with the rules of ethics of business relations by employees becomes the “business card” of the company and largely determines the desire of external partners or customers to cooperate with this organization, as well as how successfully their relationship will develop. Employees and others always perceive the introduction of corporate ethics standards into the practice of corporate relations benevolently, even if a person does not have enough proven skills in applying the rules of ethics. The effect of perception is enhance if ethical behavior becomes natural and only possible in a given organization.

2 Study Methodology

The purpose of the publication is to analyze the scientific literature, regulatory framework and the results of research on corporate ethics of the transport sector to determine the main trends in its development in accordance with the socio-economic development of Russia. The study used the following methods: systematic approach, comparative analysis, analysis of official statistics; method of analysis of documents. Analysis of corporate ethics in the context of labor relations is a new direction in economic science. Of the total volume of scientific literature, first of all, it should be noted the work of economic and philosophical nature of foreign and Russian authors (A. sen, A. Rich, P. Kozlovsky, K. Shtaylman, I. Agapov, M. Makashev, etc.) on General economic ethics, which, along with others, affect the problems of corporate ethics. Close to our topic of the work of domestic authors on corporate governance, personnel management, management styles, scientific organization and motivation (M. Grachev, V. Vesnin, V. Dyatlov, A. Rofe, A. Zhukov, etc.). However, this group of researchers did not set itself the task of special consideration of corporate ethics. Recently, there have been works of domestic authors, especially devoted to the problems of business ethics in Russia (V. benedictova, E. Utkin, Yu. Petrunin, V. Borisov, V. Spivak, etc.), as well as a number of empirical studies on this topic (V. Radaev, R. Ryvkina, etc.). Thus, it should be note that traditionally the problem of corporate ethics has been reduce mainly to the ethics of business relations. Relations between entrepreneurs themselves, as well as their relations with customers, the public, authorities.

3 Assessment and Results

According to experts, the following types of codes are currently the most popular in the field of personnel management: professional and corporate. Professional ethical codes regulate the relationship of people within the professional community and, according to experts, are most effective for professional teams, where professional ethical dilemmas are most pronounce [2].

Corporate codes of ethics, which we will consider in this article, are aim at regulating possible contradictions in the interests of interested groups: personnel, shareholders, suppliers, contractors, and the state. The main objective of such documents is to establish priorities in relation to the above-mentioned target groups and ways to harmonize their interests [3].

Corporate ethics of the company “DHL” is express in the Code of business ethics of the concern “Deutsche Post DHL”. The provisions of this code apply to all employees of the concern. Codes of the concern’s subdivisions and regional structures must comply with this Code [4].

The main provisions of this document are as follows. Employees should demonstrate perfect behavior with clients and shareholders; maintain transparency of operations, not to disclose internal information and not to “launder” money. In addition, they should work in accordance with the norms of free market and competition, as well as anti-corruption norms. Employees must keep a written record of all business transactions in accordance with the reporting standards. Employees have the right to choose whether to join a trade Union or not. Employees should not engage in illegal activities in the workplace. In addition, employees should contribute to the improvement of the atmosphere of partnership and openness in the team. In addition, they are responsible for the personal data with which they work, for the property of the concern.

The company highly appreciates such abilities of employees as initiative, responsibility for their actions. The company also strives to improve the emotional and physical well-being of employees in the workplace by improving working conditions, reducing the possibility of accidents, prohibiting discrimination against employees on any grounds prohibited by law. Interaction with stakeholders is important for the concern’s management. Therefore, programmers of personnel development, meetings with shareholders, and the determination of the points of view of the customers on various issues [5].

Issues of social responsibility of the concern are expressed in the motto “Responsibility as a way of life”, which implies the introduction of technologies that preserve the environment, monitoring of carbon dioxide emissions, supporting the education of employees, providing assistance in case of disasters.

The provisions of this code based on international documents such as the universal Declaration of human rights, the UN global compact and the Declaration on fundamental principles and rights at work [6].

Several points should be add to continue the description of this Code of Conduct. The concept of quality is the basis of concern management and employee behavior. Employee qualifications are measure by skills, performance, and ethical behavior. Giving and receiving gifts must comply with applicable laws and business ethics. As part of compliance with this Code, an employee must report violations to their supervisor or use a hotline number [7].

Corporate ethics of JSC “Russian Railways” expressed in the Code of business ethics. The code of business ethics based on the legislation of the Russian Federation, the principles of international law, business ethics, as well as long-standing traditions of the railway industry. This Code serves as the basis of business ethics of Russian Railways holding, contains basic corporate values, norms and rules. Codes of subsidiaries should not contradict the code of JSC “Russian Railways» [8].

The main ethical principles in JSC “Russian Railways” are:

- put the person in the first place;
- to work on the conscience;
- be proud of the title of an employee of Russian Railways»;
- rely on skill;
- result-oriented;
- make informed decisions;
- by a leader;
- to observe the economic interests of Russian Railways»;
- the desire for new.

Due to the nearly two hundred years of the company’s history, it developed the values of the Russian Railways brand, which improve production activities, positively affect team cohesion and enhance the prestige of the Russian Railways brand. These values are express through specific competencies in Table 1.

Table 1. The relationship of the values of the brand “Russian Railways” and the competencies of their employees

Values	Competences
Skill	Competence
	Client orientation
Integrity	Corporate identity and responsibility
	Quality and safety
Update	Creativity and innovation
	Leadership

The basis of the interaction of the JSC “Russian Railways” and employees is mutual respect and focus on results [9].

The company’s responsibility to employees is to comply with the legislation of the Russian Federation, to ensure a stable salary, to provide social security, to provide material or social support, to develop the education system, motivation, to prohibit discrimination on any grounds, non-interference in the personal life of employees. The responsibility of employees to the company is compliance with the legislation of the Russian Federation, the performance of their duties, the manifestation of responsibility and initiative, respect for the interests of the company, refusal to participate in questionable transactions, correct behavior with colleagues and customers, the presentation of all business documentation of the company in accounting, compliance with anti-corruption requirements [10].

Employees should be guide by the following principles: creating an atmosphere of trust and mutual understanding, discipline, punctuality, teamwork, rejection of corruption.

The principles of the company's management: to proceed from the interests of the company, to respect the rights of employees, to maintain the reputation of the company, to comply with the legislation of the Russian Federation, to prevent the company's participation in questionable transactions, to maintain a culture of rejection of corruption, to regulate conflicts of interests of employees [11].

The company does not have a policy of protectionism, benefits and privileges of individual employees. Company employees are responsible for disclosing confidential information.

Giving and receiving gifts is possible, if it does not contradict business practice, the legislation of the Russian Federation and ethical requirements.

Occupational safety is the responsibility of the company's managers. Employees are obliged to observe safety precautions not to harm not only themselves but also others, as the railway infrastructure is a source of increased danger for citizens [12].

The JSC "Russian Railways» is committed to environmental protection and rational use of its resources.

Being a system-forming enterprise, JSC "Russian Railways" in relations with the shareholder (Russian Federation), subsidiaries, customers, and competitors conducts transparent activities based on honesty, mutual respect and trust.

The JSC "Russian Railways" conducts an active socially responsible policy in all regions of its presence through the construction of educational and medical institutions, interaction with communities, ensuring the safety of workplaces, organizing sponsorship activities, by promoting significant values through corporate media.

Control over the observance of the provisions of this Code deals with the Commissioner on business ethics, appointed by the President of JSC "Russian Railways, as well as a special Commission [13].

General principles of corporate ethics of Deutsche Post DHL and JSC "Russian Railways": prohibition of discrimination, General competence (quality, customer focus, responsibility), keeping records of business documents, rejection of corruption, inadmissibility of participation of the company in questionable transactions, responsibility for non-disclosure of confidential information, interaction of companies with stakeholders on the basis of honesty and trust, procedure for receiving and giving gifts, social responsibility and environmental protection, teamwork of employees, occupational safety.

In addition, the features of corporate ethics in these companies are highlight. The Code of business ethics of Deutsche Post DHL based on international documents, as the concern operates not only in Germany, but also in other countries of the world.

The Code of business ethics of JSC "Russian Railways" is based on the principles of international law, as well as the legislation of the Russian Federation, as JSC "Russian Railways" carries out its main activities in Russia, also takes into account the peculiarities of the Russian company. In terms of monitoring compliance with the Code, the management of the concern "Deutsche Post DHL" relies on the consciousness and activity of the staff in identifying cases of violations of the Code and in the company of JSC "Russian Railways" for the implementation of the Code Commissioner responsible business ethics and a special Commission. JSC "Russian Railways" noted a strong influence on the behavior of employees of the traditions inherent in the railway industry, as well as a well-developed system of values of the company and the system of communication of brand and competencies. In JSC "Russian Railways" features of the railway industry affect the awareness of employees of the responsibility for the safety of citizens (passengers, customers).

The system of motives and incentives in companies encourages employees fully disclose their abilities, effectively and with full dedication to work and effectively use production resources [14].

The motivation system in DHL is present in the form of the following instruments: material and non-material incentives. It should be note that the methods of material incentives, as well as training, as a method of non-material incentives based on the grading system, which involves ranking positions in the organization, assigning each weight and the allocation of the ranked positions of levels or groups with different amounts of contributions [15].

1. At DHL, material incentives include methods such as:
2. Wages. It is present in the form of salary.
3. The increase in wages. The increase in the level of wages occurs once a year based on certification of employees and reaches 10%.
4. Bonus system. It operates on the principles of payments to employees in different amounts, with different frequency, as well as according to the principle of the General formation of the premium part of the remuneration of employees at all levels. The premium system based on the company's mission and goals in the market (regional and global). The award consists of three parts: the amount of remuneration for the implementation of individual goals and objectives, team tasks and goals of the company [16].
   Below is a description of the structure of the premium for each category of employees with the same scheme of bonuses in Table 2.
5. Benefit system (social package). Compensation, benefits and guarantees in DHL distributed according to the level of the position, its weight within the company. General benefits (i.e. for all employees at all levels) are paid Lunches, medical insurance, tuition, sick leave, vouchers, travel expenses (for those who travel on business trips). Benefits for employees at different levels may include mobile phones, cars, etc. Packages of such benefits may depend on the needs of a particular position or the level of positions.
6. Long-term life insurance program. It consists in the payment of sums of money to an employee of the company. The guarantees are a letter from the company's headquarters, which establishes an obligation to pay the amounts and a tripartite

Table 2. Characteristics of the structure of the premium part of DHL employees

DHL employee category with the same award scheme	Characteristics of the structure of the premium part
1. Top managers and line managers	The award is calculate on three indicators: profitability of the company (60% of the total premium), service and customer satisfaction (30% of the total premium) and individual achievements of managers (10% of the total premium). The total amount of the bonus can be up to 30% of the annual earnings
2. Trader	The scheme of the award, the frequency of payments associated with tracking the actual and measurable results. The total amount of the bonus can be up to 40% of the monthly salary
3. Employees from the front-line group (couriers, agents, etc.)	The total amount of the bonus can be up to 15% of the monthly salary
4. Employees from the back-line group (accountants, HR Department employees, secretaries, etc.).	Annual bonus or 13th salary, which is up to 9% of the annual earnings. This award is relate to the overall achievements of the company on the main indicators: profit, sales, service level

agreement between the head office of the insurance company, the head office of DHL and the division of the company. Nevertheless, it is worth noting that this program is rarely use because of its unreliability and complexity of providing guarantees of payment of funds to employees under this program [17].

Corporate parties and employee training represent methods of non-financial incentives. Staff training includes such types as social programmer (at the level of the headquarters of the “DHL”), the annual learning MBA, MBA training at the local, and promotion up the job ladder within the company.

To start, consider material incentive method:

The system of employee motivation in JSC “Russian Railways” can be consider in the aspects of material and non-material incentives, as instruments of motivation.

To start, consider material incentive method:

1. The corporate system of remuneration. It determines the salary scheme of employees depending on the level of the position. Wages of workers is carried out at hourly wage rates, which are determined by the wage scale for workers, consisting of 4 categories. The work of employees is paid on a monthly salary based on a seven-digit tariff scale, which includes categories from the 2-nd to the 8th. Remuneration of managers and specialists based on monthly salaries, the amount of which depends on the complexity and importance of labor functions.
2. Bonus system. It includes 3 levels in Table 3.

Table 3. Bonus system levels

Bonus system level	Characteristics of the level of the bonus system
First level	Conditions for awarding employees, which reflect the level of train safety, health and safety
Second level	Key tasks that help to assess the effectiveness of production and economic activity of the branch of the company (structural unit)
Third level	Individual performance bonuses, which give the characteristics of the employee or group of employees

3. Social package. The social package of JSC "Russian Railways" includes compensations, benefits, guarantees that employees receive based on the legislation of the Russian Federation, in excess of the legislation of the Russian Federation, guarantees, compensation and benefits to non-working pensioners and their families. The social package based on the legislation of the Russian Federation includes indexation of wages, payment to employees (those who do not receive an official salary) of additional remuneration for non-working holidays in which they were not involved in work and so on. The social package in excess of the legislation of the Russian Federation includes guarantees, benefits and compensation related to the peculiarities of the production and technological process in railway transport (for example, compensation to employees who live in residential premises of the housing stock of JSC "RZD", the costs of their employment), various types of material assistance (for example, material assistance when leaving for annual paid leave, payment of a one-time disability benefit received through the fault of the company, etc.) [18]. Social security of pensioners includes non-state pension provision of employees through NPF "Blagosostoyanye", financial assistance to veterans of the great Patriotic war to the victory Day and other. Support for employees' families includes payment of maternity benefits in the amount of 100% of the average monthly earnings, payment of a one-time benefit in the amount of 4600 rubles for the birth of a child in excess of the legislation of the Russian Federation and so on. After describing how motivation carried out in the company of JSC "Russian Railways", we should highlight some of the problems associated with motivation in this company, namely: reducing the prestige of railway professions, uncompetitive wages of employees compared to other industries, high age of staff. Therefore, these companies have methods of material and non-material incentives. They share a salary, a bonus system and a social package (benefits) as methods of material incentives, as well as training, holidays and parties (non-financial incentives). Regarding this, it is worth noting that the company "DHL" in comparison with the company of JSC "Russian Railways", also held an increase in wages and there is a long-term life insurance program. And "DHL", and OAO "Russian Railways" salary is calculated depending on the level of the post ("DHL" - given grading system in JSC "Russian Railways" - given the pay scale and complexity, the importance of job functions). In the award system of DHL, there are categories of employees with a certain bonus scheme in addition to the levels of the bonus

system, and in Russian Railways, the bonus awarded at certain levels. As for the social package, the content of the social package in JSC "Russian Railways" differs depending on the level at which the social package is provided, at the legislative level or at the level above the legislation. In addition, non-working pensioners and their families have a special content of the social package. At DHL, compensation, benefits and guarantees vary depending on the level and weight of the position in the company. Problems also identified in the methods of material and non-material incentives in these companies. Thus, the problems in JSC "Russian Railways" related to the low prestige of railway professions, uncompetitive salary compared to other industries, high age of staff. At DHL, the problem is the poor performance of the long-term life insurance program due to the unreliability and complexity of providing guarantees for the payment of funds to employees under this program. As for communication in organizations, the most stable operation of the system of internal communication depends on the number of communication channels, the frequency of their use and the vector of the direction of communication flows. Companies often use such communication channels as meetings, meetings, training sessions, publication of information on stands, on Internet sites, in Newspapers, magazines, sending information to certain employees at home e-mail addresses, sending information to employees at workplaces, publishing brochures, catalogs, and leaflets. In the Russian representative office of the DHL Express Company, internal corporate communications carried out by means of a corporate portal, mass media, an internal social network, and Bulletin boards. For example, the company publishes monthly newspaper "DHL Live" for employees, quarterly magazine "Inside", and publishes news on the corporate Internet [19]. In addition, the Moscow contact center "DHL Express" as a means of communication used: training program for new employees CIS (Certified International Specialist), personal meetings with employees to monitor their work, "Communication Day" (an event held in order to convey to employees the global goals and objectives of the company), "As One" (speech of senior management with words of gratitude to each employee), "Tea with the Director of the Department" (monthly meeting of employees with the head of the Department in a relaxed atmosphere) to increase the motivation of employees, as well as joint trips, trips to sports events [20]. External communications are carried out through websites, social networks, job sites, media, outdoor advertising. By the way, speaking of magazines, it noted that a corporate magazine "Delivered" published for the company's customers. External communications manifested through the social activities of the company. Thus, the company pays special attention to the protection of nature and the environment (GoGreen), disaster relief, natural disasters (GoHelp), education (GoTeach), support for volunteer activity of employees (international volunteer Day, volunteer theater DHL Charity team from DHL Express in Russia). The system of internal corporate communication in JSC "Russian Railways" is necessary for the formation of a common information and value space in JSC "Russian Railways", as well as to create a corporate identity of employees of JSC "Russian Railways» . An effective system of internal corporate communication contributes to the involvement of employees in the work, motivation, creating a favorable climate in the team, the formation of a corporate culture according to the values of the brand, improving feedback. Units responsible for the organization of this system carry out internal corporate communication [21]. At the Central level, the Center of internal policy and development of corporate culture is responsible for the organization of internal corporate communications, carrying out functions on the formation of approaches to the implementation, functioning, coordination of processes of internal corporate communications. At the regional level for the organization of internal communications are responsible:

- corporate communications services of the regional center of corporate governance, which are engaged in ensuring the operation of the communication infrastructure;
- personnel management services of the regional center of corporate governance, which in particular are engaged in communication support of career guidance;
- assessment centers, monitoring of personnel and youth policy, which deal with informing employees and getting feedback.

Units executing an order for internal corporate communications bring information to the target audience through communication channels in accordance with the goals, objectives and principles of the internal corporate communications system.

4. Internal communications include the following communication channels in Table 4.

Means of external communication contribute to the formation of the image of JSC “Russian Railways”. Therefore, the company uses the following means of external communication:

1. Means of communication with the external public: the website of JSC “Russian Railways”, the media, brochures at stations, video advertising in modern cars on video panels.
2. Means of communication with the professional community: business media, transport, railway media, organization of own forums, conferences, meetings (participation in such events held by other entities). For example, the company holds a conference “Strategic partnership 1520” to unite the interests of manufacturers and consumers of railway equipment and technology for business development and economic relations of countries with a railway gauge of 1520 mm.
3. Social activities (cooperation of the company with state and local authorities on the development of sports, culture, education and health) [22].

Next, you should compare the system of internal and external communications in DHL and Russian Railways and identify the features.

Internal communication: these companies have similar means of communication, such as formal communication (document management system), informal communication (personal communications of employees, communication in social networks), corporate media (magazines, Newspapers, Internet), visual information (DHL - Bulletin boards, JSC Russian Railways - stands, wall Newspapers), awareness raising activities (DHL - Communication day, JSC “Russian Railways” - information Day), corporate education (in “DHL” - CIS program, in JSC “ Russian Railways » - professional development programs, special training programs). The peculiarity of internal communication in the company “DHL” is that in the Moscow contact center “DHL Express”

Table 4. Internal communication channels

Communication channel	Communication channel example	Characteristics and features of the communication channel
1	2	3
1. Formal communication channels		
Document management system	Orders, instructions, instructions	Information capacity, limited only by official information, high subordination between recipient and sender
Session	Session in the office of the chief, in the conference rooms	High efficiency, small audience coverage and the need to distract employees from work
2. Corporate mass media		
Print and electronic corporate media	Road Newspapers, the magazine “control Panel” newsletter “On the home. Russian Railways”, etc.	High employee trust, availability, high information capacity
Web tool	Internet	Work in online, an increased effect of feedback, low availability
Corporate television	Corporate TV channel Russian Railways	High impact communication ability, short life of message
3. Awareness-raising products		
Distributing material	Brochures, booklets, posters, leaflets, etc.	Visibility for a long period of use
Visual information tools	Information stands, wall Newspapers, etc.	Traditional, visual, flexible format, the need for visual presentation and periodic updating of information
4. Corporate event		
Corporate event	Information day	Informing employees of the company about important work issues at the same time in all departments
5. Informal communication channels		
Personal communications of employees	The conversation of the members during a break, to share work	Informality, emotional involvement of communication participants, distortion of information, poor communication control
Public informal communication in social networks	Social network: vk.com, facebook.com, twitter.com, odnoklassniki.ru и т.д.	Almost complete anonymity and high efficiency of information, weak psychological involvement (compared to informal communication)

(*continued*)

Table 4. (*continued*)

Communication channel	Communication channel example	Characteristics and features of the communication channel
6. The system of corporate education		
Professional development programs, special training programs for employees of JSC “Russian Railways”, etc.	Training program for managers and specialists of divisions of JSC “Russian Railways”, training program for locomotive drivers, etc.	High assimilation of information
7. Feedback tools		
Sociological research in labor collectives	Unified sociological survey to control the implementation of the Strategy of development of the company’s personnel potential and the study of the socio-psychological climate in the teams	Analysis of the situation, identification of problems and ways to solve them
Help resources	Unified information and reference resource “Hot line” for employees of JSC “ Russian Railways»	Functioning on the principle of a common feedback channel. The work carried out by collecting applications of employees of JSC “Russian Railways”, coming to the management
Television program	TV program “Open conversation»	Direct communication of the President with employees on issues of interest to employees
Corporate blogs and social media groups	Forums on the official website of JSC “Russian Railways”, on the portal of the Corporate club “Team 2030»	Receiving feedback from employees United on different grounds (age, profession)

practiced personal meetings with employees, informal meetings of employees with superiors, an event where the management thanks employees for their work, joint trips, trips to sporting events [23]. The company of JSC “Russian Railways”, in turn, has a corporate television, handouts are used, and there is a highly developed system of receiving feedback from employees.

Both companies use company websites, mass media, outdoor advertising, and social activities as means of external communication. The main difference is that Russian Railways holds its own forums and conferences.

4 Conclusions

Increasing the role of ethical aspects in the modern system of labor relations allows us to consider corporate ethics as an important tool for effective social management. As such, corporate ethics has a number of features:

- corporate ethics, brings together all participants of the company;
- company personnel are increasingly involved in the development of corporate ethics;
- forms of corporate ethics are very diverse and largely depend on national and regional characteristics, the specifics of the sphere of economic activity, industry;
- corporate ethics requires rather long-term explanatory and educational work among the objects of its impact;
- a characteristic feature of corporate ethics is that its subjects (participants in the development) become simultaneously the objects of its impact.

We consider the following factors to be objective: with the growing maturity of market relations, the role of corporate ethics in the regulation of the system of labor relations and the economic interest in its use as a tool for improving the competitiveness of the company increases; socio-cultural factors also act on the formation of corporate ethics. The role of trade unions in the transforming socio-economic conditions, as well as the weakness of the ethical basis of entrepreneurship can be consider as a subjective factor.

Based on the analysis of features the main directions of improvement of corporate ethics of the companies in modern social and economic conditions allocated:

- updating of the code of ethics, which should focus on labor relations, the interests not only of the external environment (consumers, business partners, the state), but also the needs of the subjects of the Corporation (shareholders, managers, employees);
- use of in-house education as a tool to disseminate ethical standards;
- Strengthening the role of trade unions and social partnership in the formation and implementation of corporate ethics.

A comparative analysis of the corporate ethics of DHL and Russian Railways showed that objective and subjective factors closely intertwined in any national corporate ethics, universal features combined with the national characteristics of the labor relations system and the specifics of the regional mentality, the industry [24].

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Efficiency of the Production Process of Grinding Rails on the Basis of Optimizing the Periodicity of Works

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Abstract. Rails grinding process in the conditions of the railway track - this is one of the most promising technologies that allows extending the rails service life due to the timely elimination of defects on the rolling surface. The main problem constraining the correct application of modern technology is the appointment of a rational frequency of rail processing, which does not allow defects to develop to a critical level. At the same time, very frequent grinding results in additional operating costs and a decrease in the service life of the rails due to artificial wear-out. Thus, a contradiction arises, on the solution of which the researches presented in this article are directed. As a criterion for the efficiency of the production process of grinding of rails, the indicator is adopted - the life cycle cost of rails (Life Cycle Costs, LCC). To calculate the LCC, the costs that have the greatest impact on the life cycle cost of the rails were determined. A method for calculating the LCC has been developed and an approach has been proposed for evaluating the effectiveness of the assigned processing frequency using the values of this indicator. The proposed solutions are based on the managing normative-technical documentation. Based on the developed methodology, the LCC was estimated in two ways: with recommended periodicity values and with adjusted periodicity, obtained based on the results of statistical studies. The calculations showed that the main influence on the annual operating costs have a rails defectiveness and the frequency of their grinding. The value of these costs will be different for different parts of the track, differing by design and operational characteristics. Accordingly, the recommendations for periodicity will be different. Thus, reducing the cost of operating the railway track requires a targeted approach, and the results will serve as a basis for making decisions when planning technological impacts on the grinding of rails.

Keywords: Grinding rails · Defects of rails · Life cycle of rails · The cost of maintaining the railway track

1 Introduction

Russian railways are the one of the largest railway lines in the world, a key element of our country's transportation system. The main task of the railway is to ensure uninterrupted and safe train traffic.

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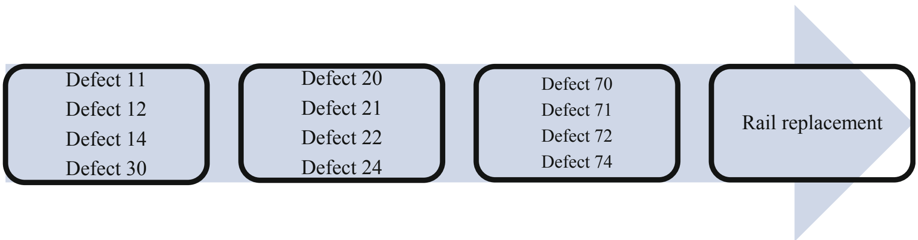
The most expensive and responsible element of the railway, the condition of which primarily determines the uninterrupted and reliable train traffic, are the rails.

In order to maintain the rail industry in good condition, more than 3 million tons of new rails are required annually. In modern conditions of railways operation with increasing speeds and load density, the need for new rails only increases every year, so the task of extending the life cycle of rails has a huge importance for the railway sector's railway facilities [1].

As for today, the main technology to solve these problems is rail grinding technology using rail grinding trains. The main advantage of this technology is the possibility of processing the rails directly on the track without dismantling them [1, 2].

The rail grinding technology is primarily aimed at removing defects that occur on the rolling surface. Such defects include wave-like wear-out and slippage, cracks and chipping, mechanical damage, crushing and delamination of the metal. In addition, to ensure the best contact of the wheel and the rail, grinding provides the required geometry of its transverse profile [1, 2].

Although predominantly the defects located on the rolling surface of the rails are removed by grinding, it is also necessary to note the significant influence of rail grinding on the defects of other groups. This is because not timely removal of the surface defect at an early stage will lead to its development and transition to the defect of another group. A new defect will no longer be possible to remove by grinding, and the rail itself with this defect will be a defect-free one that requires the immediate replacement. For example, if the longitudinal contact fatigue cracks (defects 11 and 12) will not be eliminated in time, their development will lead to the formation of chipping, which pass into transverse fatigue cracks (defects 21 and 22) and can lead to the rail fracture (defect 71 and 72) if they are not detected in time (Fig. 1) [3, 4].



Defects 11, 12, 14 - cracks and chipping on the surface; defect 30 - longitudinal cracks in the rail head; defects 20, 21, 22, 24 - transverse cracks; defects 70, 71, 72, 74 - kinks [4].

Fig. 1. Block diagram of the interconnection of defects

Such an interrelationship of defects significantly affects the duration of the rails' life cycle. We can say that by managing defects, we manage the life cycle of the rails.

At present, the frequency of rails processing by means of grinding is made on the basis of regulatory and technical documentation [5, 6]. The planning of technological impacts on the rails grinding is carried out taking into account the class, group and category of the track. In accordance with the approved recommendations for railways of the first class, it is predominantly 175 million of tons gross, for the second class - 115 million of tons gross, for high-speed and mostly passenger traffic with speeds of 140 km/h and more - about 60 million of tons gross.

The specified regulatory and technical documentation allows changing the frequency of the work on grinding the rails, taking into account their actual condition. In this case, specific values for the change in frequency are not given. The establishment of possible values of the grinding frequency for railway tracks with different design and operational parameters is currently an unsolved problem.

The solution of this problem has involved many scientists in Russia and abroad. At the same time, all research results were reduced to particular cases of specific sections of the railway track [7–9]. The solution of this problem was complicated by the influence of many additional factors determining the intensity of the defects development in the rails. Thus, we can conclude that the actual defectiveness of the rails in a particular section of the railway track will determine the frequency of grinding in this section.

The assignment of the optimal grinding frequency is a multifactorial task, the optimization criterion of which is the economic component, in which we take the parameter - life cycle cost of rails (Life Cycle Costs, LCC).

2 Research Methodology

Many scientists have been engaged in the question of estimating the cost of the life cycle [10–13]. Accordingly, there is a fairly large number of approaches in the definition of LCC.

In our research, we will build on the current regulatory documents of Russian Railways OJSC. In accordance with them, the life cycle cost of the technical system of railway transport can be determined by the formula [14]:

$$LCC = C + \sum_{t=1}^{T} (C_Y + \Delta K - L) \cdot \alpha,$$

where C – the initial cost of the technical system, ths. RUR; C_Y – annual costs of a technical system operating, ths. RUR; ΔK – associated one-time costs associated with the introduction of the technical system into operation, ths. RUR; L – liquidation value of the technical system, ths. RUR; α – discount coefficient; t – current year of operation; T – useful life, which is set in accordance with specifications or other normative documents, years.

As applied to the operation of a railway track, the LCC assessment is a very complicated process, which is explained by the large number of structural elements of the track, technological processes of construction, maintenance and repair of the track, complexity of the force effect of trains and the superstructure of the railway. In addition, a very large number of operational factors affecting the reliability, maintainability and safety of this technical system is also important. All this leads to the difficulty of assessing the railway LCC, since such an assessment as a whole must have very many components. Therefore, the concept of a life cycle can be interpreted for the railway, not as a whole, but for individual components. In this study, the subject of study is the assessment of the life cycle cost of one of the most important and expensive structural elements of a railway track - rails.

In the presented formula, the most significant indicator that will significantly change depending on the defectiveness of the rails and the frequency of grinding is CY - annual operating costs of the technical system or applied to solving our problem - the cost of the rails operation.

In general, the costs associated with the operation of rails consist of the cost of rail grinding, losses associated with delayed train traffic due to the organization of process windows, the cost of the rail flaw detection inspection and the cost of a single rail replacement related to the elimination of critical defects (Fig. 2).

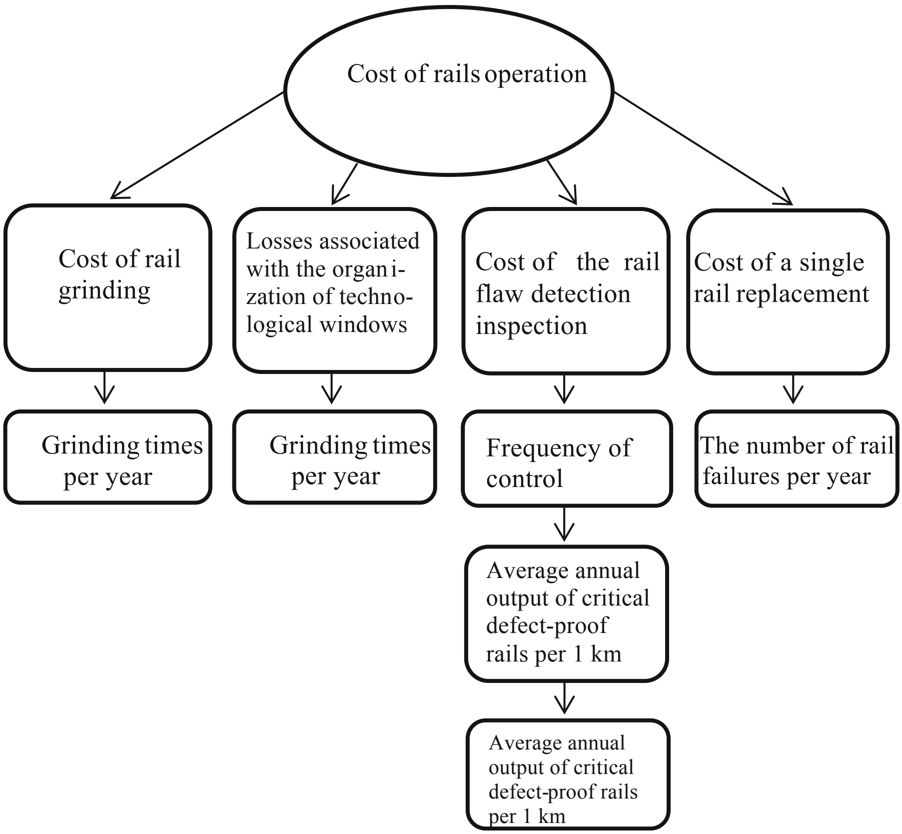


Fig. 2. Block diagram of the rails operating cost

To determine the operating costs for the maintenance of the rails, as the initial data, the values of the following parameters of the railway track are required: cargo density (million of tons gross/km per year); the highest set speed of passenger and freight trains (km/h); capacity (the number of missed trains per month), which are reflected in the class, group and category of the track.

The cost of the rails grinding was determined by considering the number of grinding per year (considering the established frequency), the cost of a car-shift per 1 km of track and the salary of the brigade of the rail-grinding train. In calculating the cost of providing technological “windows”, costs were considered due to train downtime in accordance with the methodology [5]. The calculation of the costs of flaw detection was carried out by considering the periodicity of the inspection and the average value of the output of the defect-proof rails per 1 km in accordance with the methodology [15]. In the cost of a single rail replacement, the number of replaceable rails was taken into account based on one kilometer of track per year and the cost of one rail.

3 Formulation of the Task

As a good example of the implementation of an approach to evaluating the effectiveness of the designated grinding frequency using LCC values, let us consider an estimate of the life cycle cost of rails and its changes based on the PCH-19 data from the Zarinsk station of the West Siberian Railway. In accordance with the LCC calculation methodology, we accept the following baseline data: the length of the estimated section of the railway track is 20 km, the continuous junction, the line with heavy traffic, the number of skipped trains per month is 31–100 trains, the average load capacity of 60 million tons, the speed on the section of the route is 101–120 km/h, the standard period of operation time is 700 million tons gross, the grinding frequency is 175 million tons gross.

It is necessary to determine the LCC values for the two options of organizing the production process of grinding the rails: with the recommended frequency of work (175 million tons gross) and with the adjusted periodicity obtained on the basis of the results of statistical studies.

4 Results of the Researches

On the basis of the obtained statistical data on the withdrawal of defect-proof rails with defects of groups 21 and 22, the dynamics of changes in defects on the considered section of the route during the period of the standard resource were identified (Fig. 3). We impose the data on grinding the rails with a given frequency of grinding - 175 million tons gross - on the obtained diagram.

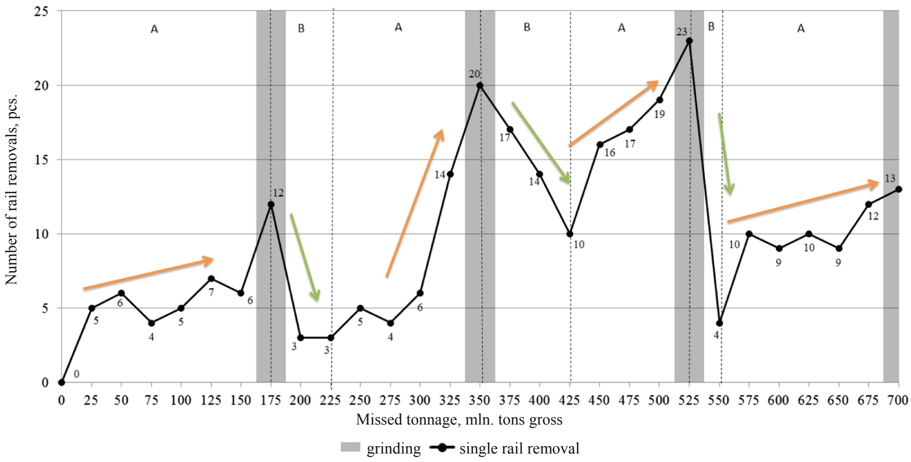


Fig. 3. Dynamics of single rail removals by the defects of groups 21 and 22

It can be seen from the diagram that the number of removals of defect-proof rails changes during the operation of a railway track and at different periods of time tends to either increase (zone A) or decrease (zone B). Comparing these data with the time of grinding the rails every 175 million tons gross it can be stated that the beginning of zone B, which characterizes the reduction of defects, occurs immediately after the planned work on grinding the rails. The reduction occurs over 25–125 million tons gross, after which the number of rail removals begins to increase again. At the same time, it can be noted that different values of operating time at which there is a decrease in the number of rail removals tells, first of all, about the different quality of work performed. The quality of grinding the rails is determined by the degree of removal of all defects. If any defects remain that continue to act as a stress concentrators, then among them the defects to be eliminated will appear soon. The more such concentrators remain, the faster the curve will appear on the diagram.

Thus, the analysis performed shows that the grinding frequency established by the regulatory documentation—175 million tons gross is not sufficient, since it does not give a lasting effect on the defectiveness of the track section. This indicates the need to adjust the frequency of grinding in the direction of its reduction.

The analysis of early studies on the effect of grinding frequency on the occurrence and development of defects of the contact-fatigue group [8, 16, 17] indicates a proportional decrease in the defectiveness of the rail with a decrease in the grinding frequency.

Based on the type of diagram (Fig. 3), an assumption was made about the need to reduce the grinding frequency to such values that they were in the zone of minimal extremes of the curve. Thus, the adjusted frequency, on average, should be 50 million tons gross.

Analysis of the works [18–20] shows that reducing the frequency from 175 to 50 million tons gross should potentially lead to a decrease in the defectiveness of the rails by 30–40% and, as a consequence, extend the standard service life of the rails from 700 to 1200 million tons gross.

Based on the conclusions above, a plot diagram (Fig. 4) shows the number of actually detected defects and the potential number of defects under all conditions being equal but reduced to 50 million tons gross grinding frequency.

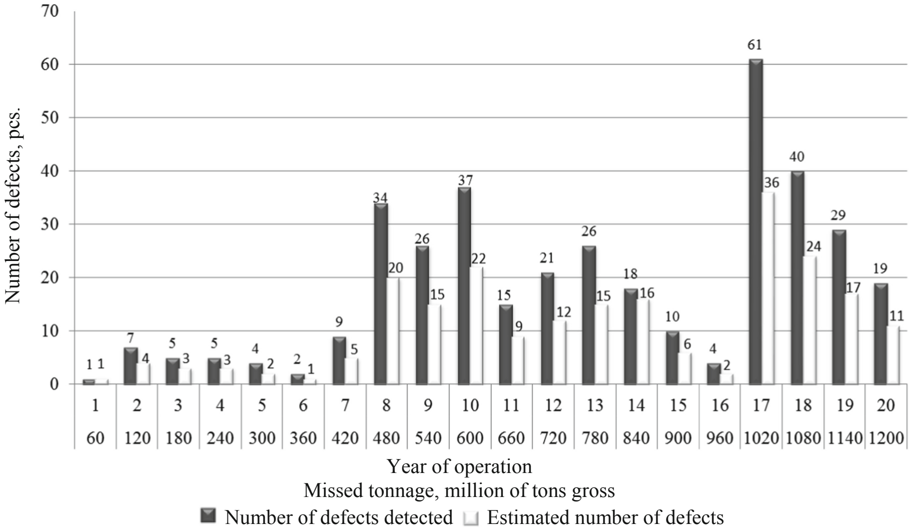


Fig. 4. - Actual and predicted number of detected defects

Taking into account the planned data on the defectiveness of the rails during the normative service life of rails, 1,200 million tons gross of the missed tonnage, the operating costs of maintaining the railway track during this period were determined for a standardized grinding frequency of 175 million tons gross and in case of a reduction in the grinding frequency to 50 million tons gross. It was taken into account that, with a service life of 700 million tons gross, the railway track undergoes a major overhaul after this period. In the calculations, the cost of overhaul of 1 km of track is accepted - 15 million rubles/km.

The results of calculations on the operation cost of 1 km of the track are presented in Fig. 4, where the life cycle cost of the rails is determined according to two options (Fig. 5).

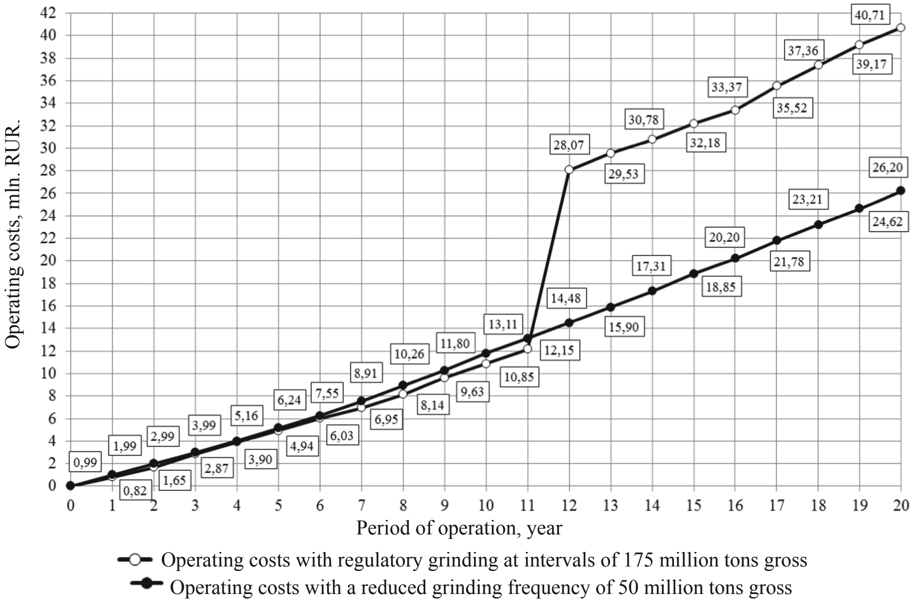


Fig. 5. - Comparative life cycle cost of rails with different grinding frequency

5 Findings

A statistical analysis of removals of defect-proof rails from a section of a railway track showed that:

- The periodicity of grinding 175 mln. tons gross set by standard technical documentation provides the effect of reducing the defectiveness of rails for a non-significant period (25–125 mln. tons gross), which is determined by the insufficient quality of work and the presence of residual stress concentrators on the rails surface;
- The reducing of the grinding frequency from 175 to 50 million tons gross will lead to a decrease in single rail removals by an average of 30–40% in the regulatory period of operation, which in turn will ensure the extension of the service life of the rails from 700 to 1200 million tons gross.

On the basis of the developed methodology for estimating the cost of the life cycle of rails, which takes into account the costs of operation and maintenance of the railway, calculations were made based on the results of which it can be concluded that reducing the grinding frequency allows, in addition to increasing the service life, reducing operating costs. Thus, with a standard operating time of 1200 million tons gross, the reduction of the grinding frequency from 175 to 50 million tons gross, the total operating costs will decrease from 40 to 26 million rubles per kilometer, respectively.

The conducted studies allow drawing a conclusion about the possibility of applying the presented approach to the appointment of an optimal and economically feasible frequency of rails grinding, taking into account the design and operational parameters of a railway track.

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Impact of the Use of Intellectual Assets on the Economic Growth of Russian Railways

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Abstract. The proposed paper is relevant because of the significant increase in the role of intellectual assets in ensuring the competitiveness of companies, especially companies with complex technological processes and extreme technologies. The object under the study, JSC Russian Railways (JSC "RZD"), belongs to such companies. The highest level of capital intensity of the company causes the need to balance it with the level of intelligence capacity, which will ensure its smooth economic growth. It should be noted that the assessment of the intellectual capital of organizations is a significant problem, and a serious problem is the consideration of assets in a quantitative assessment of the organizations' efficiency. The aim of the study is a quantitative assessment of the nature of intellectual assets of JSC "RZD" and their impact on economic growth. The research methodology includes classical methods of scientific cognition (observation, analysis, synthesis, formalization, logic) and special methods, such as: the formation of a system of indicators for the quantitative and qualitative assessment of the main parameters of the activity of the object under consideration, analysis of time series, and correlation and regression analysis of factor systems. Analysis of the impact of the company's intellectual assets on its economic growth showed a very close direct connection between its intelligence capacity and economic growth, as well as the positive dynamics of the effectiveness of the use of intellectual assets.

Keywords: Intellectual assets · Competitiveness of companies · Intelligence capacity · Management of economic systems · Intellectual capital

1 Introduction

For many years, at different levels of the management hierarchy, the national economy of Russia has been called the knowledge economy, the innovation economy, the economy of a post-industrial society. It is known that the category "post-industrial society" was introduced into scientific use by D. Riesman in 1958. However, systematic research in this subject area began later, and the concept of post-industrial society was formulated and used as a scientific basis for forecasting scientific, technical and social progress in the USA in 1965 under the leadership of D. Bell, who is represented in the scientific community as a postindustrial theorist. D. Bell considered himself a Marxist, he relied on the idea of K. Marx that "as large-scale industry

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develops, the creation of real wealth becomes less dependent on working time and the labor input, but depends on the general state of science and on the degree of development of technology or from the application of this science to production” [2].

D. Bell defined post-industrial society and formulated its main characteristics. He defined it as the “knowledge society” and stated that the source of innovation is research and development [3].

Our domestic science in this subject area is vividly represented in the studies of V. A. Trapeznikov, published back in 1971. V.A. Trapeznikov directly relates the efficiency of economic systems management with scientific and technical progress, which, in turn, relates to the level of knowledge: “Scientific and technical progress is the growth of knowledge about how to build and operate means of labor. Therefore, it is characterized by a change in the value of Y—the level of knowledge! The level of knowledge is determined by the knowledge accumulated by society, the qualifications and skills of people involved in management, starting with those who work directly with instruments of labor and manage them, and ending with chief executive officers” [4]. The concept of a significant role of knowledge in the management of economic systems is fundamental in the theory and practice of modern management. One of the founders of management theory, P. Drucker, presented knowledge as an essential characteristic of management. He noted that management is the use of knowledge to obtain the necessary results.

It should be noted that the role of knowledge in the management of economic systems increases dramatically. The fact is that at present, it is growing at a very fast pace, “… moreover, the value of knowledge is growing so fast that today it forms the main part of the total market value of many companies, especially in high-tech industries. In fact, this means: for any company, the most important thing is not what buildings, equipment and raw materials it possesses, but what its potential to create promising competitive products. And the larger the company’s knowledge base, the higher this potential” [4]. Now we are in the conditions of intellectual redistribution of the world, not territorial and raw materials redistribution. In order to occupy a worthy place in this redistribution, it is necessary to effectively use our intellectual assets. It is no coincidence that M. Porter called innovation one of the five forces to achieve a high level of competitiveness by companies. Back in 2012, V.V. Putin spoke about the relevance of the issues of increasing the efficiency of using intellectual assets in managing economic systems in the Presidential Address to the Federal Assembly of the Russian Federation: “Global development is becoming increasingly uneven … Competition for resources is becoming tougher. And … not only for metals, oil and gas, but, above all, for human resources, for intelligence”. Thus, for any company, a very important factor in the growth of its efficiency is the expansion of the essential characteristics of its technologies. Starting with Aristotle, technology means the combination of engineering with a set of knowledge, competencies, and skills. “Technology in the modern sense of the word … includes the entire set of knowledge and information necessary for the production of equipment for specific purposes, knowledge of the rules and principles of managing technological processes, a set of natural, financial, human, energy, instrumental information and intellectual assets…”.

The inclusion of human and information and intellectual assets in the content of technology is especially important, in our opinion, for modern production processes.

"We understand any production process as a set of technologies used to solve practical problems, including the production of goods, works and services. The modern period of technology development is characterized by an increase in the level of their extremes. By extreme technology, we mean the technology that gives the greatest effect compared to other technologies per unit of resource use. The increase in the number of extreme innovative technologies significantly increases the efficiency of production processes, but also the risks. The principle is manifested: if one of the technologies per unit of resource used has a greater effect than the other, then with a shortage of this resource, it is the more efficient technology that will suffer huge losses. We call this principle the basic principle of the technology extremity".

It should be noted that in terms of the development of the idea of A.I. Rakitov about technologies, it is necessary to include the considered principle of technology extremity in the set of principles for managing technological processes. Currently, this principle is vividly pronounced with a shortage of intellectual assets. With a shortage of intellectual assets, the company will suffer losses in proportion to this shortage, sometimes catastrophic losses. At the same time, direct losses may entail a number of additional significant losses, including loss of face and a high probability of bankruptcy. All this indicates a high value of the nature of knowledge systems of organizations and the quality of management of their intellectual capital to ensure their effectiveness and competitiveness. The purpose of the study is a quantitative assessment of the nature of the intellectual assets of JSC "RZD" and their impact on the effectiveness of its activities.

2 Research Methods

The methodological tools of this study include general scientific research methods (observation, analysis, synthesis, formalization, logic, induction) and specific methods used in economic research to quantify the parameters of the functioning and development of economic systems: formation of indicator systems, time series analysis, and regression and correlation analysis of factor systems.

3 Research Results

It should be noted that the assessment of the impact of intellectual capital on the efficiency and effectiveness of organizations is a significant problem for well-defined reasons: structuring, measuring and assessing intellectual capital in organizations are subjective, depending on the goals, strategy; unsuccessful attempts to create official standards and methodologies for assessing intellectual capital; national standards and official methodologies do not always allow forming a professional judgment on the value of organizations' intellectual assets.

A serious problem is the consideration of intellectual assets in the quantitative assessment of the effectiveness of organizations, although it is the intelligence capacity of production that gives the greatest economic effect and represents a higher value for competitiveness and innovative development than capital intensity. As for the commercial value of capital intensity and intelligence capacity, they are apparently equivalent in conditions of a stable external and internal environment of organizations. For example, V.A. Trapeznikov determines the growth rate of the economy as the square root of the product of the capital intensity and the intelligence capacity of production. Besides, the dependence of labor productivity in an organization on the level of scientific and technological progress is quantified as the coefficient of elasticity of changes in labor productivity according to its capital-labor ratio, multiplied by the square root of the product of the capital-labor ratio by knowledge level.

It should be noted that effective companies in developed countries give particular importance to such factors as increasing the research intensity, information intensity, and intelligence capacity of production and management in the formation of models of effective development. At the same time, the models include factors of restraining the growth of the capital intensity of production. The stakeholders of companies, including investors, consider the intellectual assets of companies (intellectual property, qualified personnel, intellectual capital) to be the main factor of their efficiency and the key source of value added.

Much attention is paid to the management of intellectual assets in one of the largest Russian companies – JSC "RZD". The patent strategy of JSC "RZD" until 2030 is approved by the order of JSC "RZD" No. 74r dated January 20, 2010. "The strategy is aimed at ensuring the innovation development of JSC "RZD" and enhancing the competitiveness of JSC "RZD". The main objectives of this Strategy are: increasing the competitiveness of JSC "RZD" on the domestic and international markets for transport and other related services; ensuring the protection of economic interests and economic security of JSC "RZD"; an increase in the capitalization of JSC "RZD" due to the legal protection of the results of intellectual activity and their use, an increase in the level of business reputation of JSC "RZD" and its investment attractiveness".

Despite the relevance of assessing the effectiveness of companies taking into account intellectual assets and highlighting the influence of this factor on the effective performance indicators, so far there are no clear methods for quantifying intellectual capital. Specialists divide existing methods into 5 groups: methods of direct assessment (monetary value of intangible assets); market capitalization methods (the difference between the company's market capitalization and the value of its tangible assets); methods of determining the return on assets (average annual profit from intangible assets is divided by the weighted average cost of capital of the company); scoring methods and precision measuring systems. The determination of the value of intellectual capital will enable the determination of the intelligence capacity of production or products, as well as the determination of the rate of economic growth of the organization and the added value. It is known that the relationship between the value added of an industry or organization can be described by a production function (utility function), for example, the Cobb-Douglas function, which presents a factor model of the relationship between output and labor and capital costs. However, in real economic practice, the production function should include a lot of other factors determining the nature of intellectual assets or intellectual capital. Consequently, the system of factors of the production function should be expanded to include in it a stock of intellectual assets or intellectual capital. The choice of the method for assessing the intellectual capital of an organization depends on many factors: on the form of ownership, the structure of equity capital, the character of indicators for assessing the intelligence capacity of production. The choice of the method for assessing intellectual assets for JSC “RZD” is based on the peculiarities of its functioning and development. Nowadays, market capitalization methods cannot be used to assess the intellectual assets of JSC “RZD” due to the fact that the company’s shares are not listed on the financial markets, i.e. there is no way to assess the company’s market capitalization. Although now there are ideas for the transfer of shares of JSC “RZD” to financial markets. The method of determining return on assets (ROA) is currently difficult to use due to the fact that the calculation algorithm involves comparing the return on assets of a company (ROA) with the corresponding indicators of transport companies from other countries. In addition, the method of calculation provides for the use of the weighted average cost of capital of the company, which is impossible according to public reporting. Scoring methods and the use of precision measuring systems can be used in the case of a rich regulatory framework on key parameters for managing intellectual assets. Besides, in this case, it is necessary to create a database of expert assessments. To assess the intelligence capacity of production, it makes no sense to use these techniques, since they do not provide an easy-to-assess integral value indicator, but can be effectively used to assess intellectual capital with other objectives.

Based on the mentioned above, an adequate method for assessing intellectual assets is a direct estimate method, which determines the monetary value of intangible assets and also uses the concept of goodwill, which characterizes the phenomenon of the difference between the market and book value of a company, and is determined by International Financial Reporting Standards (IFRS). By assigning the intellectual assets of the company to the volume of production, the intelligence capacity of production (products) is determined. This approach has long been actively used in the domestic practice of managing the efficiency of organizations and taking into account the influence of intellectual assets on it [3].

If the amount of intangible assets and the results of research and development in the system of the Russian Accounting Standards (RAS) are taken as the intellectual assets of JSC “RZD”, then some general assessment of the state of its intellectual assets can be made (Table 1).

Table 1. Intellectual assets of JSC “RZD” according to RAS, million rubles

Year	Intellectual assets	Value of assets	Share of intellectual assets in the total value of assets, %
2012	10357	4330803	0.24
2013	11661	4577538	0.25
2014	12228	4846744	0.25
2015	12860	5057111	0.25
2016	13382	5683706	0.24
2017	15317	5962397	0.26
2018	18168	6257578	0.28

Calculations show an increase in the scope of intellectual assets of JSC “RZD” for the period from 2012 to 2018. The qualitative characteristics of intellectual assets change insignificantly in dynamics; from 2012 to 2016, there has been some stagnation, growth begins in 2016.

The dynamics of indicators characterizing the intellectual assets of JSC “RZD”, accounted for under IFRS, are presented in Table 2.

Table 2. Intellectual assets of JSC “RZD” according to IFRS, million rubles

Year	Intangible assets	Goodwill	Intellectual assets	Value of assets	Share of intellectual assets in the total value of assets, %
2012	61908	11829	73737	3492586	2.11
2013	66796	13093	79889	3521660	2.27
2014	85979	18292	104271	3805437	2.74
2015	99636	23796	123432	4032551	3.06
2016	77484	17850	95334	4083730	2.33
2017	78509	19284	97793	4467681	2.19
2018	77435	20097	97532	4632913	2.10

The calculation of the volume and quality characteristics of the intellectual assets of JSC “RZD” on the basis of reporting prepared in accordance with international standards showed the levels that are significantly higher than the levels of these characteristics obtained under IFRS. However, the quality indicator dynamics is positive until 2016 and negative in subsequent years. A very significant decrease in the share of intellectual assets in the total value of assets (from 3.06% to 2.10% over three years) indicates a decrease in the efficiency of management of these assets, which can lead to a loss in the rate of innovation development.

The efficiency of managing intellectual assets has a positive impact not only on the rate of innovation development of organizations but also on the effectiveness of production activity. The most significant impact on the growth of production is provided by capital, labor and intellectual assets.

The impact of capital and intellectual assets of JSC “RZD” on production output can be demonstrated using the tools of correlation and regression analysis and company reporting information in the RAS system in dynamics for the period from 2012 to 2018.

As a characteristic of capital, the capital intensity indicator was taken, which is determined by the ratio of the book value of fixed assets to revenue, and as the characteristic of intellectual assets, the indicator of intelligence capacity was taken, which is determined by the ratio of the book value of intangible assets and results of research and development to revenue. By the nature of the dynamics of the studied indicators (revenue - S billion rubles, capital intensity - F rubles/rubles, and intelligence capacity - I rubles/thousand rubles), we can assume a straight-line relationship between the indicators and link them with a multiple regression equation:

$$S_{FI} = a_0 + a_1F + a_2I \tag{1}$$

To find the parameters of this equation, we apply the least squares method and solve the system of equations:

$$\begin{aligned} \sum S &= a_0 n + a_1 \sum F + a_2 \sum I \\ \sum SF &= a_0 \sum F + a_1 \sum F^2 + a_2 \sum FI \\ \sum SI &= a_0 \sum I + a_1 \sum FI + a_2 \sum I^2 \end{aligned} \tag{2}$$

The initial information for the correlation and regression analysis is presented in Table 3. The numerical expression of the parameters of the system of Eqs. (2) is presented in Table 4. Based on the indicators of Table 4, we obtain the numerical expression of the system of equations:

$$\begin{aligned} 10727 &= a_0 7 + a_1 35,43 + a_2 69.40 \\ 29495 &= a_0 35,43 + a_1 52,59 + a_2 166.80 \\ 93955 &= a_0 69,40 + a_1 166,80 + a_2 533.21 \end{aligned} \tag{3}$$

Table 3. Financial reporting data of JSC "RZD" under RAS for 2012–2018

Years	S	I	F
1	2	3	4
2012	1366	7.60	2.51
2013	1376	8.50	2.61
2014	1402	8.70	2.67
2015	1511	8.50	2.64
2016	1577	8.50	2.96
2017	1697	9.00	2.89
2018	1798	10.10	2.87
Total	10727	69.40	35.43

Table 4. Numerical expression of the parameters of the system of equations

Years	F^2	I^2	FI	FS	IS	S^1	σ_S^2	σ_{S1}^2
1	1	2	3	4	5	6	7	8
2012	6.30	57.76	19.08	3429	10382	1325	27556	42041
2013	6.81	72.25	22.18	3591	11696	1502	24336	794
2014	7.13	75.69	23.23	3743	12197	1537	16900	50
2015	7.00	72.25	22.44	4000	12843	1498	444	986
2016	8.76	72.25	25.16	4668	13404	1464	2025	4343
2017	8.35	81.00	26.01	4904	15273	1576	27226	2107
2018	8.24	102.01	28.73	5160	18160	1807	70756	76951
Total	52.59	533.21	166.80	29495	93955	10709	169240	127272

Having solved the system of equations, we obtain the regression equation, which characterizes the quantitative relationship between the studied parameters:

$$S = 10.80 - 107.80F + 208.50I \quad (4)$$

Substituting the values of F and I into this equation, we calculate the theoretical multiple regression $\mathbf{S^1}$ (column 6 of Table 4). To estimate the closeness of correlation dependence between the indicators, we calculate the theoretical correlation ratio, which, in the straight-line form of the dependence, can be called the total correlation coefficient or the multiple correlation coefficient:

$$R = \sqrt{\sigma_{S1}^2 / \sigma_S^2} \quad (5)$$

Where: σ_{S1}^2 – the variance of the theoretical values of revenue (column 8 of Table 4);

σ_S^2 – the variance of the actual values of revenue (column 7 of Table 4).

Hence the multiple correlation coefficient is 0.87.

It can be said that simultaneous changes in the size of the capital intensity and intellectual capacity greatly affect the changes in the revenue of JSC "RZD". The regression equation quite originally confirms the highest influence of capital and intelligence on production: if we turn off capital and intelligence, we get annual revenues totaling 10.8 billion rubles. It seems strange that the growth of capital intensity in the equation reduces revenue, but perhaps this does not contradict common sense, but suggests that increasing tangible capital without a high increase in its efficiency leads to a decrease in production potential.

An important conclusion from the performed analysis is that the change in the intelligence capacity of the products of JSC "RZD" has a greater impact on revenue than a change in capital intensity (almost 2 times), as indicated by the regression coefficients. The above-mentioned thesis is confirmed that it is the intelligence capacity of production that gives the greatest economic effect and represents a higher value for competitiveness and innovation development than capital intensity.

It's possible to check the idea of V.A. Trapeznikov, who defines the growth rate of the economy as the square root of the product of the capital intensity and the intelligence capacity of production using the example of the dynamics of these indicators of JSC "RZD" for the period from 2012 to 2018 (Table 5).

Table 5. Dynamics of indicators of JSC "RZD" according to RAS for the period from 2012 to 2018

No	Chain growth rate	Years						
		2012	2013	2014	2015	2016	2017	2018
1	Revenue	1.000	1.008	1.018	1.078	1.044	1.076	1.059
2	Intelligence capacity	1.000	1.118	1.024	0.977	1.000	1.059	1.122
3	Capital intensity	1.000	1.039	1.022	0.988	1.122	0.979	0.993
4	Revenue *	1.000	1.078	1.023	0.983	1.059	1.016	1.059

If we proceed from the idea of V.A. Trapeznikov, then the economic growth of the company (line 4) is ensured by the rapid growth of intelligence capacity, with the exception of 2015 and 2016, which were difficult years in the field of accumulation of intellectual assets. Due to the growth of intelligence capacity and capital intensity (line 4), the economic growth is ahead of the growth of actual revenue (line 1), with the exception of 2015 and 2017. During these years, the growth revenue was driven by other factors. We can say that the thesis of V.A. Trapeznikov on the growth rate of the economy as the square root of the product of capital intensity and intelligence capacity of production works.

4 Conclusion

Foreign and domestic systems for assessing the intellectual capital of organizations is a significant problem and make it difficult to objectively and adequately assess the impact of intellectual assets on economic growth. Therefore, in this study, intellectual assets are measured on the basis of a generally accepted approach in accordance with RAS and IFRS systems. A quantitative assessment of the nature of the intellectual assets of JSC "RZD" and their impact on the economic growth of the company was carried out. The analysis of the impact of the company's intellectual assets on its economic growth showed a very close direct connection between its intelligence capacity and economic growth, as well as the positive dynamics of the effectiveness of the use of intellectual assets. This study is of practical importance for the development of ideas about the need for the formation of serious knowledge systems at JSC "RZD" and the development of tactics for managing the intellectual assets. The development of methodological tools for quantifying the intellectual capital of JSC "RZD" and an adequate assessment of its impact on the company's economic growth can be a promising direction for further studies in this subject area.

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Bases of the Methodology of Monitoring the Impact of the Human Factor on the Reliability of the Railway Infrastructure

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Abstract. Experimental studies of the impact of hardware failures on the operational performance of the railway are given and, in particular, the impact of hardware failures on the organizational and technological reliability of production processes has been studied. When processing statistical information, regression equations were obtained for the 1st and 2nd categories of failures and the human factor that allows predicting changes in technical and economic indicators that affect the main results of the road, as well as planning measures to improve the reliability of technical means and reduce technological violations at West Siberian Railway.

Keywords: Failure · Human factor · Reliability · Infrastructure · Railway

1 Introduction

The technical maintenance of the Russia railway network requires a lot of economic costs associated with maintaining the reliability of infrastructure facilities and ensuring the safety of the transportation process. A significant role in the organization of production activities and the functioning of management structures have business processes, which prompted the rail transport to a radical restructuring. The strategy for the development of railway transport in the Russian Federation until 2030 is aimed at solving the following state tasks:

– formation of an accessible and sustainable transport system as an infrastructure basis for ensuring the transport integrity, independence and defense of the country, the socio-economic growth of the Russian economy and the creation of conditions for the realization of citizens' constitutional rights to freedom of movement;
– reduction of total national transport costs;
– integration into the global transport system;
– bringing the level of quality and safety of transportation in line with the requirements of the population and the economy and the best world standards based on the technological and technical "breakthrough" development of railway transport;
– increasing the investment attractiveness of rail transport;

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– maintaining social stability in railway transport;
– ensuring the rights of citizens of the Russian Federation to a favorable environment.

The solution of these tasks led to the formation of new functional vertically integrated structures with the coordinating role of regional corporate governance centers (RTSKU). However, their development required the development of a set of methods used in the field of activity.

2 Research Methodology

Under the methodology in this article, the authors understand the purposeful organizational human activity, its streamlining into an integral system with well-defined characteristics, logical structure and process of its implementation using a combination of a system of principles, rules, methods, models, algorithms and techniques designed in order to solve the tasks successfully.

The potential for a transport event should be assessed under current conditions, taking into account organizational flaws in which hidden procedural or technical failures combined with errors and technological disruptions of operating personnel in accordance with Reason's model lead to actions that bypass the protective measures. The study of the influence of the human factor in the operation and maintenance of complex technical systems is devoted to the work of many domestic and foreign scientists in various fields of activity: all types of transport, the coal industry, nuclear energy, and medicine [12–15]. But today, complex technical systems with double or even triple redundancy (in aviation) by automating part of the monitoring and control functions reduce the load on the operator of a technical facility, while increasing the load and requirements for technical specialists serving the technical facility [16, 17]. Thus, the increase in the complexity of technical systems leads to the redistribution of errors from one category of specialists to another. This gives grounds to assert that the problem of accounting for the influence of the human factor (HF) on the organizational and technological reliability of industrial processes of the infrastructure of railways, formulated in the thesis as a development of a methodical approach to improving the efficiency of production organization by reducing the influence of the human factor on the organizational and technological reliability of production railway infrastructure is relevant [7–10].

3 Results

The initial data for the execution of the study served as the official investigation acts, which are documented by an additional document to the Regulations on the procedure for recording, investigating and analyzing cases of failures in the operation of technical equipment of Russian Railways OJSC [4–6], supplemented by the «Human Factor» .

The studies were conducted for two years, which will be indicated as "1st year" and "2nd year".

Having analyzed the information on failures of technical equipment of the 1st and 2nd categories in the KASANT system with territorial division by regions for the "1st year" and "2nd year", as well as information about the detained trains caused by these failures, we presented the data in Table 1.

These data for convenience of analysis are shown in the form of histograms in Figs. 1 and 2.

Table 1. The list of failures of the 1st and 2nd categories in the KASANT system with the division geographically by the regions.

Region	Total failure 1st and 2nd categories, pcs.		Failures that led to train delays					
			Coach		Suburban		Cargo	
	1-st year	2-nd year	1-st year	2-nd year	1-st year	2-nd year	1-st year	2-nd year
REG-1	1117	679	146	109	70	45	1076	655
REG-2	982	784	247	195	163	140	930	710
REG-3	740	538	127	111	73	63	696	499
REG-4	760	547	63	50	88	72	704	493
In total	3599	2548	583	465	394	320	3406	2357

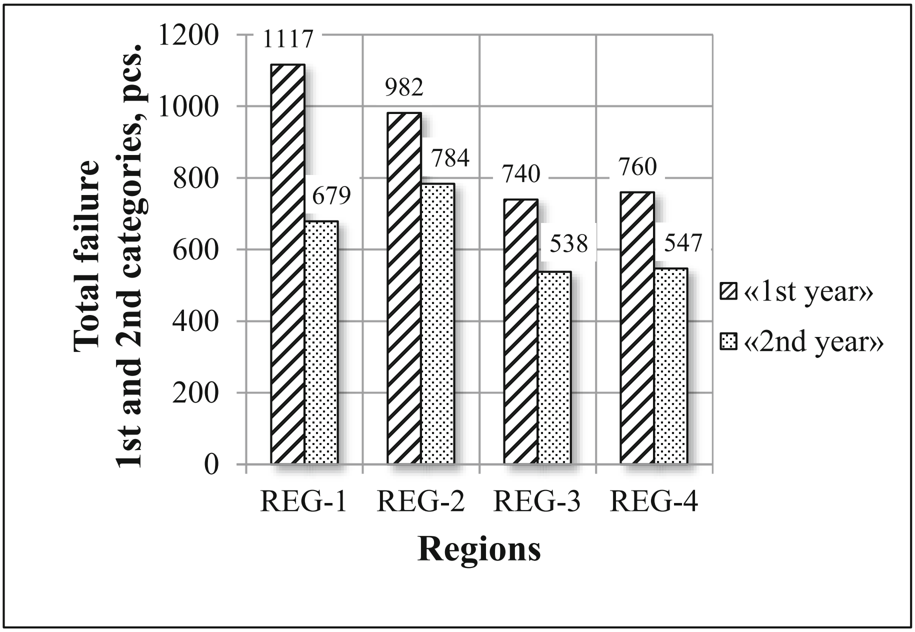

Fig. 1. Analysis of failures of technical means with the division geographically by regions.

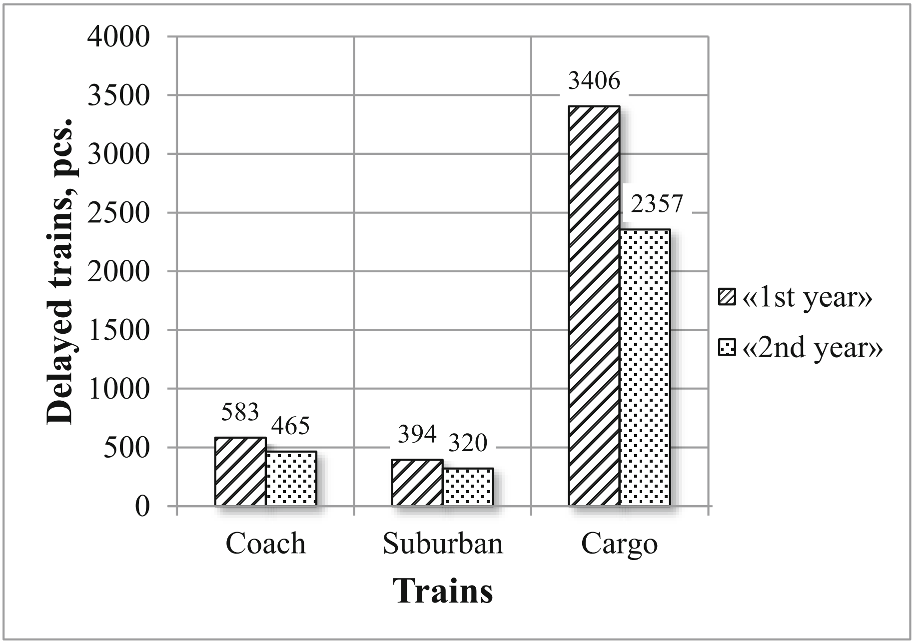

Fig. 2. Analysis of the delayed trains in connection with the failures of technical equipment of the 1st and 2nd categories.

The analysis shows that there was a significant decrease in the number of failures during the second year in all regions up to 28.7%. The highest decrease of the number of failures is observed at the objects of the first region (39.3%), i.e. the most efficient complex of activities aimed at the decrease of the number of technical failures. Consequently, on average, train delays decreased up to 23.3% in 2016. The maximum decrease, which concerns freight train delays, is 30.8%.

Continuing the analysis of the influence of the human factor on equipment failures and technological process violations, described in previous works [1–3, 11], we established the total duration of the failures of technical equipment of the 1st and 2nd categories for facilities services under the influence of the human factor for the "1st year" and "2nd year" (Table 2).

For each of the objects and hardware, a list of failures of hardware under the influence of the human factor is established (Table 3).

After analyzing the data in Table 3, we see that the largest number of failures in the facilities of services due to unintentional erroneous actions were detected on the Lines of the central automatic block system devices, railway automation and remote control, and the minimum - on the earth bed; diesel and diesel engine locomotive devices, multiple unit rolling stock; automatic control systems, electronic equipment of the locomotive; as well as on the Remote information monitoring system/multifunctional complex of technical means device.

Table 2. The total duration of failures of technical equipment of the 1st and 2nd categories by facilities under the influence of the human factor for the “1st year” and “2nd year”.

The nature of technical failures	«1st year»	«2nd year»
Devices of central automatic block system, railway automation and telemechanics	371	270
Freight car	254	426
Locomotive Traction Electrical Machines, multiple unit rolling stock	61	26
Contact network	39	28
Track	16	20
Special self-propelled rolling stock	12	7
Lines of the central automatic block system (AB)	11	8
Electrical equipment of the power circuit, auxiliary circuits and locomotive control circuits, multiple unit rolling stock	10	10
Locomotive safety devices, multiple unit rolling stock	7	4
Coach	7	4
Railroad switches	6	2
Derailed wheels detectors	6	1
Vehicle-part and mechanical equipment of the locomotive, multiple unit rolling stock	4	3
Radio communication	3	1
Brake and pneumatic equipment of the locomotive, multiple unit rolling stock	3	2
Earth bed	1	1
Diesel and diesel locomotive equipment, multiple unit rolling stock	1	0
Systems of automatic control of the modes of thrust and braking, electronic equipment of the locomotive	1	0
Remote information monitoring system/multifunctional complex of technical means	0	1
IN TOTAL	**813**	**814**

Table 3. The list of failures of technical equipment for the "1st year" and "2nd year" under the influence of the human factor, pcs.

	Unintended missteps		Low performing staff discipline		Low labor discipline of staff		Non-compliance with standard requirements		Qualification mismatch		Non-compliance of the number of operating personnel with the requirements of the technological process		Poor physical condition		Lack of necessary knowledge		Technical equipment mismatch	
	«1st year»	«2nd year»	«1st year»	«2nd year»	«1st year»	«2nd year»	«1st year»	«2nd year»	«1st year»	«2nd year»	«1st year»	«2nd year»	«1st year»	«2nd year»	«1st year»	«2nd year»	«1st year»	«2nd year»
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Devices of central automatic block system, railway automation and telemechanics	208	169	106	80	22	8	25	7	5	1	1	1	1	2	1	2	1	–
Freight car	64	205	120	128	66	48	1	21	1	18	–	1	–	–	1	4	–	1
Locomotive Traction Electrical Machines, multiple unit rolling stock	32	14	18	4	6	6	–	1	2	1	–	–	–	–	–	–	3	–
Contact network	13	13	23	9	2	5	2	–	–	1	–	–	–	–	–	–	–	–
Track	11	8	3	1	1	5	1	2	1	–	–	2	–	1	–	1	–	–
Special self-propelled rolling stock	4	2	6	2	–	–	1	2	–	–	–	–	–	–	1	1	–	–
Lines of the central automatic block system (AB)	3	3	4	1	3	1	1	1	–	–	–	–	–	–	–	–	–	–
Electrical equipment of the power circuit, auxiliary circuits and locomotive control circuits, multiple unit rolling stock	5	5	4	3	–	1	–	1	–	–	–	–	–	–	–	–	1	–
Locomotive safety devices, multiple unit rolling stock	5	2	1	1	1	–	–	–	–	1	–	–	–	–	–	–	–	–
Coach	1	–	3	4	2	–	1	–		–	–	–	–	–	–	–	–	–
Railroad switches	3	1	1	1	1	–	–	–	1	–	–	–	–	–	–	–	–	–
Derailed wheels detectors	4	1	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Vehicle-part and mechanical equipment of the locomotive, multiple unit rolling stock	3	2	1	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–

(*continued*)

Table 3. (*continued*)

	Unintended missteps		Low performing staff discipline		Low labor discipline of staff		Non-compliance with standard requirements		Qualification mismatch		Non-compliance of the number of operating personnel with the requirements of the technological process		Poor physical condition		Lack of necessary knowledge		Technical equipment mismatch	
	«1st year»	«2nd year»	«1st year»	«2nd year»	«1st year»	«2nd year»	«1st year»	«2nd year»	«1st year»	«2nd year»	«1st year»	«2nd year»	«1st year»	«2nd year»	«1st year»	«2nd year»	«1st year»	«2nd year»
Radio communication	3	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–
Brake and pneumatic equipment of the locomotive, multiple unit rolling stock	2	2	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Railroad switches	3	1	1	1	1	–	–	–	1	–	–	–	–	–	–	–	–	–
Derailed wheels detectors	4	1	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Vehicle-part and mechanical equipment of the locomotive, multiple unit rolling stock	3	2	1	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
Radio communication	3	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–
Brake and pneumatic equipment of the locomotive, multiple unit rolling stock	2	2	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Earth bed	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Diesel and diesel locomotive equipment, multiple unit rolling stock	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Systems of automatic control of the modes of thrust and braking, electronic equipment of the locomotive	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Remote information monitoring system/multifunctional complex of technical means	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
IN TOTAL	**364**	**429**	**293**	**234**	**104**	**75**	**32**	**36**	**10**	**22**	**1**	**4**	**1**	**3**	**3**	**8**	**5**	**1**

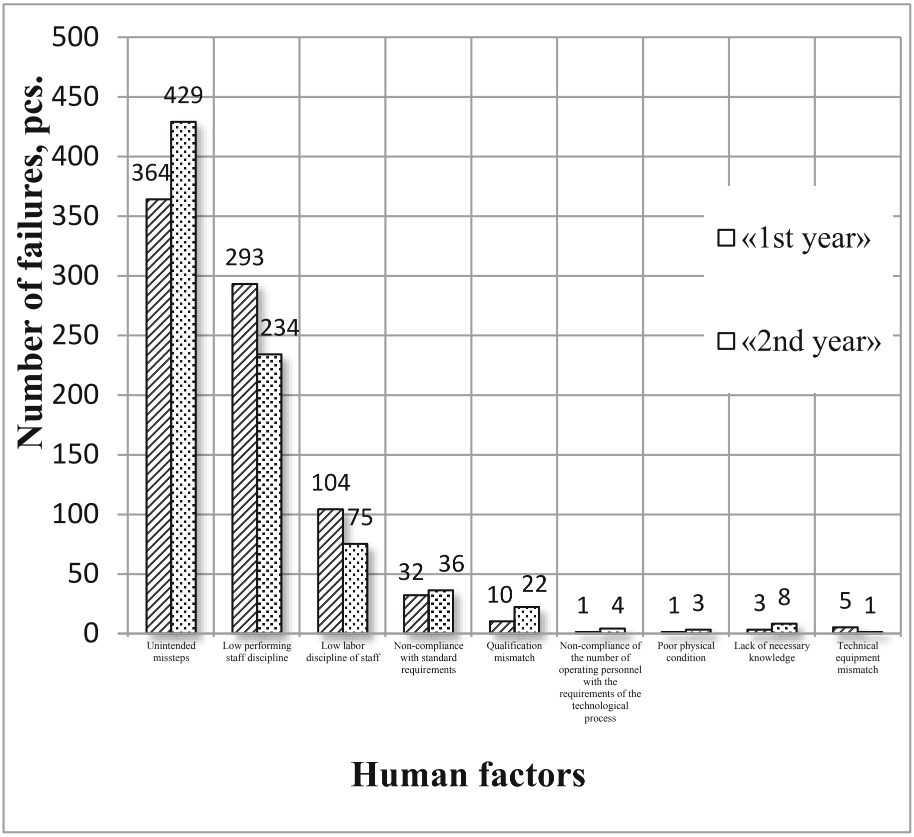

Fig. 3. Analysis of the delayed trains in connection with the failures of technical equipment of the 1st and 2nd category.

These tables are illustrated in Fig. 3.

For the convenience of perception of information in Table 4, the refusals of the 1st, 2nd category, their duration and train delays are entered by objects and the type of HF.

The data given in Table 4 is illustrated by Fig. 4. It follows from them that the greatest number of failures is observed in freight cars and devices of central automatic block system, railway automation and telemechanics.

Figures 5 and 6 indicate the total duration of failures of structural elements and equipment of infrastructure facilities and the total time of train delays caused by technical failures due to the human factor. The list of technical means failures due to the human factor is given in Table 5.

Table 4. The total duration of technical failures by facilities of services under the influence of the HF.

Types of technical means	Human factor	1st category failures			2nd category failures			In total		
		Number of failures	Time of failure, min.	Total delay, min.	Number of failures	Time of failure, min.	Total delay, min.	Number of failures	Time of failure, min.	Total delay, min.
1	2	3	4	5	6	7	8	9	10	11
Devices of central automatic block system, railway automation and telemechanics	Unintended missteps	20	1538	6108	188	6634	14546	208	8172	20654
	Low performing staff discipline	12	824	5481	94	3314	6860	106	4138	12341
	Low labor discipline of staff	2	111	248	20	649	1471	22	760	1719
	Non-compliance with standard requirements	1	29	623	24	703	1201	25	732	1824
	Qualification mismatch				5	217	331	5	217	331
	Technical equipment mismatch				2	106	161	2	106	161
	Non-compliance of the number of operating personnel with the requirements of the technological process				1	107	123	1	107	123
	Poor physical condition				1	33	66	1	33	66
	Lack of necessary knowledge				1	7	7	1	7	7
	IN TOTAL:	**35**	**2502**	**12460**	**336**	**11770**	**24766**	**371**	**14272**	**37226**
Freight car	Unintended missteps	24	1770	7009	40	998	2991	64	2768	10000
	Low performing staff discipline	50	3125	16807	71	2338	6630	121	5463	23437
	Low labor discipline of staff	33	1751	15549	33	1246	2816	66	2997	18365
	Qualification mismatch	1	80	80				1	80	80
	Lack of necessary knowledge	1	57	200				1	57	200
	Non-compliance with standard requirements				1	11	16	1	11	16
	IN TOTAL:	**35**	**2502**	**12460**	**336**	**11770**	**24766**	**371**	**14272**	**37226**
Locomotive Traction Electrical Machines, multiple unit rolling stock	Unintended missteps	13	1140	4320	19	541	1174	32	1681	5494
	Low performing staff discipline	7	386	1781	11	308	1370	18	694	3151
	Low labor discipline of staff	1	9	117	5	127	401	6	136	518
	Technical equipment mismatch	2	58	899	1	8	26	3	66	925
	Qualification mismatch	2	113	637				2	113	637
	IN TOTAL:	**25**	**1706**	**7754**	**36**	**984**	**2971**	**61**	**2690**	**10725**
Contact network	Unintended missteps	7	433	3368	5	64	168	12	497	3536
	Low performing staff discipline	13	1086	7369	10	396	742	23	1482	8111
	Low labor discipline of staff				2	58	87	2	58	87
	Non-compliance with standard requirements	1	84	326	1	7	7	2	91	333
	IN TOTAL:	**21**	**1603**	**11063**	**18**	**525**	**1004**	**39**	**2128**	**12067**

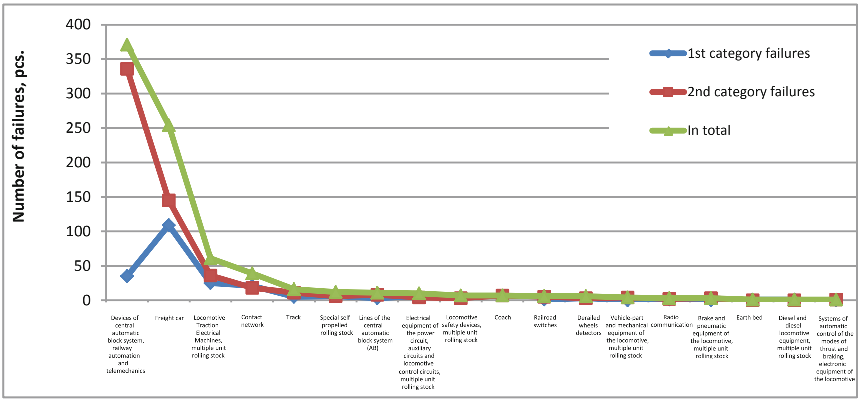

Fig. 4. Failures of technical equipment that led to the delay of trains, under the influence of the human factor.

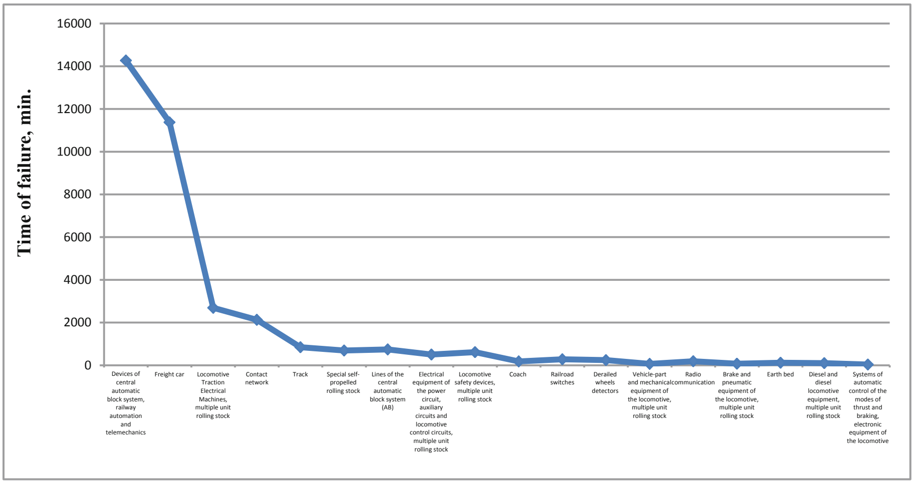

Fig. 5. The total duration of failures for structural elements and technical means of infrastructure facilities.

Table 5. The list of failures of technical means under the influence of the human factor.

Types of technical means	1st category failures			2nd category failures			In total		
	Total delay, min.	Number of failures	Time of failure, min.	Total delay, min.	Number of failures	Time of failure, min.	Total delay, min.	Number of failures	Total delay, min.
Devices of central automatic block system, railway automation and telemechanics	35	2502	12460	336	11770	24766	371	14272	37226
Freight car	109	6783	39645	145	4593	12453	254	11376	52098
Locomotive Traction Electrical Machines, multiple unit rolling stock	25	1706	7754	36	984	2971	61	2690	10725
Contact network	21	1603	11063	18	525	1004	39	2128	12067
Track	5	423	6308	11	422	998	16	845	7306
Special self-propelled rolling stock	6	521	2485	6	172	434	12	693	2919
Lines of the central automatic block system (AB)	3	373	964	8	370	709	11	743	1673
Electrical equipment of the power circuit, auxiliary circuits and locomotive control circuits, multiple unit rolling stock	6	353	3322	4	151	650	10	504	3972
Locomotive safety devices, multiple unit rolling stock	4	501	625	3	115	116	7	616	741
Coach				7	180	451	7	180	451
Railroad switches	1	151	277	5	129	292	6	280	569
Derailed wheels detectors	3	134	335	3	110	307	6	244	642
Vehicle-part and mechanical equipment of the locomotive, multiple unit rolling stock				4	66	238	4	66	238
Radio communication	1	117	127	2	71	150	3	188	277
Brake and pneumatic equipment of the locomotive, multiple unit rolling stock				3	74	353	3	74	353
Earth bed	1	118	495				1	118	495
Diesel and diesel locomotive equipment, multiple unit rolling stock	1	99	71				1	99	71
Systems of automatic control of the modes of thrust and braking, electronic equipment of the locomotive				1	36	160	1	36	160

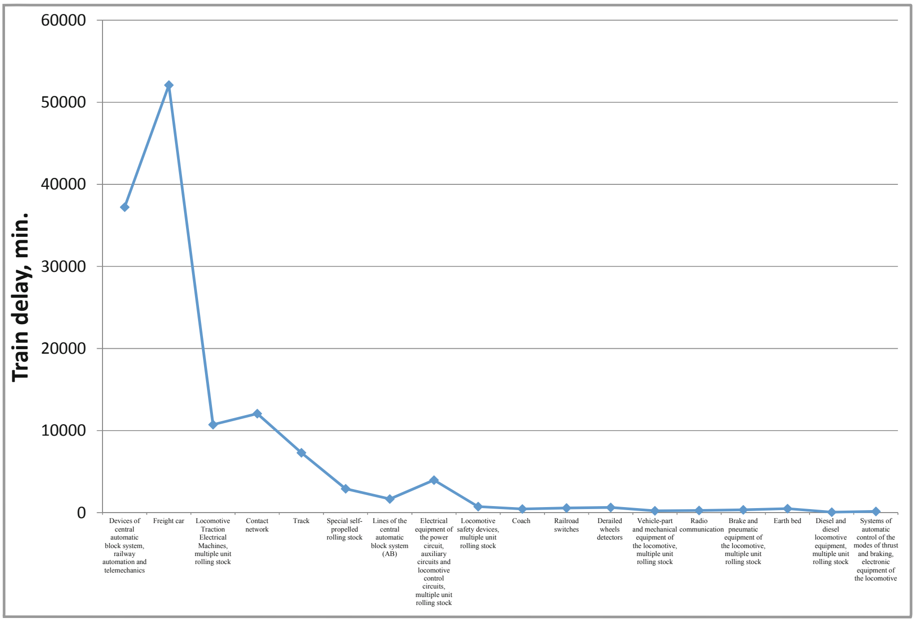

Fig. 6. The total time delay of trains caused by the failure of technical means due to the influence of the human factor.

As indicators of organizational and technological reliability, we used the following indicators, the main ones:

- the number of failures of technical equipment or violations of TNAs caused by negative events related to the HF;
- probability of occurrence of failures of technical equipment or violations of TNAs on time interval less than specified ($P(T \leq t)$), caused by negative events related to the HF;
- the intensity of TNAs failures related to the HF;
- recovery time of a working condition of technical means or violations of TNAs after the impact of negative factors that have occurred under the influence of the HF;
- the intensity of technical failures caused by negative events associated with the HF (the number of failures per unit of time);
- the intensity of failures that occurred under the influence of the HF (the number of failures per 1 million tons km gross).
- Important in the management of the HF are risk indicators:
- probability of occurrence of negative events associated with the HF that potentially could lead to a technical means failures;
- probability that the HF will not be detected in the fact of failure of the technical mean;
- probability of a false reference of the fact of a technical failure to the cause appeared due to the HF.

As an example, Figs. 7 and 8 show the probability of the duration of failures of the 1st category of contact network before recovery caused by human factor and the probability that the risk of failures of the 1st category of contact network caused by human factor will not exceed the specified duration before recovery.

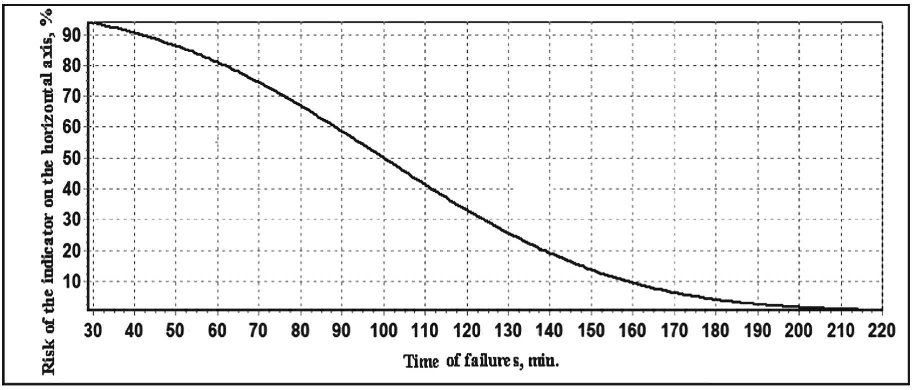

Fig. 7. Probability of the duration of failures of the 1st category of contact network before recovery caused by human factor

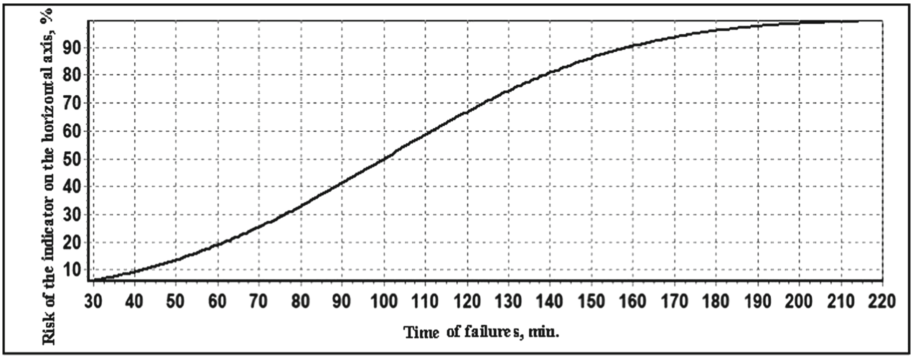

Fig. 8. Probability that the risk of failures of the 1st category of contact network caused by human factor will not exceed the specified duration before recovery.

Similarly performed probabilistic statistical calculations are shown in Table 6.

Mathematical models were developed based on the regression analysis method, which established a statistical relationship between the train delay time (y) and the duration of failure of structural elements and technical means until the moment of restoration (Table 6).

The coefficients of Concordance allow applying for prediction of the train delays and subsequent estimation of economic losses the regression equations stated in the table, preferring the dependencies with the highest R^2.

Table 6. Summary table of statistical models of the dependence of the delay time of trains (y) and the duration of failures of the 1st, 2nd categories of structural elements and technical means caused by the influence of the human factor until the moment of recovery.

Objects	Failures	Linear	Logarithmic	Power	Exponential
Track	1st category	$y = 12.732x - - 996,33$ $R^2 = 0.9825$	$y = 2998.7\ln(x) - - 13144$ $R^2 = 0.8656$	$y = 0.088x^{1.7154}$ $R^2 = 0.8563$	$y = 95.324e^{0.0071x}$ $R^2 = 0.9213$
	2nd category	$y = 0.8517x + + 65.22$ $R^2 = 0.6993$	$y = 113.59\ln(x) - - 321.48$ $R^2 = 0.8495$	$y = 0.6606x^{1.1552}$ $R^2 = 0.7529$	$y = 39.444e^{0.0073x}$ $R^2 = 0.445$
	In total	$y = 7.9437x - - 586.21$ $R^2 = 0.9755$	$y = 1671\ln(x) - - 6610.4$ $R^2 = 0.6272$	$y = 0.0969x^{1.6306}$ $R^2 = 0.9584$	$y = 68.281e^{0.0053x}$ $R^2 = 0.702$
Contact network	1st category	$y = 5.5176x + + 466.26$ $R^2 = 0.9248$	$y = 1976\ln(x) - - 8322.8$ $R^2 = 0.8762$	$y = 27.528x^{0.7731}$ $R^2 = 0.9458$	$y = 900.6e^{0.0021x}$ $R^2 = 0.905$
	2nd category	$y = 2.0989x - - 21.845$ $R^2 = 0.9539$	$y = 258\ln(x) - - 940.44$ $R^2 = 0.9995$	$y = 0.1454x^{1.5012}$ $R^2 = 0.9584$	$y = 33.675e^{0.0115x}$ $R^2 = 0.8153$
	In total	$y = 5.0996x + + 318.48$ $R^2 = 0.9754$	$y = 2069.9\ln(x) - - 9116.5$ $R^2 = 0.8554$	$y = 21.583x^{0.7952}$ $R^2 = 0.9862$	$y = 901.77e^{0.0018x}$ $R^2 = 0.9233$
Devices of central automatic block system, railway automation and telemechanics	1st category	$y = 3.5294x + + 45.637$ $R^2 = 0.9957$	$y = 1609.4\ln(x) - - 7322.2$ $R^2 = 0.9732$	$y = 8.0029x^{0.8874}$ $R^2 = 0.9966$	$y = 531.11e^{0.0018x}$ $R^2 = 0.9301$
	2nd category	$y = 1.857x + + 76.908$ $R^2 = 0.9996$	$y = 1551.4\ln(x) - - 5536.9$ $R^2 = 0.7952$	$y = 2.6714x^{0.9709}$ $R^2 = 0.976$	$y = 122.91e^{0.0009x}$ $R^2 = 0.7172$
	In total	$y = 2.1266x + + 79.668$ $R^2 = 0.9993$	$y = 1989.1\ln(x) - - 7213.9$ $R^2 = 0.75$	$y = 2.4499x^{0.9989}$ $R^2 = 0.9765$	$y = 142.52e^{0.0008x}$ $R^2 = 0.6764$
Locomotive Traction Electrical Machines, multiple unit rolling stock	1st category	$y = 4.8389x - -325.96$ $R^2 = 0.9786$	$y = 944.35\ln(x) - - 4201.7$ $R^2 = 0.9504$	$y = 0.0995x^{1.6162}$ $R^2 = 0.8818$	$y = 74.413e^{0.0084x}$ $R^2 = 0.9272$
	2nd category	$y = 1.2893x + + 110.22$ $R^2 = 0.4105$	$y = 204.41\ln(x) - - 678.59$ $R^2 = 0.4694$	$y = 2.6465x^{0.9216}$ $R^2 = 0.55$	$y = 96.116e^{0.0056x}$ $R^2 = 0.4477$
	In total	$y = 2.7834x - -89.83$ $R^2 = 0.8006$	$y = 605.68\ln(x) - - 2488.5$ $R^2 = 0.6519$	$y = 1.6536x^{1.0426}$ $R^2 = 0.7587$	$y = 116.73e^{0.0043x}$ $R^2 = 0.7444$
Freight car	1st category	$y = 6.5684x - - 2513.9$ $R^2 = 0.9593$	$y = 5339.9\ln(x) - - 23628$ $R^2 = 0.4833$	$y = 3.08x^{1.0472}$ $R^2 = 0.9514$	$y = 569.04e^{0.0008x}$ $R^2 = 0.7041$
	2nd category	$y = 1.4288x + + 548.79$ $R^2 = 0.8168$	$y = 1032.2\ln(x) - - 3495.4$ $R^2 = 0.7309$	$y = 6.2166x^{0.8405}$ $R^2 = 0.9446$	$y = 229.27e^{0.0009x}$ $R^2 = 0.5758$
	In total	$y = 4.5382x - - 715.75$ $R^2 = 0.9981$	$y = 4876.3\ln(x) - - 18930$ $R^2 = 0.4997$	$y = 4.3456x^{0.9811}$ $R^2 = 0.9729$	$y = 534.42e^{0.0005x}$ $R^2 = 0.5859$

4 Conclusion

Studies of the influence of the human factor in structural elements and hardware are based on the data of the KASANT system widely used on the railway network, as well as the KASAT and KASKOR systems taking into account the influence of the human factor on the transportation process and targeted preventive work with personnel.

In the research:

1. The directions of the influence of the human factor on the organizational and technological characteristics of the production processes of the infrastructure were identified by the example of the West-Siberian Railway branch of the Russian Railways OJSC.
2. A grouping of the causes of the negative impact of the human factor on the reliability of technical equipment was carried out.
3. Based on the processing of a large amount of statistical data on failures of the 1st and 2nd categories of technical means on the West-Siberian railway, their distribution laws have been found out, which makes it possible to predict the probability of such failures and the associated risks.
4. The research results form the basis of the methodology for identifying and recording the influence of the HF on the organizational and technological reliability of production.

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Lean Transportation in Science is no Longer "Terra Incognita"

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Abstract. The purpose of research is to determine the areas and justify why the use of the lean concept in these areas can provide improved performance of road transport at industrial enterprises. The research methods included: observation, collection, and analysis of statistical data, expert survey, modeling a transportation system, developing indicators for evaluating the efficiency of transportation losses elimination. An analytical review showed that in lean transportation, the first steps in scientific research aimed at adapting the principles of lean production to road transport operation are being taken. The research revealed the existence of at least sixteen types of transportation losses. This fact differs significantly from the results of the losses research in the industry. An expert survey to analyze the losses is used. The Delphi method is used to identify the causal chains of factors leading to the loss generation. To evaluate the mutual impact of causes, a quantitative assessment is performed. This leads to a significant acceleration in the work aimed at improving the operations of road transport that provides services to industrial enterprises. The "black box" model of the transportation system allowed identifying the resources of the transportation process participants as inputs. There are two other groups of input factors: cargo characteristics and external environment impact. The output characteristics of the model include transportation volume and its quality indicators. A differentiation of the spent resources into useful costs, which are used for cargo transportation, and losses, which are proposed to estimate using cost indicators, was provided.

Keywords: Lean transportation · Lean concept · Lean production · Road transport · Transportation losses

1 Introduction

The term "lean production" appeared first in 1988 in the article by Krafcik [1], who was working on his Master's thesis at the time at the Massachusetts Institute of Technology (MIT). In the article, Krafcik relied upon his previous experience as a quality engineer

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at the General Motors and Toyota joint venture (GM-Toyota), describing the characteristics of the Toyota Production System, TPS [2]. In the article, Krafcik paid much attention to the development of an enterprise of just-in-time delivery of components and materials and to the opportunities for neutralizing the emerging risks. Based on the lean production concept, James Womack developed the lean thinking philosophy, which consists in not only eliminating surplus stock at all stages of industrial production. The philosophy proposed by James Womack involves, according to the set of five basic principles, focusing on searching for and eliminating losses in the course of creating value of the final product [3].

Transport is inseparably integrated into both economy and social life, and plays a critical role therein. Traditionally, transport is considered a principal means for achieving the objectives of lean production through the implementation of just-in-time delivery and a reduction in transportation costs. At the same time, it would be appropriate to consider the possibility of implementing the lean thinking ideas in the improvement of road transportation per se. The main effect from implementing the lean thinking philosophy occurs due to an increase in the production flow velocity as the time of the process cycle is greatly reduced. One of the results, in addition to overall reduction in costs, is acceleration of capital turnover. The work performed by road transport supporting industrial production is linked directly to the velocity of objects of labor move within the production chain, and thus, requires careful consideration within lean thinking. In addition, taking into account the need to accelerate the return on investment, we should keep in mind that road transportation is rather capital-intensive: modern vehicles are expensive. The purpose of research is to determine the areas and justify why the use of the lean concept in these areas can provide improved performance of road transport at industrial enterprises.

2 Research Methods

An analytical review is necessary to examine all present-day approaches to considering road transport within the lean thinking concept. A study of certain aspects of road transport operation for providing services to industrial enterprises will allow generating a systematic view of the ways to organize its work.

To achieve the objective of the study, it's necessary to perform a comparative analysis, which and to what extent the basic provisions of lean thinking developed for industrial enterprises can be applied to increase the efficiency of road transport services. This requires an analysis of the system and a study of the features of road transportation systems. We need to determine the structure of the road transportation system, its incoming and outgoing flows, and interaction with external environment.

We need to analyze the cargo transportation cost structure. Road transport has its own local efficiency criteria, which should correspond to its role in supporting the activity of industrial enterprises. The general efficiency model should take into account both the resources spent on achieving a beneficial result and the resulting losses.

3 Approaches to Viewing Road Transport Within the Lean Thinking Concept

The research of road transport operation from the aspect of lean thinking have been conducted in many countries around the world: from Mexico and Columbia to Jordan, and from the USA to such European countries as, for example, Denmark, Italy, Germany, and the United Kingdom. Both university scientists and employees of consulting, transportation, and logistics companies have devoted attention to this subject.

In a number of studies, you can find a complete and detailed review of the research conducted to date in lean transportation. Usually, the starting point of analysis is the classification of production losses proposed by Taiichi Ohno. By using this classification, a similar list, which accounts for the features of transport operations, is compiled. A general conclusion regarding the opportunity to adapt the experience of the Toyota Production System (TPS) to the analysis of transport operations is given in the publications of Villarreal, Garza-Reyes, Kumar, Forero and their colleagues being co-authors of the published articles [4–6]. In particular, reference [4] mentions that in the scientific community, according to the expert opinions, "Seven Deadly Wastes of Logistics" and "Seven Transportation Extended Wastes (STEWs)" are identified. In different publications, the following causes of losses are provided: unconfirmed transportation orders; delay or waiting; using too many vehicles; errors made by staff; interruptions in the driver's work; excessive downtime in the course of loading and unloading operations; underutilization of vehicle capacity; loss of cargo in the course of loading operations; low speed; damage to cargo. Unfortunately, the lists of losses contain almost no comments or explanations.

Both university scientists and company CEOs are interested in lean transportation. In co-authorship with Goldsby, Professor of Logistics at Ohio State University (USA), Martichenko, the CEO of LeanCor Supply Chain Group (head office located in Florence, USA), published a book on strategic development of business on the basis of the lean logistics concept [7]. In co-authorship with Linda Taylor, top manager of Fedex Corporation (USA), he also published an article [8], wherein an attempt was made to formulate four "laws" of transportation in accordance with lean concept (Lean Transportation Laws). The proposed definitions are preceded by the classic list of seven losses proposed by Ohno and eight rules of logistics (8 right). The "laws" themselves cover the following areas: (1) transportation losses; (2) transportation strategy; (3) daily management of events according to the Deming cycle; (4) vehicle performance indicators. The important areas have clearly been defined; however, all of them are relevant not only in the transportation but in any type of business. In all economic areas, at any enterprise, we need to fight losses, develop a strategy, routinely manage processes and properly choose the performance indicators. In this sense, the proposed "laws" are general in their nature.

Another example shedding light on viewing the lean concept in the logistics business environment is the article by Intrieri [9] published on the website of Arkieva, the company specializing in software development for supply chain management. Unlike already discussed publication [8], the author cites not four lean transportation "laws", but five ways to optimize logistics and transportation using the lean concept. In another version of this article by Chuck Intrieri published on the website of the Cerasis company, which offers solutions in logistics management, the proposed recommendations are called practical applications. The recommended methods for improving transport operations include: (1) focusing on customer expectations; (2) eliminating transportation losses; (3) using key performance indicators; (4) understanding the structure of transportation costs; (5) daily management of events based on the Deming cycle. Brief explanations given by the author to each method account for the features of motor vehicle transportation and can prove useful in improving efficiency of transport performance.

The analytical review revealed a diversity in interpretations and a lack of consistency of the authors' opinions on these issues. Scientific articles have been published in many countries around the world but are still few in number. The publications of business figures do not have full scientific justification and, possibly, one of the objectives pursued here is creating a positive image for the companies which show interest in lean transportation. Further studies, which should focus on the features of the road transport operations in the logistics systems, should be performed. The use of proven approaches to analyzing losses generated during industrial production is necessary. However, we need to focus primarily on the features of road transportation.

4 Adaptation of Types of Losses Generated at Industrial Enterprises to Road Transport Operations

Traditionally, in the lean thinking concept, seven types of losses proposed in the 1950s by Taiichi Ohno, director of Toyota Motor [2], are identified:

1. losses generated due to overproduction of goods that have no demand;
2. time losses due to waiting for the next process step;
3. losses generated as a result of unnecessary transportation that could have been avoided;
4. losses generated due to extra processing steps which could have been removed when reviewing design and engineering documentation or streamlining production equipment;
5. losses generated due to excess inventory, which exceeds the minimum required quantity;
6. losses generated as a result of unnecessary movement of staff to get tools, workpieces, drawings, instructions, etc.;
7. losses generated due to defective goods production.

We can see that transport in this list is considered as one of the sources of loss.

The Toyota experience served as the principal basis for the development of the lean philosophy in the USA. Later on, in the 1990s–2000s, James Womack and Daniel Jones proposed that the basic list should be supplemented with one more type of losses: losses generated due to design of goods and services that do not meet the consumer's needs [2]. In his book published in 2004, Jeffrey Liker, based on, just like James Womack and Daniel Jones, the study of the Toyota experience, added losses generated due to underutilization of the employees' creative potential to the list of losses [10].

The losses identified by American experts have general significance and reduce efficiency in all areas of activity, including industry, transportation, and other sectors of economy. The losses generated as a result of unnecessary movement of staff, identified by Taiichi Ohno, has the same universal significance. As for other types of losses, most of them can be adapted to transport services.

The losses generated due to overproduction can be interpreted as the extra costs incurred due to vehicles moving at a higher speed than required or arriving at the destination earlier than scheduled. Higher speed leads to excessive fuel consumption, and saving time does not always allow you to perform extra trips and transport additional cargo. Moreover, the customer might not need additional transportation services. Also, if a vehicle arrives at the destination earlier than scheduled, it presents a complete analogy of a work-in-progress: the delivered cargo is not unloaded and is not used in the production process, and the vehicle itself, being in use, cannot perform other transportation services.

The losses generated due to waiting is, perhaps, one of the major and most notable types of losses in road transportation. The time factor in the transportation of cargo by road, in ensuring and evaluating the reliability of such transportation, is extremely important [11]. Vehicles often have to stand in line, waiting to be loaded or unloaded, waiting until the cargo is ready to be dispatched or until the supporting documentation is prepared. The availability of equipment, the readiness of staff, and a sufficient number of loading and unloading areas, so that vehicles would not create lines, are of great importance in cases like these. Note that losses are generated not only because the vehicles have to wait. The downtime of loading and unloading equipment also leads to the loss generation. To analyze this type of transportation losses and obtain quantitative estimates, we need statistical observations.

As an example, we looked at the transportation of dairy products (based on the analysis of A. V. Pavlinin and I. G. Suslova), where the following results were obtained: when dairy products are dispatched from the manufacturer to retailers, loading operations take 29 min on average, the downtime of the vehicles, when they wait in line for loading, is 11 min, the downtime due to the absence of containers is 4 min, the downtime due to the absence of movers in the workplace is up to 2 min, the downtime due to preparation of cargo documents is 15 min. The non-scheduled downtime of dump trucks used for transporting bulk cargo in construction is 4.2% of the total working time during the day shift, and up to 16.7% during the night shift [12]. The downtime of vehicles in the loading and unloading areas fluctuates significantly. For example, when loading reinforced concrete structures at a building-construction plant, the mean loading time is 17.099 min, and dispersion is 19.520 min [13, 14].

The third type of losses is related to the quality of transportation orders preparation. If the customer placed an order for transportation that was not necessary, the transport service must perform it. The losses thus generated come as a result of the shortcomings in the work of the enterprise or the department, wherein the transportation orders are placed, but not the shortcomings in the operation of the transport service. The losses generated due to extra processing steps can be interpreted as the costs incurred due to inefficient routes, due to which the vehicles are driven extra miles and take extra time to deliver the ordered goods. Just like the time wasted on waiting, the losses generated due to unnecessary runs is a main source of losses in road transportation. Repairs and maintenance of vehicles differ little from similar works performed to ensure the proper functioning of equipment at an industrial enterprise. So, the losses generated due to excess spare parts, maintenance materials, the purchase and storage of which require additional costs, is also common for road transportation. The share of the vehicle repair and maintenance expenses in the cost of transportation of cargo by road is 10–20%, on average. Not only efficient organization of repair and maintenance works, but also their standardization based on the actual mileage of vehicles from the start date of their use (the "age" of the vehicle) help reducing the costs on these items. The technical condition and the maintenance works required to keep the vehicle in a proper working condition depend on the vehicle's mileage from the start date of its use. The use of standards ensures the implementation of a management function—the control: "the implementation of control begins with setting standards" [15]. A standard is a control parameter that allows making a justified conclusion on how well or poorly the production process is organized, on how well or poorly the participants of this process perform their duties.

A defect in road transportation is a violation of the transportation terms agreed upon with the customer. The basic terms include transportation of the accepted quantity of cargo while keeping it safe and complying with the specified delivery time.

Thus, six types of losses identified by Taiichi Ohno and two additional types of losses formulated by American experts can be adapted to road transportation.

5 Losses Inherent to Road Transportation that are Absent in the Industry

The adaptation of losses generated at industrial enterprises does not exhaust all types of possible losses in road transportation. Due to the features of road transport operation, the following types of losses, which are not identified in the industrial production, are inherent to it. Based on the analysis of the road transport services provided to industrial enterprises in metallurgy, in construction, and in the food industry, the following types of transportation losses have been identified.

1. During transportation, the loss is often generated as a result of underutilization of the vehicle capacity (load capacity or volume of the body/van).
2. The losses generated due to inefficient allocation of transport vehicles by transportation orders are not always obvious. The transportation of the same quantity of cargo by one large vehicle costs, on average, 1.5 times less than transportation by two light vehicles.
3. The losses are also generated because simultaneous vehicle loading is not used.
4. Another type of losses is inherent to road transport. Fuel costs form a significant share in the cost structure of cargo transportation by road. For Russia, the share varies between 25 to 50%. Therefore, it is essential to prevent excess fuel consumption, which can be achieved by implementing a series of special measures.
5. In many cases, road transportation allows using trailers. If, instead of single vehicles, cargo could be transported by road trains consisting of a tow vehicle and a

trailer, productivity could be increased almost twice while costs would increase by only approximately 20–30%.

6. Unlike the staff of industrial enterprises, a driver often works outside the production area, on public roads. If he were left unattended, the possibility of deviation from the route for personal reasons should not be excluded, which leads to the losses due to changes in the time of delivery or excessive mileage.
7. The features of road transport operations include frequent loading and unloading operations. The loss can be generated if the vehicle capacity does not meet the technical capabilities of loading equipment, or if the equipment capacity is too low or too high.
8. Another feature of road transportation is high probability of criminal acts and theft of goods during transportation, stops made during the trip and during loading and unloading operations. As a result, the use of the lean thinking concept to improve road transportation generally involves the analysis of at least 16 types of losses. Undertaking systematic efforts to eliminate them can provide an increase in productivity and a reduction in costs of industrial enterprises. The end result will be increased competitiveness in the market segment.

6 Examination of Cause-and-Effect Relationships in the Transportation Losses Analysis

All transportation losses identified in accordance with the lean thinking concept can be divided into three categories: (1) violations of the regulatory and process requirements to the transportation process arrangement; (2) arising as a result of accidental factors; (3) hidden losses that can be identified in the analysis.

The first category includes such losses as, for example, a reduction in vehicle speed due to poor condition of access routes at the points of acceptance and delivery of cargo, vehicles waiting in line due to unscheduled arrival for loading, losses generated due to the cargo being not prepared for dispatching at the scheduled time, etc.

Due to accidental factors such losses as, for example, downtime of vehicles due to breakdown of loading equipment, delay of vehicles on the road due to traffic congestion, arise.

Hidden losses include, for example, the losses generated due to inefficient layout at the loading and unloading points, loading large quantities of packages without first placing them on pallets, extremely long distances traveled between the place of storage and the place of loading of cargoes.

The work on improving the transportation process within the lean thinking concept begins by compiling a list of losses at the enterprise. Each loss should be estimated and have a clearly stated objective that will be achieved once this transportation loss is eliminated, which describes the target function:

Different types of transportation losses require the implementation of different measures to eliminate them, as they are caused by different reasons. The analysis of the causes of existing transportation losses is hierarchical in nature. The first-level causes are directly responsible for the analyzed transportation loss. The second-level causes lead to the emergence of the first-level causes. Such sequential analysis of causes by hierarchy levels allows building a tree structure (Fig. 1) and give a formalized description of the target function of eliminating transportation losses similar to the study of problem situations [13] in a transportation process:

$$\delta_{FC} = f\,(S_{11}, \ldots, S_{1i}, \ldots, S_{1n}, \ldots, S_{2j}, \ldots, S_{2m}, \ldots, S_{ql}, \ldots, S_{(q+1)p}, \ldots, S_{tk}) \quad (1)$$

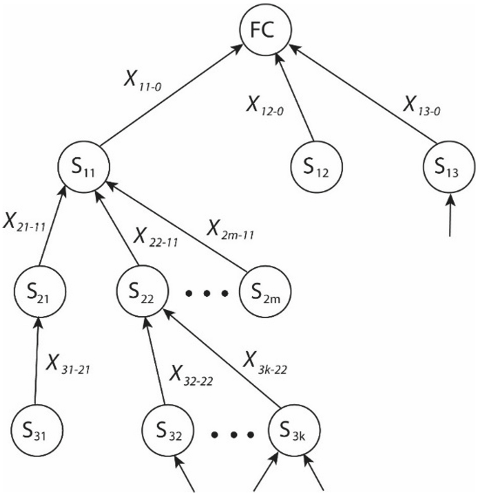

Fig. 1. The causal chains of a transportation loss. **FC** is the target function; $\mathbf{S_{ij}}$ is the i-th cause of the j-th level; $\boldsymbol{X_{ij\text{-}kl}}$ is the coefficient of impact of the causes of a transportation loss [13, 14].

where

δ_{FC} is the deviation of the actual value of the target function from the desired value;
$S_{1\ i}$ are the first-level causes of a transportation loss;
q is the cause hierarchy level; $q = 1, \ldots, t$;
S_{ql} is the l-th cause of the q-th level;

n, m l, p, k are the number of causes of the *1*-st, *2*-nd, *q*-th, (*q* + *1*)-th, *t*-th level.

The question is how extensive does the hierarchical analysis of the causes of each transportation loss has to be? Based on the recommendation of Ohno "5 Whys" [2], the number of levels in a hierarchy should not be more than five.

Both the transportation losses and their causes are identified on the basis of a multi-round expert survey. To solve this task, we implemented the Dephi method [13]. Note that, in practice, it is not always the case that every cause and effect has one cause-and-effect relationship. There may be cases where one cause may have an impact on two or more effects, or, in turn, be the effect of the action of several causes of the lower levels of hierarchy. Even reverse cause-and-effect relationships with a reverse impact are possible. Reality does not always fit into regular schemes; there are direct and reverse relationships, single, branching and converging ones.

An expert survey allows solving another important task. The examination of causes, even when limited to five hierarchy levels, provides a large array of data. From this set, we must select, based on the Pareto principle [16], the causes, which should be eliminated first. To do this, the experts should evaluate the mutual impact of causes, resulting in the quantitative estimates $X_{ij\text{-}kl}$ (Fig. 2). The estimates of the impact of causes obtained using the Delphi method include a median of the distribution of estimates Me_x and an interquartile interval $(Q_1–Q_3)$, which contains the true estimate of the mutual impact of causes. An analysis based on the “20/80” principle [16] and selecting the key causes of the identified losses [13, 14, 17] to work on drastically reduces the need for resources to improve the transportation process. As a result, from dozens of causes of the loss selected for analysis, we can focus on the key ones in the first turn.

For example, when analyzing the time during which vehicles have to wait in line when transporting reinforced concrete structures, from 30 causes, we selected 5 most significant ones [13, 14, 17]: no schedule for transporting sets of reinforced concrete products from the building construction plant to the construction site; non-compliance with the schedule for first loading of the vehicles; a broken crane or the crane being used for other works; an unexpected change in vehicle access rules to the production site; poor technical readiness of the vehicles at the motor company. The key causes of vehicle downtime at the industrial site of the metallurgical enterprise include: inconsistency in the work of the metallurgical plant divisions; no supervisor for the works performed; failure of loading and unloading equipment; incomplete scope of work; complex document workflow [18].

7 A Model for the Transportation System and a Cost Estimate for Transportation Losses

The input parameters of the transportation system are the resources of the transportation process participants. The interaction between the participants of the transportation process begins at the consignor’s cargo loading area and ends at the consignee’s final cargo destination. When organizing the transportation process, the cargo characteristics, such as its appearance (packaged, bulk, liquid cargo), quantity, physical and chemical properties, etc., should be considered. The external environment, which, in this case, can include the road network, the transport services market and a number of other factors, has an impact on road transportation.

The output characteristics of the road transportation are: the volume (amount) of the transportation services provided and the quality characteristics of these services, first of all, the reliability of the transportation process (the safety of the cargo transported and the timeliness of delivery). To evaluate the efficiency of transportation, the output characteristics received should be compared with the resources spent to achieve this result. Two groups should be distinguished from the total resources spent. The first group of costs includes costs that directly led to the beneficial result of the transportation process. The second group of costs includes the transportation losses.

The identification of input and output characteristics of a transportation system allows building a “black box” model (Fig. 2). The progress of the transportation process and different arising situations depend on various combinations of input parameters. Therefore, this model can be interpreted as a situational model for the transportation process, and the input characteristics may be understood as situational variables [13, 14]. The proposed model of the transportation system allows assessing the prospects for implementation of the lean thinking concept to improve the efficiency of the transportation process. The efficiency evaluation is based on comparing costs to the positive result obtained. If we accept the quantity of delivered cargo, measured in tons, as a positive result of transportation, then the efficiency of transportation can be estimated by unit costs in currency per one ton of delivered cargo.

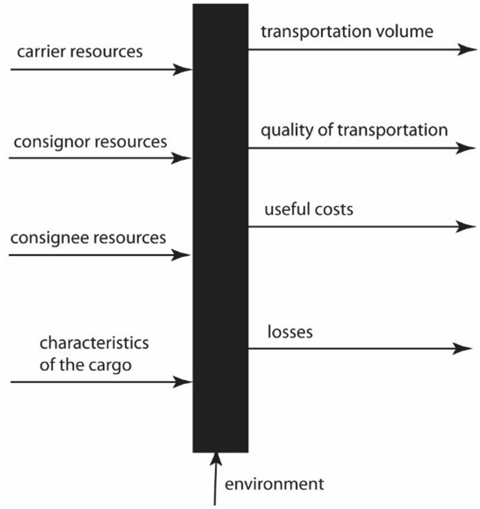

Fig. 2. Model of a “black box” transportation system (based on the situational model of the transportation process [13, 14]).

The differentiation of costs into useful ones that have provided the volume of transport services obtained and non-useful (downtime due to waiting, losses generated as a result of excess fuel consumption, losses generated due to damage or shortage of goods, losses due to non-compliance with the delivery times) will allow calculating not only the actual, but also standard unit costs:

$$u_r = \frac{\sum_{i}^{n} C_{ui} + \sum_{i}^{n} C_{li}}{Q} \quad (2)$$

$$u_s = \frac{\sum_i^n C_{ui}}{Q} \tag{3}$$

where

u_r and u_s are the actual and standard unit costs, respectively;

Q is the quantity of transport services provided;

C_{ui} is the useful costs of the *i*–th participant of transportation that provided the transportation services;

C_{li} is the losses or non-useful costs of the *i*–th participant of transportation

The completeness of assessment of u_r and u_s depend on whether or not the costs of all the transportation process participants have been taken into account.

The efficiency of the transportation process can further be assessed using the value of the actual and standard unit costs of each transportation process participant.

8 Discussion

The concept is being successfully implemented in the industry and it has now become the widely accepted standard in arranging production in all industrialized countries. A relatively new area of research is the use of the lean thinking basic principles in other sectors of economy, namely, in transportation. The works published earlier focus on adapting lean production to the features of road transportation and developing an innovative lean transportation approach.

The performed studies allowed expanding our view on the possibilities of the lean concept in transportation and obtaining new results. It was shown that, due to the features of road transportation, the possible losses in this area are much more diverse than in the industry. While Taiichi Ohno identifies seven types of losses in his classic text devoted to the Toyota Production System, at least 16 types of losses can be identified in the road transport providing services to industrial plants. This is a reason why road transport is usually less efficient than the industrial enterprises it provides services to.

The authors of this article propose a new method for analyzing transportation losses. To implement it, the experts develop causal chains of factors, which lead to the identified losses. The evaluation of the mutual impact of causes, and then, on the analyzed type of loss is novel. The evaluations of the impact of causes obtained using the Delphi method include the median distribution of estimates Me_x and the interquartile interval $(Q_1–Q_3)$, which comprises the true estimate of the mutual impact of causes. Due to this, from a whole set of causes, according to the Pareto principle, the key ones are identified and eliminated in accordance with the program for improving the performance of road transport providing services to the industrial enterprises. The proposed approach allows drastically reducing the labor intensity of the work and obtaining a positive result faster.

It is not always possible to assess the efficiency obtained from the elimination of losses. The authors of the article propose to differentiate all costs into two groups. The first group includes useful costs that are used to transport cargo and ensure the quality of the transportation process. The second group of costs includes losses. A generalized estimate of efficiency can be given with unit costs, as measured by the transportation volume per one currency unit of total costs and per one currency unit of useful costs. The comparison of the two indicators will show the current potential for efficiency growth in transportation.

The development of the lean transportation concept is at the beginning stage. The first steps have been taken to adapt lean production to the features of the transport services provided to the industrial enterprises. In many respects, lean transportation still represents "terra incognita" in the scientific sense and awaits new research.

9 Conclusion

The article examines the theoretical issues of improving transport services at industrial enterprises based on the lean concept. The types of the transportation losses are identified, and their similarities and differences as compared to the losses generated at industrial enterprises are described. A "black box" model of the transportation system is built, on the basis of which the efficiency criteria for assessing the measures taken to eliminate transportation losses are proposed.

In further research, the practical applications of the lean concept to increase the efficiency of road transport services provided to the industrial enterprises in metallurgy, in construction, and in the food industry will be considered.

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Economic and Investment Fields of Railroad Sections and Stations

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Abstract. This paper considers the use of equations of mathematical physics, in particular, Maxwell equations, to analyze the investment processes and their dynamics when designing railroad sections. Electromagnetic field theory has been analyzed to determine the properties of Maxwell equations in the context of expanding their functional application in various fields of science and technology. The performed analysis demonstrated the existence of interrelations between the properties of electromagnetic fields and wave processes in railroad transport. The suggested novel approach to analysis of economic and temporal properties of the newly built railroad transport infrastructure units has several prospective fields of application.

Keywords: Economic and investment fields · Designing railroad sections · Electromagnetic fields · Railroad transport infrastructure

1 Introduction

Any object created by man, including railroads, functions within its environment. The notion of "environment" manifests itself in two aspects: nature and economics. A crucial part of economics is investment: securities, property having monetary value, money invested to gain benefits (net profit) [1, 2].

In the life of a society, economics is a fundamental component of the country functioning that shapes the processes providing the society with material resources for existence: food, lodging, clothes, etc. It plays a significant role in the country's defense capabilities. Economics and investment are closely linked: without investment, there is no economic development, and without economics, there is no investment. Economics and investment form an integral whole, as does the electromagnetic field in physics. If we conceive that "nature" as part of the environment obeys certain laws of physics, then "economics" is governed by similar laws. To illustrate the above, let us consider applying Maxwell's equations [3–5] in electrodynamics to economics and investment.

The Maxwell theory had a tremendous influence not only on the part of physics that studies electromagnetism, but also on numerous other parts not directly related to electromagnetism: relativity theory, condensed matter physics, etc.

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2 Materials and Methods

Let us demonstrate how the Maxwell theory works in economics [6].

We shall assume that electric and magnetic fields according to Maxwell correspond to the investment field, while currents and charges correspond to the economic field. The economic field has a finite propagation time, which determines the lag in economic interaction.

According to Maxwell, not only the current (investment), but also the electric (investment) field which changes over time give rise to the magnetic (economic) field, which in turn generates the investment field. Investment and economic waves propagate in space. Similar to the Maxwell theory, we may assume the existence of a unified economic and investment field that is generated by a system of pinpoint (unit) investments. As applied to the railroad, with similar characteristics of the natural environment (geography, hydrography, geology), investments made at a section of a railroad and at a railroad station will be different, that is, the economic and investment fields of the section and the station will be unequal. Using the investments distribution, we can identify the properties of the generated economic and investment fields. Again, similar to the Maxwell theory, no intrinsic mechanisms, phenomena occurring in the environment and causing the generation of economic and investment fields are considered here. The environment is divided according to two parameters: conductivity a_1 and permeability a_2. These parameters depend on the properties of the environment and on the field magnitude in a given point (unit), and thus, will be different for sections and stations. Upon transition to investment and economic fields, the first Maxwell equation can be interpreted as:

$$\int_s Dds = \int pds \quad (1)$$

where s is a two-dimensional closed surface (district, region, county, country); ds is an element of area s; D is the vector of investment displacement (similar to the Maxwell theory, investment induction); p is the investment density;

The total investment volume for the area s:

$$\int_s pds \quad (2)$$

$$\overrightarrow{D} = a_1 \overrightarrow{E} \quad (3)$$

where $\overrightarrow{E}$ is the investment field strength characterizing the investment field in a given point.

The investment field strength $\overrightarrow{E}$ shows how the investment field acts on a “unit” investment (for example, one million rubles) in a given point (unit) of the investment field. The resulting effect of the investment, e.g., for every one million rubles at sections and stations, is determined by the functional:

$$\overrightarrow{E} = \overrightarrow{E}(x, \mathrm{y}, t) \tag{4}$$

where x and y are the coordinates of the point (unit) in the plane; t is time.

It should be stressed that investment field strength $\overrightarrow{E}$ depends on time and most likely decreases over time, in the general case—it changes.

For railroad sections:

$$\overrightarrow{E} = \overrightarrow{E}(L, t) \tag{5}$$

where L is the linear coordinate (km, milestone).

For stations:

$$\overrightarrow{E} = \overrightarrow{E}(L, y, t) \tag{6}$$

Similar to common interpretation of the Maxwell's equations, it can be stated that: Eq. (1) shows that the investment and economic field is created only by investments; or the flux of investment induction through a closed surface is proportional to the amount of investment bound by this surface (area), or, in projection onto a linear infrastructure, by an interval: the amount of investment inside the considered interval.

The force property of the economic field is characterized, similar to the Maxwell theory, by economic induction $\overrightarrow{B}$. Economic induction $\overrightarrow{B}$ shows the "force" that the economic field exerts on an investment q propagating with a velocity V. When $V = 0$, $B = 0$ as well.

The second Maxwell equation is written as follows:

$$\int_s Bds = 0(s) \tag{7}$$

In projection onto a linear infrastructure:

$$\int_L BdL = 0 \tag{8}$$

In line with Maxwell, Eqs. (7, 8) state that if there is no "movement" ("variation") in the units of the economic field, then the flux of economic "induction" through a closed surface beyond the ends of the interval for a linear infrastructure is zero.

$$\overrightarrow{B} = a_2\overrightarrow{H} \tag{9}$$

where $\overrightarrow{H}$ is economic field strength;

Economic field strength is a value equal to the difference of vector $\overrightarrow{B}$ and vector $\overrightarrow{M}$, where the latter can be defined as "cost effectiveness", since it characterizes the economic state of a unit. The units of measurement $\overrightarrow{H}$ for a linear infrastructure: $\frac{mln\,rub.}{km}$ or $\frac{rub.}{m}$.

Similar to the Maxwell theory, we may consider that the economic and varying investment field are related to each other as follows: the economic field can be generated by a "varying" investment field, while a varying economic field promotes the generation of the investment field. The complex interrelations between the values D, H and E, B are revealed during spatial or temporal dispersions. Investments in a given unit of space in the case of spatial dispersion depend on field magnitude in this and in adjacent points. In the case of temporal dispersion, the values of D, E and B, H are determined, in addition to field magnitude in a given moment, by field magnitudes in the preceding time periods.

The established analogy between the electromagnetic and the economic and investment fields requires further extensive study to identify the properties, including the "force" properties of these fields.

The third Maxwell equation in projection onto economic and magnetic field:

$$\oint_n Edn = \oint_s dS \tag{10}$$

shows that a varying economic field B is the source of "vortex" investment field E, where n is a closed contour bounding the surface S.

But a varying investment field D can also generate economic field H, which is the counterpart of the 4th Maxwell equation. Thus, these fields cannot be treated as independent: when one of them changes over time the other one emerges, i.e. the economic and investment fields present one unified field.

Similar to electromagnetic waves, the economic and investment waves propagate in the medium, or environment, with a velocity:

$$V = \frac{1}{\sqrt{a_1 a_2}} \tag{11}$$

Let us denote:

$$a_1 a_2 = A \tag{12}$$

Then:

$$V = \frac{1}{\sqrt{A}} \tag{13}$$

$$V = \frac{\lambda}{T} \tag{14}$$

where

$$T = \frac{1}{\eta} \tag{15}$$

here, λ is wavelength; T is wave period; η is oscillation frequency;

From (12, 13), let us define wavelength at $T = 1$ year:

$$\lambda = \frac{1}{\sqrt{A}} \tag{16}$$

In projection onto a linear unit into which investment is made, we can state that for this unit the wavelength is inversely proportional to the square root of the investment and economic characteristics of the environment A.

Wave equations are known to describe many processes in nature: waves on water, propagation of sound, light, etc.

The notions of economic and investment fields introduced above can be explained as follows. The economic field (economics) of a region (country, county) is a set of territorially and "economically" interrelated units with various specializations within the considered space whose operation creates synergies. The investment field is investments in various units (of a region, county, country). A change in capital (investment) is a perturbation that creates waves; hence, the corresponding waves appear in the economic field.

These fields cannot be considered invariant (unchanging), as their parameters (properties) change with various transformations or under various conditions.

As already mentioned, the created waves are characterized by the velocity of their propagation.

As the economic and investment fields are directionally anisotropic, wave velocities along different directions will also be different. The rate of capital investment along a newly built linear unit will be much higher than in the transversal direction. Suppose that the cost of building a section of a railroad is 500 million rubles and the duration of construction is 25 months. Then the velocity of the investment wave will be $20\,\frac{mln\ rub.}{month}$. While in the transversal direction, the velocity of the investment wave is often zero. But this relates only to railroad sections. At stations, the velocity of the investment wave is not zero.

The following comments are also in order. When building a railroad, a lack of resources can result in the construction of the railroad as a start-up facility, in which only the most important units are built according to the set priorities: ensuring railroad operation. After commissioning the start-up facility, the remaining units are commissioned (constructed) over several to dozens of years. For example, the second tracks of the Reshety—Aramil railroad were commissioned as two start-up facilities, and investments were ultimately spread over additional 12 years [7].

Usually a start-up facility refers to stations. Therefore, the propagation velocity of the transversal wave of the economic and investment field varies over time, from near zero to maximum velocity, i.e. $0 \leq V \leq Vmax$.

Any additional investment in excess of the initial one changes the propagation velocity of the investment wave.

Similar to the Maxwell theory, the environment defines the interaction of economic and investment fields, while the environment exists even in their absence.

Let us consider a graph where the principal and additional investments are located along the axes in a two-dimensional space, as depicted in Fig. 1. Here, the symbols denote the following: t is the duration of one cycle of investments in a unit (per year); V is investment rate; K is additional investments; g is the rate of additional investments.

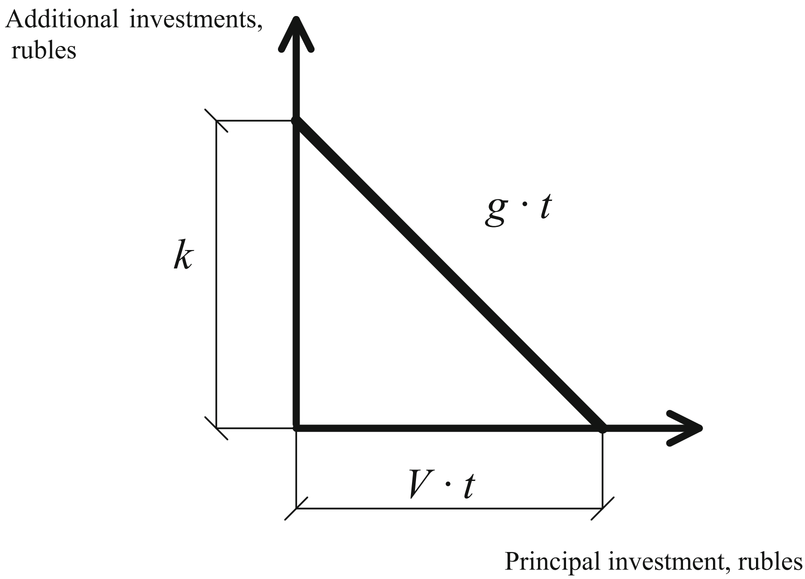

Fig. 1. Graph showing the principal and additional investment rates.

Inspection of this graph shows that $g > V$;

$$K^2 = (gt)^2 - (Vt)^2 \tag{17}$$

$$t = \sqrt{\frac{K^2}{g^2 - V^2}} \tag{18}$$

$$t = \frac{1}{V}\sqrt{\frac{K^2}{\gamma - 1}} \tag{19}$$

$$t = \frac{K}{V}\sqrt{\frac{1}{\gamma - 1}} \tag{20}$$

$$\lambda = \frac{g^2}{V^2} \tag{21}$$

where, as can be seen in Fig. 1, the following inequality always holds: $\gamma > 1$. Duration t decreases if $\gamma \geq 2$, for $2 > \gamma > 1$ cycle duration t, despite additional investments, increases.

Let us rearrange Eq. (20) as

$$t = \frac{K}{V^2} b \tag{22}$$

where argument b is defined as

$$b = (\gamma - 1)^2 \tag{23}$$

A graphical representation of function $b = f(\gamma)$ is shown in Fig. 2.

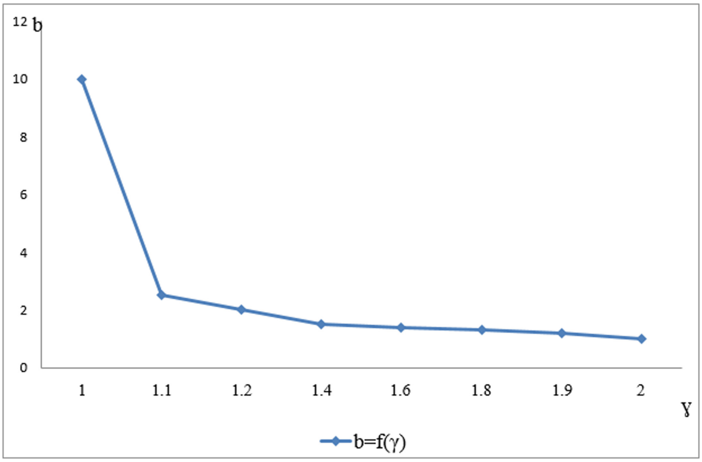

Fig. 2. Function $b = f(\gamma)$ from Eq. (23).

The graph in Fig. 2 confirms that if the square of the rate of additional investments is in the range: $2V^2 > g^2 > V^2$, then cycle duration increases, i.e. the shortening of the investment cycle is primarily caused not by the volume of additional investments, but rather by their rate. However, the rate of additional investments can be increased either by increasing the investments K themselves, or by shortening the cycle of additional investments at a fixed rate of base capital investments.

A practical application of the suggestions given above depends on further investigations and on availability of quantitative values for certain parameters, first of all: a_1 and a_2.

One of the first attempts to provide a quantitative economic and investment assessment was undertaken in the paper [7]. But this was done with a very specific objective: to determine the dependence of innovations in railroad construction on natural factors and "habitability" of the environment.

However, using Eq. (13), we can determine the parameter characterizing the environment, A,

$$A = \frac{1}{V^2} \tag{24}$$

Taking as an example $V = 20\,\frac{mln\,rub.}{month}$, we obtain: $A = 0.0025\,\frac{month^2.}{mln\,rub.^2}$.

Note that parameter A depends not only on the properties of the environment, but also on the absolute field magnitude in this point (on investments).

The complexity of the suggested studies is further compounded by the relativity of our view of the world. We often understand the environment differently based on our experience and intuition. For example, Einstein demonstrated that space and time are not absolute, that is, "in the absence of absolute space, there are no reasons for two observers to necessarily perceive an object as being of equal size." [8] One and the same capital (money) is seen as large or small depending on who perceives it and how it is perceived. "Some worry about thin soup, some worry about small pearls."

From the fundamental Einstein equation:

$$E = mc^2, \tag{25}$$

where E is energy; m is mass; c is the speed of light, it follows that the notions of energy and mass are interchangeable, as are, for example, ruble and dollar; c^2 is the coefficient that determines the exchange rate [8]. Coefficient c^2 may be called a scaling coefficient. For example, a map scale converts distances on the map into distances on the ground. The same applies to weighing coefficients reflecting factor dependence when solving a multi-criterion problem. But in contrast to (25), where c is constant, in economics, this value is variable and depends on time t.

3 Conclusions

1. Similar to the electromagnetic field, an economic and investment field can be considered, the propagation velocity of which depends on the properties of the environment and on the field magnitude (investments) in a given point.
2. The economic and investment field is anisotropic in space, i.e. the velocity of its propagation along axes X and Y is generally not equal: thus, at railroad sections, the transversal velocity along the Y axis of the economic and investment field is zero, while at stations it is not zero.

3. As the source of economics is society, which is not constant over time, the "scaling" coefficient is also not constant.
4. The shortening of the investment cycle is primarily caused not by the volume of additional investments, but rather by their rate.
5. Although the economic and investment fields require further research, they can already be used in the preliminary design of railroads.

Digitalization and automation of forecasting and designing of human activity processes allow to exclude the "human factor", it makes them more objective. This is especially important to solving problems, which relate to the development of regions and transport networks, for example ignorance of the laws of interaction between the economy and investment can lead to difficult to correct and "expensive" mistakes. The using of Maxwell's laws avoids them.

In our day the concepts "smart house, city", "smart car, railway track" are used widely in Russia. The using of electrodynamic laws for economic and investment processes contribute to emergence concepts "smart district", "smart railway", "smart transport network".

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Public Finance Policy for the Development of the Transport Industry

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Abstract. The purpose of the article is to study the effect of public funding on the transport industry development. The research subject concerns the influence of the funding amount on the implementation of the Federal Targeted Program (FTP) for the Development of the Transport System in Russia. The object of the research includes the target and actual values of the funding under this FTP. Both general scientific and special methods of inquiry were used. The SC technique was applied to estimate the risk of the state regulation for the funding of FTP for the Development of the Transport System in Russia. This research is associated with the decrease in public funding. The following three main funding sources were identified: the federal budget, the budgets of constituent entities of the Russian Federation, and extra-budgetary sources. Also, the following three items of expenditures were highlighted: Capital Investments, R&D, Other. Based on this, it has been concluded that in 2016, the highest risk of funding of FTP was associated with extra-budgetary sources. It has been concluded that the implementation of the Modernization of the Baikal-Amur Mainline and the Trans-Siberian Railway Infrastructure project is primarily associated with the risks of state regulation.

Keywords: Infrastructure · Investment project · Capital Investment · Mainline · Risk · Transport Development Strategy · National Welfare Fund · Targeted Program

1 Introduction

The Russian Federation long-term state policy in the area of railway transport is defined in the Concept of the Long-Term Social and Economic Development of the Russian Federation for the period up to 2020, the Transport Strategy and the Russian Federation Railway Transport Development Strategy for the period up to 2030.

The aim of the Russian Federation Railway Transport Development Strategy is to create the conditions for stable social and economic development of Russia, to enhance the population mobility, to optimize the goods distribution, to strengthen the economic sovereignty, the national security and defense capabilities, to decrease the total transportation expenses of the economy, to improve the competitiveness of the national economy, and to ensure the leadership of Russia. All this is to be supported by the

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railway transport rapid innovative development brought in balance with the development in other industries, means of transport, and regions of the country.

Based on the Message of President of Russia to the Federal Assembly and Presidential Decree of May 7, 2018 No. 204 On the National Objectives and the Strategical Tasks of the Development of the Russian Federation for the period of up to 2024, the Comprehensive Plan for the Modernization and the Promotion of the Mainstream Infrastructure for the period of up to 2030, the Russian Federation Railway Transport Development Strategy for the period up to 2030, the Strategy of the Innovative Development of Russia for the period of up to 2020, the Strategy for the Development of RZD Holding for the period of up to 2030, a long-term program of RZD OJSC development for the period of up to 2025 was approved by Decree of March 19, 2019 No. 466-r.

2 Topicality

In the context of implementation of the long-term program of RZD OJSC development, provision is made, in particular, for development of integrated servicing of cargo shippers, improvement in the cargo carriage quality, enhancement of the population mobility both within and between agglomerations, development of container shipping, expansion of high-speed networks, development of the infrastructure to provide future carriage volumes, transition to a “digital railway”.

Renovation of the Baikal-Amur and Trans-Siberian Mainline Railways is under way for several years now. In March 2018, Russian President Vladimir Putin declared, in his message to the Federal Assembly, that it is necessary to increase, in the next 6 years, the traffic capacity of the Baikal-Amur and Trans-Siberian Mainline Railways in the direction of the Far East border points by half (up to 180 mln tonnes). Modernization of the Baikal-Amur and Trans-Siberian Mainline Railways, including construction of new railway lines, will make it possible to implement over 50 large-scale investment projects with the total investment of 3.7 trillion rubles (1.2 trillion rubles of which will be invested into the development of railway infrastructure).

The Project objective is to develop the railway infrastructure in order to provide for the required carrying capacity in the direction of sea ports and border points of the Far East (export of stone coal and various ores from fields of this operating domain).

The passport of the infrastructure project for Modernization of the Baikal-Amur and Trans-Siberian Railway Infrastructure was approved by Order of the Russian Federation Government No. 2116-r of October 24, 2014. The Project duration: Construction phase (2013–2017); Operation phase (since 2018).

In 2013, the Russian Federation Government made a decision to provide funding to RZD OJSC from the National Welfare Fund (NWF) to implement the project for reconstruction and modernization of the Baikal-Amur and Trans-Siberian railway infrastructure. In view of high cost of the projects, the Russian Government acted as their co-investor, investing the resources from the NWF in these projects.

The investment amounted to 450 billion rubles at the initial stage. In 2013, the Russian Federation Government made a decision to provide funding to RZD OJSC from the National Welfare Fund (NWF) to implement the project for reconstruction and modernization of the Baikal-Amur and Trans-Siberian railway infrastructure. The sources of investment into the Baikal-Amur and Trans-Siberian railway development are approved in the Project passport.

It was planned that the total investment into the development of the Baikal-Amur and Trans-Siberian railways would amount to 696 billion rubles until 2025 [1].

It was planned to take 110.2 billion rubles from the federal budget of which 44.57 billion rubles were to be spent during 2018. However, no allocations to implement the projects have been planned in the federal budget for 2018 [2].

The NWF resources were to amount to 150 billion rubles including 30.44 billion rubles in 2018. The dynamics of the investments that were approved in the Project passport for the period from 2014 to 2019 is shown in Table 1.

Table 1. Planned volumes of investment into implementation of the infrastructure project for the Baikal-Amur and Trans-Siberian railway development (million rubles).

Source	2014	2015	2016	2017	2018	2019	Total
Federal budget	3.645.5	7.374.9	9.479.3	0.0	44.575.8	44.167.8	110.217.8
NWF	0.0	7.880.5	39.126.9	44.349.1	30.440.0	25.872.2	150.000.0
RZD	45.727.9	48.953.4	51.204.5	51.482.9	46.977.1	24.355.9	302.219.3
Total	49.373.3	64.208.8	99.810.7	95.832.0	121.993	94.395.8	562.437.1

It should be reminded that sovereign welfare funds (the Reserve Fund and the NWF) were created in the Russian Federation in 2008. Specifically, the NWF was formed as a supplementary pension fund; however, it has never been used as such. The aim of the NWF creation is enshrined in the Budgetary Code of the Russian Federation as follows: “to ensure co-financing of voluntary retirement savings of Russian citizens as well as to ensure the balance (covering the deficit) of the RF Pension Fund budget” [3].

In 2008–2009, a part of the NWF resources was used for urgent anti-crisis assistance to the banking system, and the other part was invested into long-term self-sustaining infrastructure projects including modernization of the Trans-Siberian and Baikal-Amur railways.

Sovereign welfare funds play the key role in the economic development in all countries around the world [4]. The Russian experience of creating sovereign welfare funds fits into the recommendations of the International Monetary Fund (IMF). At the third stage of development of such projects (at which the NWF is now), the IMF recommends clearly stating the investment priorities. The merge of the NWF with the Reserve Fund in 2018 provides an opportunity to invest the reserves (upon accumulation of threshold values at 7% of GDP) into the national economy and potentially leads to its transformation into a development fund. At the beginning of 2018, the NWF amounted to 3 trillion 752.94 billion rubles, which is equivalent to $65.15 billion.

By the end of 2017, the Government of the Russian Federation agreed to reduce the budget investment into the Baikal-Amur and Trans-Siberian railway development projects. Since 2018, the infrastructure projects of the East Operating Domain have not been receiving the previously pledged financing from the federal budget. After the decision made by the Government, only the NWF resources are envisaged to be used for the funding. By 2017, RZD OJSC has invested 173.5 billion rubles into modernization of the Baikal-Amur and Trans-Siberian railways. For 2018, the investment program of RD OJSC is to be about 510 billion rubles. Partially, RZD will be able to cover the lack of financing by a 2% increase in the cargo rates, with a substantial part of proceeds from the rate increase to be used to fund the Baikal-Amur and Trans-Siberian railways.

3 Purpose and Tasks

The purpose of the article is to study the effect of public funding on the transport industry development. The object of the research includes the target and actual values of the funding volumes under the Federal Targeted Program for the Development of the Transport System in Russia. The research subject concerns the influence of the funding volumes and sources on the implementation of the Federal Targeted Program for the Development of the Transport System in Russia. To achieve the purpose, it is necessary to solve the following tasks:

1. To analyze the actual use of the funds of the Federal Targeted Program for the Development of the Transport System in Russia in terms of the items of expenditure and the sources of funding, and to compare the values obtained with the planned figures.
2. To evaluate the risk of the program implementation in terms of sources of funding.

4 Research Methods and Research Subject

Implementation of any project or program, in general, mainly depends on the amount of financing. At the same time, a peculiarity of the national economy is that Russian major companies spend much less on R&D than international ones [6].

Planned amounts of funding of the Federal Targeted Program (FTP) for the Development of the Transport System in Russia (2010–2021) are shown in Table 2.

Table 2. Planned amounts of funding of the FTP for the Development of the Transport System in Russia for 2015–2017, billion rubles.

Source	2015	2016	2017
Federal budget	334.8	342.4	362.3
Budgets of the RF constituent entities	8.3	8.9	8.4
Extra-budgetary sources	533.3	571.1	524.1
Total	876.4	922.4	894.8

Actual cash expenditure for funding of the FTP is shown in Table 3.

Table 3. Actual cash expenditure for funding of the FTP for the Development of the Transport System in Russia for 2015–2017, billion rubles.

Source	2015	2016	2017
Federal budget	309.5	319.9	338.9
Budgets of the RF constituent entities	7.6	6.1	8.6
Extra-budgetary sources	439.9	496.6	545.4
Total	757.0	822.6	892.9

The data in Tables 2 and 3 are indicative of actual reduction in the cash expenditure of the funding for each source. The only exception is 2017, when financing from extra-budgetary sources exceeds the planned values.

5 Risk Assessment

Experts do not have a universal definition of the risk of state regulation of funding. This results in different views on the essence of such risks and their management methods [9]. To assess the risk of state regulation of project funding and programs in general, it is necessary to compare constantly the target and actual funding amounts. Both "top-down" and "bottom-up" models can be applied to identify, quantitatively evaluate, analyze, and manage this risk [10].

Let us assess the risk of state regulation of the FTP funding for the Development of the Transport System in Russia. This risk is associated with the decrease in the state funding. The following three items of expenditure are identified to estimate the risk: Capital Investments, R&D, Other. Table 4 shows items of expenditure from three various sources.

Table 4. Actual utilization of funds in terms of expenditure items and funding sources, billion rubles.

Items of expenditure	Federal budget			Budgets of the RF constituent entities			Extra-budgetary sources		
	2015	2016	2017	2015	2016	2017	2015	2016	2017
Total expenditure, including:	309,492.9	319,874.0	338,901.2	7,616.0	6,067.5	8,616.8	439,931.5	496,624.6	545,359.2
Capital investment	207,653.1	179,282.1	214,860.2	7,616.0	6,067.5	8,616.8	424,185.3	481,450.4	510,558.2
R&D	831.4	830.4	763.4	0.0	0.0	0.0	506.2	268.2	376.5
Other	101,008.4	139,761.5	123,277.6	0.0	0.0	0.0	15,240.0	14,905.9	34,424.5

Based on the analysis for 2016–2017, assessment of the risk of state regulation of funding of the FTP for the Development of the Transport System in Russia in 2016 is shown in Table 5.

Table 5. Assessment of the risk of state regulation of funding of the FTP for the Development of the Transport System in Russia in 2016.

Source	Target	Cash expenditure	Accomplished, %	Grade, score	Risk, score
"Capital Investment" item					
Federal budget	265,803.1	179,282.1	67.7	68	32
Budgets of the RF constituent entities	8,989.2	6,067.5	67.5	68	32
Extra-budgetary sources	456,532.0	481,450.4	105.5	100	0
"R&D" item					
Federal budget	1,045.6	830.4	79.4	79	20
Budgets of the RF constituent entities	0.0	0.0	0.0	0	0
Extra-budgetary sources	1,509.7	268.2	17.8	18	80
"Other" item					
Federal budget	157,919.4	139,761.5	88.5	89	11
Budgets of the RF constituent entities	0.0	0.0	0.0	0	0
Extra-budgetary sources	113,084.9	14,905.9	13.2	13	87

For overall assessment of the risk in terms of the funding sources, we integrate the results obtained for all the sources of funding of the FTP in 2016 and rate them according to their significance: the federal budget—0.5, budgets of the RF constituent entities—0.1, extra-budgetary sources—0.4 (Table 6).

Table 6. Integral assessment of the risk in terms of the sources of funding of the FTP for the Development of the Transport System in Russia in 2016.

Source	Capital Investment	R&D	Other
Federal budget	32 * 0.5	20 * 0.5	11 * 0.5
Budgets of the RF constituent entities	32 * 0.1	0 * 0.1	0 * 0.1
Extra-budgetary sources	0 * 0.4	80 * 0.4	87 * 0.4
Total risk, score	19.2	42.0	40.3

The performed calculations reveal that the highest risk of the FTP funding is associated with the R&D funding (score 42).

Assessment of the risk of state regulation of funding of the FTP for the Development of the Transport System in Russia in 2017 is shown in Table 7.

Table 7. Assessment of the risk of state regulation of funding of the FTP for the Development of the Transport System in Russia in 2017.

Source	Target	Cash expenditure	Accomplished, %	Grade, score	Risk, score
"Capital Investment" item					
Federal budget	235,631.8	214,860.2	91.2	91	9
Budgets of the RF constituent entities	8,396.4	8,616.8	102.6	100	0
Extra-budgetary sources	433,998.9	510,558.2	117.6	100	0
"R&D" item					
Federal budget	782.8	763.4	97.5	98	2
Budgets of the RF constituent entities	0.0	0.0	0.0	0	0
Extra-budgetary sources	1,498.7	376.5	25.1	25	75
"Other" item					
Federal budget	114,017.8	123,277.6	108.1	100	0
Budgets of the RF constituent entities	0.0	0.0	0.0	0	0
Extra-budgetary sources	88,605	34,424.5	38.9	39	61

Table 8. Integral assessment of the risk in terms of the sources of funding of the FTP for the Development of the Transport System in Russia in 2017.

Source	Capital Investment	R&D	Other
Federal budget	9 * 0.5	2 * 0.5	0 * 0.5
Budgets of the RF constituent entities	0 * 0.1	0 * 0.1	0 * 0.1
Extra-budgetary sources	0 * 0.4	75 * 0.4	61 * 0.4
Total risk, score	4.5	31	24.4

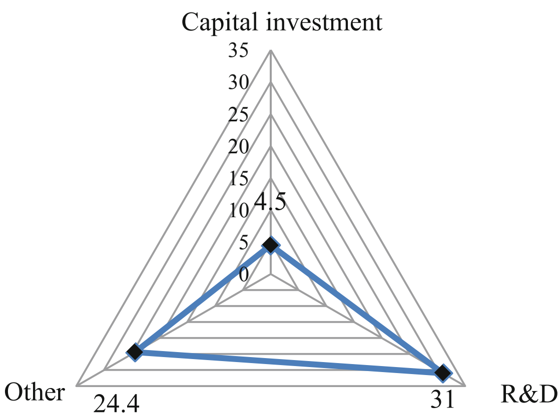

Fig. 1. Graphical interpretation of the risk integral assessment.

Integrating the results obtained for all the sources of funding of the FTP in 2017 (Table 8).

The data shown in Table 8 prove that the highest risk of the FTP funding is associated with the R&D financing (score 31) (Fig. 1).

6 Conclusions

On the basis of the performed calculations, it can be concluded that R&D financing is the most vulnerable point in the funding of the Federal Targeted Program for the Development of the Transport System in Russia from three funding sources during the analysis period.

Decree of the Russian Federation Government No. 2116-r of October 24, 2014 On Approval of the Passport of the Infrastructure Project for Modernization of the Baikal-Amur and Trans-Siberian Railway Infrastructure with the Development of Traffic and Carrying Capacities formulated the investment project implementation risks and the degree of their effect on the project implementation (Table 9).

Table 9. Risks of the investment project implementation.

Risk types	Risk level
Contractual policy risks	Medium
Technical risks	Low
The project competitiveness, exposure to market risks	Low
The project legal frame (analysis of risks distribution among lenders and other project participants)	Low
Risks of a contractor of the investment project promoter	Medium
Risks of change in the market value of preferred shares of RZD OJSC that are caused by possible deterioration in financial standing of the company	Medium
Risk of late payment of dividends on preferred shares purchased at the expense of the National Welfare Fund, due to deterioration in financial standing of RZD OJSC and absence (lack) of the required amount of net profit generated from the company's activities over the corresponding financial year	Medium

There is a rule to manage complex systems: a system can help to achieve goals in view, if it meets certain requirements [7].

In our opinion, the implementation of the Modernization of the Baikal-Amur Mainline and the Trans-Siberian Railway Infrastructure project is primarily associated with the risks of state regulation. The risk of lack of (failure to comply with) long-term government decisions regarding railway transport development funding is assessed as a critical one with high likelihood of occurring. The risk of decrease in the amount of state funding makes it necessary to raise external debt funds and pay the interest thereon, as well as leads to reduction in the investment program volume.

To mitigate the effect of the aforesaid risks of state regulation on the project implementation, alternative sources and mechanisms of its funding should be searched for. Besides, it becomes necessary to optimize engineering solutions for capital projects as well as to divide projects into stages and to prioritize their implementation.

Reduction in investment into infrastructure projects of the East Operating Domain would result in a slowdown of their implementation, and this would have an adverse effect on both cargo shippers and cargo receivers, as well as on RZD OJSC as a whole. The transport system is a key component of business processes and directly influences their efficiency in terms of a number of factors: transport accessibility, time of implementation of business ideas, business profitability [8].

For fifty years now, the Trans-Siberian Railway remains the longest railway line in the world. The development of this largest mainline in Eurasia is aimed not only on the development of regional infrastructure but should also enable Russia to play the key role in the global transit of goods along the route that unites Europe to Asia. Financial support from the Russian Federation Government is essential to implementation of the East Operating Domain development projects.

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The Multi-level Model of the Service Enterprises Human Capital Value

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Abstract. Human resources play an important role both in the development of a separate enterprise and in the development of the whole country, therefore the issues related to the definition of the concept of "human capital" and methods of its assessment are relevant today. The article discusses the currently best-known methods and approaches to assessing the human capital of service enterprises. The analysis carried out in the study made it possible to clarify the economic content of the concept of human capital and to identify its key features that allow it to be characterized and to use specific methods of evaluation. The author suggests an approach to assessing the human capital of service enterprises as part of intellectual capital based on a multi-level value structure. It is offered to estimate the cost of personnel as the sum of two components - the current component, which is the income that is formed by the personnel of the enterprise as a result of the current implementation of the statutory activities of the enterprise, as well as the future component - investment, which provides the stream of the company's income in the future. The model of human capital assessment will allow achieving not only its quantitative growth, but also the qualitative development of enterprises. The method of calculation, as well as evaluation results of the enterprise human capital are given. The results are compared with the results evaluated by the well-known VAIC method.

Keywords: Service enterprises · Human capital · Intellectual capital · Methods of evaluation · VAIC method · Multi-level value structure

1 Introduction

At present, in the context of globalization and integration of the economy, the services sector is a particularly important component of the development of many countries of the world, including Russia. The service sector is characterized as one of the main components of the post-industrial economy and acts as the dominant way of meeting human needs. Production needs to improve the quality of service and the introduction of mechanisms to create demand for services, which, in turn, increase the demand for manufactured goods. The share of the services sector currently stands at about 60% in GDP.

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The above facts once again confirm the inevitable processes of mutual influence, integration and globalization in various spheres affecting the full development of the state and society. Consequently, in the modern world it becomes especially important to study the enterprises of the service industry, which correspond to the modern trends in the development of market relations. The structure of enterprises of the service sector is presented in Fig. 1.

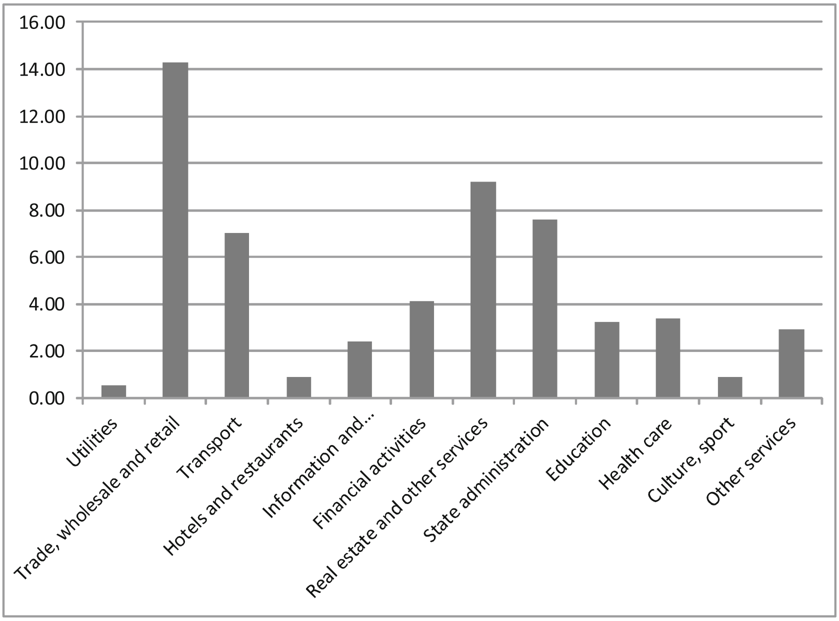

Fig. 1. The structure of enterprises of the service sector in 2018, %

Nevertheless, the human resource plays an important role, both in the development of a separate enterprise and in the development of the whole country, because the more efficiently the company works, the more it earns profits, which leads to an increase in the country's GDP. One of the promising directions in the development of modern management is the direction associated with the use of human capital.

2 The Problem of Interpreting the Concept of "Human Capital"

Currently, there are numerous publications that reveal the essence of human capital [1, 4–9]; however, the definition, and its economic essence is still the subject of heated debate between scientists.

Firstly, it relates to the introduction into the practice of management in addition to the term "human capital", such concepts as intellectual capital, network capital, structural capital, labor capital. The presence of a wide range of terms, the definitions of which have not yet settled, and the economic content often overlaps does not contribute to a clear understanding and proper use of them [2].

Secondly, the category of “human capital” is manifested and distinguished by researchers at various levels: individual (individual person), micro level (enterprises and organizations), meso-level (large associations, industries, regions), macro level (state economy), mega-level (globally). At each level, different requirements are imposed on the concept of human capital, human capital itself participates in various operations typical of other types of capital, and different stages of this turnover are manifested at different levels.

Thus, the theory of human capital explores the dependence of the incomes of an employee, an enterprise, and society on the knowledge, skills, and natural abilities of people [3]. This theory has become another step forward in economic, political, social and pedagogical views on people, but it has certain specifics: people are considered not as the main value of society, but as one of the priority factors of production and economic development of the country, therefore it is necessary to study the problems of human capital from different levels of management.

In our opinion, the following features can be considered the most important distinctive features of the concept “human capital”:

- A person, an employee or a citizen of a country acts as a carrier of human capital, i.e. he cannot be separated from him and without a man he does not exist;
- The ability to generate additional income - i.e. ability to capitalize, i.e. on the one hand, the possibility and necessity of valuation of human capital, and on the other hand - the presence of conditions under which the knowledge and skills belonging to a person can be realized.

On the one hand, such an approach makes it possible in the future to develop ways to assess human capital, and on the other, to develop methods for its effective management, including attraction and development. At the same time, a number of problems that have not been fully resolved so far [10] stand in the way of the widespread introduction of human capital into activities of modern enterprises.

In our opinion, the approach related to the assessment of human capital through knowledge, skills, abilities and other socially and economically important qualities of an employee is not sufficiently correct. These categories relate primarily to the term potential. However, the availability of their use in order to create a certain level of income or increase the value of the enterprise translates it into the concept of capital. Consequently, human capital is not just knowledge, skills and abilities (competencies), but the knowledge and skills that are used or will be used in the future to generate business income. At the same time, it is important to note that there is no direct relationship between investments in education and returns on these investments, as the general cultural features, the economic and organizational culture of the enterprise, as well as the characteristics of the employee or individual by their ability to effectively use their knowledge will play a significant role in the process of the enterprise [11].

Enterprises succeed if they develop their production and commercial activities with human capital. The main problems associated with the use of human capital in enterprises include the following: low level of development of the human capital valuation system, low degree of human capital use of the enterprise, insufficiently thought-out policy of labor resources and human capital use in general.

Consequently, in modern conditions it is necessary to implement measures at enterprises aimed at eliminating the listed problems to the system of evaluation, development and use of human capital [12]. Human capital is a capitalized (converted into value) current and future value of the enterprise's personnel's usefulness for a given enterprise and its technological and economic process, embodied in the skills and qualifications of workers, and expressed in terms of current and future income of the enterprise, or the amount of their excess over average market level.

3 Methods for Evaluating Human Capital

The purpose of human capital valuation includes the following aspects:

- The provision of information necessary for making decisions on personnel management, for high management and personnel managers;
- Provide stakeholders with methods of measuring and managing human capital;
- Talk about human resources as assets, parameters and quality of which can and should be managed.

Modern researchers classify all methods for evaluating human capital into the following groups [11]:

- Natural methods that imply an assessment of human capital value through the staff education level;
- Cost models that consider the initial cost, the cost of acquisition, replacement, as well as opportunity costs for human assets;
- Monetary models based on the assessment of future income from investments in qualifications and abilities of staff;
- Models for assessing the human capital value, implying a combination of monetary approaches with non-monetary aspects of employee behaviour.

Despite the significant variety of assessment methods in our opinion, none of the methods provides a complete assessment of the quality of human capital management. This is because the considered methods take into account human capital, either only on the basis of costs, taking into account various adjustments, or on the basis of additional income in the form of cash flow or value added.

Human capital at the enterprise level has the greatest relevance and significance for economic development. The specific abilities of human capital at the level of service enterprises include the following:

- Formed in the form of knowledge, skills, skills of the staff of a commercial enterprise;
- Manifested in the form of abilities of labor personnel and management decisions taken by them;
- The accumulation of human capital is carried out continuously in the process of involving staff in the trade and production process;
- Investments in human capital are associated with specific employees and are expressed in increasing motivation, level of education, creative and professional abilities, etc.;

- Due to the development of personnel increases the enterprise productivity;
- Creates added value, i.e. is a competitive advantage for the enterprise.

Methods for evaluating human capital, as well as their advantages and disadvantages, are presented in Table 1.

Table 1. Methods for evaluating human capital [11, 12]

Method name	Content of the approach	Advantages	Disadvantages
Human capital measurement using physical indicators	The more time spent on human education, the higher the level of education, the more human capital he has	Indicators can be considered at the regional level to characterize the level of the population education, for example, the indicator of accumulated years of education	The obtained indicators do not allow to obtain a reliable estimate
Method of calculating direct staff costs	The total economic costs invested in the personnel of the enterprise are calculated, including an assessment of costs of staff payments, taxes, protection and improvement of working conditions, costs of training and advanced training	Ease of calculation	Incomplete assessment of the real value of human capital, as part of it may not be used in the enterprise
Future capitalization method	People tend to value a certain amount of money or a set of goods in the present tense higher than the same amount or set of goods in the future	One can calculate the economic effect of using human capital	The difficulty of determining the interest rate and the discounted income
Expert method (qualitative method)	Both the quality characteristics of a particular employee and the totality of human (personnel) potential properties are assessed. Based on the use of weights	Objectively assesses the qualitative components of human capital	There is no direct link between investment in man and the cost of personal human capital. It is difficult to assess the proportion of the employee as a result of the activities of the enterprise
Investment method	The functioning effectiveness of the company (enterprise) directly depends on how literate and educated its employees are	Allows to link the level of investment in staff knowledge with the efficiency of the enterprise. Gives value estimates	Considers only the costs of professional development, excluding impairment of knowledge
Method based on the assessment of the main (physical) capital	Human capital is estimated as an investment in knowledge, considering their obsolescence (wear) and the presence of a synergistic effect	Gives valuations, considers obsolescence (wear) and multiplicative effect of development	Requires to use certain statistical information

Presented in Table 1 assessment methods as a whole make it possible to take into account the main features of the “human capital” category; however, I would like to note that one of the most important features of human capital, as the ability to generate income for an enterprise in the present and especially in the future, taking into account its development trajectory, is implemented in considered techniques not fully. Also, to the disadvantages of these approaches should be attributed to the weak consideration of the characteristics of various types of costs of human capital at different stages of the enterprise and the corresponding return on these investments.

4 Approach to Assessing the Human Capital of Service Enterprises

The development of modern approaches to assessing the cost aspects of enterprises allows us to develop an approach for the integrated assessment of the human capital of a commercial enterprise, considering the role of human capital in the fundamental value formation of the enterprise and sustainable competitive advantages involving various assessment methods. An approach to estimating the value of a commercial enterprise was proposed based on a multilevel value model, including balance, operational and investment components, as well as a component of dynamic flexibility, as a prospective cost of an enterprise’s adaptability ability to changing conditions.

A similar approach can be used to estimate the value of the human capital of service enterprises. The multi-level assessment allows you to see not only the costs of attracting human capital, but also the effectiveness of its use (capitalization) and solve the problem of managing this component of enterprise value, considering retraining and training measures for personnel at all levels. In accordance with this approach, the human capital value of a commercial enterprise can be assessed as follows:

$$V_{\mathrm{HC}} = V_{\mathrm{HCB}} + V_{\mathrm{HCO}} + V_{\mathrm{HCI}} \tag{1}$$

where:

- V_{HC} – cost of human capital;
- V_{HCB} – balance sheet component of human capital;
- V_{HCO} – operational component of human capital value;
- V_{HCI} – investment component of human capital value.

The balance sheet value of human capital can be estimated based on the replacement cost (cost approach), as the sum of the wages of all employees of the commercial enterprise. This item of cost must include the costs of searching and hiring staff, as well as the costs associated with the dismissal of personnel, determined by the legislation of the Russian Federation:

$$V_{\mathrm{HCB}} = C_{\Pi} + C_{\mathrm{h}} + C_{\mathrm{y}} \tag{2}$$

where:

- C_{Π} – salary of the enterprise staff for the reporting period;
- C_{h} – the cost of finding and hiring staff for the reporting period;
- C_{y} – the cost of dismissal of the enterprise staff for the reporting period.

The second component - operational should reflect the contribution of human capital in the dynamics of the enterprise value. Some authors propose HEVA, or HCVA, indicators that take into account the value added per employee. At the same time, in the framework of the developed approach to assess the operating value, it is necessary to assess the contribution of human capital to the creation of added value. Such an assessment can be made based on the following considerations.

In the general case, fixed assets (capital invested in fixed assets), working capital (capital invested in the working capital of an enterprise), and human capital (capital spent on staff attraction) are involved in creating value added in an enterprise. Obviously, each of the elements has an impact on the formation of economic value added, or monetary value added, so as a first approximation it can be assumed that the operational component of the value of human capital can be estimated as follows:

$$V_{HCO} = EVA\frac{V_{HCB}}{A + \overline{OC} + V_{HCB}} \quad (3)$$

where:

- EVA – economic value added;
- A – depreciation of fixed assets for the reporting period;
- $\overline{OC}$ – average working capital balance for the reporting period.

The investment component of human capital should be assessed as the estimated return on investment in human capital. The main indicator can be the coefficient of return on investment in human capital. Here, however, it is necessary to make a reservation what is meant. The interpretation proposed in this paper differs from the approaches presented in other works. This ratio reflects the ratio of growth in operating profit of a trade enterprise to the amount of investment in human capital.

This indicator should take into account the contribution to training, retraining and staff development. The total cost of the investment component of human capital can be defined as the net cash flow from investments in human capital, which is carried out in the framework of the investment activity of the enterprise. Unfortunately, using the existing forms of presenting financial and accounting statements, the calculation of this indicator may be a certain difficulty. Therefore, in this method it is proposed to limit the consideration of the investment component, as the cost of training and retraining of employees.

Below are the results of calculations of the assessment of human capital, considering the presented methodology (Table 2, Figs. 2, 3 and 4). The results are compared with the calculation of the human capital component according to the VAIC method, and the comparison is based on a comparison of the growth rates of these indicators. The correlation coefficient between HCE and VHC is 0.663, which indicates a fairly high level of closeness of the relationship between these indicators.

Table 2. Indicators of the human capital assessment of a service enterprise

№	Indicator	Reporting period					
		2012	2013	2014	2015	2016	2017
VAIC							
1	Value added VA, mln. Rub.	7 713	10 954	12 475	35 933	21 210	24 722
2	Structural capital SC, mln. Rub.	1 693	2 356	1 467	23 173	5 714	6 663
3	Net assets CE, mln. Rub.	14938	21612	27769	34145	44021	50552
4	*HCE*	1.285	1.281	1.141	2.821	1.372	1.372
5	HCE growth rate	−0.0033	−0.2443	1.7716	−0.4887	0.0003	0.0037
V_{HC}							
	V_{HCB}	6003	8553	10936	12738	15465	18020
	V_{HCO}	1539	2128	1726	5004	3509	4305
	V_{HCI}	17	45	72	23	32	39
	V_{HC}	7559	10726	12734	17765	19005	22363
	V_{HCB} growth rate	0	0.4248	0.2785	0.1648	0.2141	0.1652
	V_{HCO} growth rate	0	0.3827	−0.1888	1.8992	−0.2989	0.2269
	V_{HCI} growth rate	0	1.6286	0.6209	−0.6868	0.4083	0.2205
	V_{HC} growth rate	0	0.4190	0.1872	0.3950	0.0698	0.1767

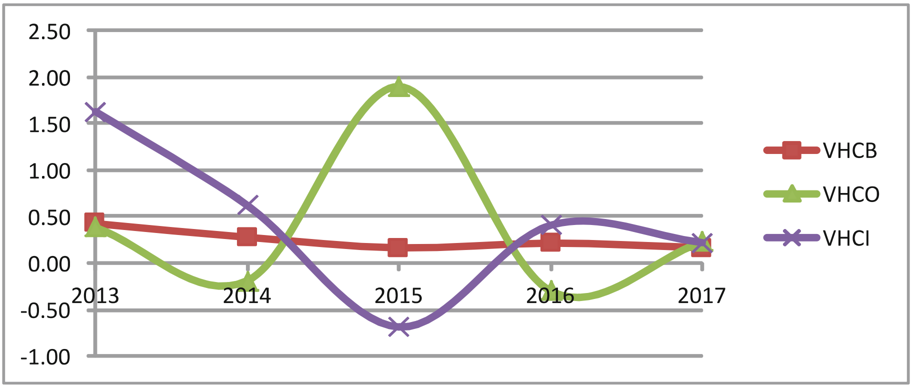

Fig. 2. Dynamics (growth rates) of the human capital structure elements of a service enterprise

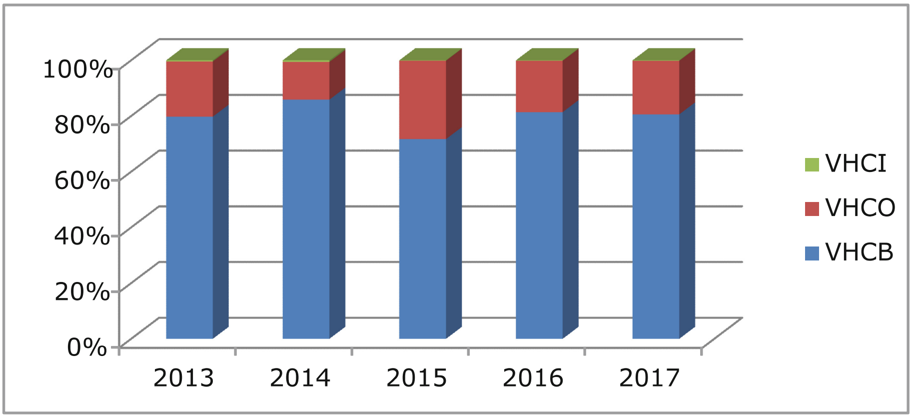

Fig. 3. Changes in the human capital structure of a service enterprise

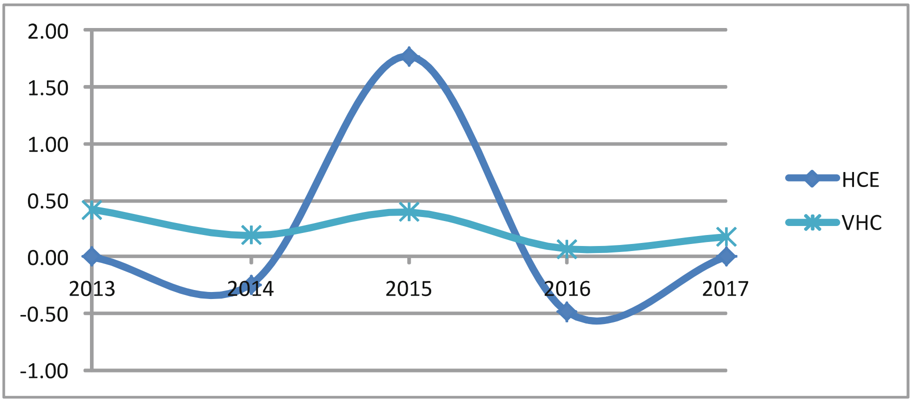

Fig. 4. The dynamics of the human capital of the services sector enterprise, calculated based on the approach VAIC

5 Conclusion

The article discusses approaches to the interpretation of the terms "human capital", as well as the advantages and disadvantages of methods for evaluating human capital, which remain controversial and relevant today. An approach to estimating the cost of personnel of an enterprise in the service sector is proposed as the sum of two components - the current component, which is the income that is formed by the personnel of the enterprise as a result of the current implementation of the company's statutory activities, and also the future component - investment, which provides an income stream for the enterprise in the future. The multi-level assessment allows you to see not only the costs of attracting human capital, but also the effectiveness of its use (capitalization) and solve the problem of managing this component of enterprise value, considering retraining and training measures for personnel at all levels. This approach takes into account the sectoral feature of the formation of human capital value, an individual approach to personnel assessment, as well as quantitative and qualitative reserves of its growth.

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Structural Diagram of an Automated System of Material Moisture Content Control

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Abstract. A block diagram of an automated system of material moisture content control is presented. The system provides automatic measurement of the amplitudes of the incident and reflected waves, automatic frequency tuning in a given range, automatic measurement of the resonant frequency, processing of data on a PC, and presentation of data in the form of numerical and graphic information on the display screen and printer.

Keywords: Metrological support · Reliability indicators · Block diagram · Probabilistic-statistical methods · Signal · Coupler · Amplitude · Load · Q-factor · Resonator

1 Introduction

Improving the reliability of control and the efficiency of controlling the drying process of materials by increasing the accuracy of measurements of technological parameters is in the spotlight when working on automation of measurements. Questions about the losses caused by the error in measuring parameters under the conditions of the functioning of information technology systems naturally lead to an understanding of the need to consider the initial concept in the metrological support of a technological operation as a system task. The possibility of technical implementation of this task leads to the ensuring the control reliability indicators at all stages of production.

2 Materials and Methods

The purpose is to determine the conditions under which the applicability of probabilistic-statistical methods to the estimation of measurement error is observed and the reliability of control reliability indicators in modern technologies is guaranteed.

The structural diagram of an automated material moisture control system is based on the principle of separation and detection of incident and reflected wave signals. A signal proportional to the power incident on the load is allocated by a directional

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incident wave coupler [3]. The signal reflected from the test load is allocated by a directional coupler of the reflected wave.

The reflection coefficient is determined by the following formula:

$$G = \sqrt{\frac{U_{refl}}{U_{inc}}}, \tag{1}$$

where G is the voltage coefficient module; U_{refl}, U_{inc} are the amplitude of the detected voltage of the incident and reflected waves, respectively.

To determine the loaded Q-factor, we use the known ratio:

$$Q_n = \frac{f_0}{f_v - f_n}, \tag{2}$$

where f_v and f_n are boundary frequencies at which the power supplied to the resonator is 2 times less than the power supplied to the resonator at the resonant frequency [1].

From this condition, taking into account the dependence between *P, G* and *SWR*, after transformations, we obtain the expression for standing wave ratio (*SWR*):

$$SWR = \frac{SWR_0^2 + SWR_0 + 1 + (1 + SWR_0)\sqrt{1 + SWR_0^2}}{SWR_0}, \tag{3}$$

where *SWR* is the value of the standing wave coefficient at a frequency f_h and f_l.

After these calculations, one can find the value of the loaded Q-factor Qn of the resonator connected according to the two-terminal circuit.

The intrinsic Q-factor of the resonator is determined from the formula

$$Q_0 + Q_l(1 + \beta) \tag{4}$$

where β is the coupling coefficient of the resonator with the load (transmission line):

$$\beta = \frac{X_c^2 Q_0 \rho}{Z_0} \tag{5}$$

where X_c is coupling resistance of the resonator with the transmission line; Z_0 is the wave impedance.

Therefore, the automated control system (ACS) should provide the following operations: automatic measurement of the amplitudes of the incident and reflected waves, automatic tuning of the frequency in a given range, automatic measurement of the resonant frequency, processing of data on a personal computer, presentation of data in the form of numerical and graphic information on the display screen and printer [4]. The block diagram of the ACS, providing these operations, is presented in Fig. 1.

The system consists of the following functional units: PC, system interface, microwave generator G4-80 with an installed electric motor ED1, frequency meter Ch 3-54, directional couplers of incident and reflected waves with detectors D1 and D2, interface unit, printer. To measure the resonant frequency, SWR, and Q-factor of the

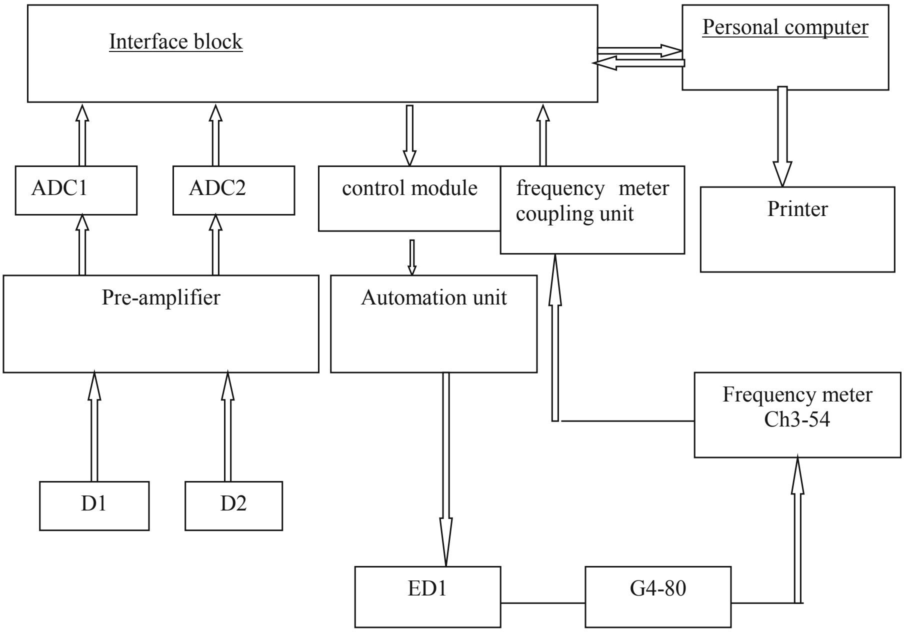

Fig. 1. The block diagram automated control system

resonator, the generator is tuned according to the PC frequency through the interface unit using an electric motor ED1. In this case, the readings of the frequency meter Ch3-54 and the amplitudes of the incident and reflected waves by the detectors D1 and D2, respectively, are taken. The PC calculates fr, SWR, Q-factor and displays the results of the calculations on a monitor or printer.

The interface unit consists of the following functional units: PC communication unit, analog-to-digital converters 1 and 2, pre-amplifier, control module (CM), frequency meter coupling unit (FMCU), automation unit, power supply.

The interface unit via a bi-directional address data bus carries out the transfer of information from external devices to computers. ADC1 and ADC2 receive signals from detectors of directional couplers through a pre-amplifier. The control module generates the necessary signals for the automation unit (engine start, reverse, stop) and generates a signal "Reset" for the Ch3-54 frequency meter.

The automation unit generates the required voltage for the electric motor ED1.

Frequency meter coupling unit receives parallel information about the state of eight decades of the frequency meter and exchanges with a PC by-bytes. The power unit provides power to the installation circuit.

Based on the resonator method, it is possible to set up an automated control system by automating the process of measuring moisture content in a stream and, to combine measurement and calculation processes by expanding circuits including PC.

Modern production puts forward rather stringent requirements for the accuracy of the measured parameters, especially since the hardware itself introduces an error in the measurement result. Under these conditions, there is a need to develop metrological support for the measurement and calculation operations of an automated control system.

The task of increasing the reliability of control and the effectiveness of controlling the drying process of materials by increasing the accuracy of measurements of technological parameters is in the spotlight when working on measurements' automation. Questions about the losses caused by the error in the measurement of parameters under the conditions of the functioning of information and technological systems naturally lead to an understanding of the need to consider the initial concept in the metrological support of a technological operation as a system task. In its turn, the possibility of the technical implementation of this task leads to the achievement of the goal of ensuring the security of control reliability indicators at all stages of production.

The task is to determine the conditions under which the applicability of probabilistic-statistical methods to the estimation of measurement error is observed and the security of control reliability indicators in modern technologies is guaranteed.

Turning to the operation of automatic control of the technological process and, following the refined concept of its metrological support, it becomes quite obvious that it is necessary to solve following tasks:

1. to solve the problem of the permissible error of measurement of technological parameters, for example, under the condition of technological tolerance for deviations of the parameter from the nominal;
2. to find an approach to assessing the error of technical means when measuring technological parameters;
3. to compare the expected technical error of the measurements with the allowable error and solve the problem of maintaining it within the allowable error by controlling the accuracy of technical measurements.

The solution of the problem of controlling the accuracy of measurements needs scientific justification from the point of view of reliability and effectiveness of its implementation under the conditions of functioning of the indicated measuring instruments.

It is known that the best way to comprehend any complex task is its mathematical modeling. Let us consider procedures for compiling a mathematical algorithm for converting measuring signals by some technical system that has a real analogue and calculating the expected measurement error of a controlled parameter [7]. The most complete is the dynamic characteristic of the transformation, which is convenient to determine from the position of recovery of the unknown input process *x(t)* from the known output process *y(t)*, representing it as a differential equation of the first or second order.

The error of the technical means of measurement, reduced to the input, is usually expressed as

$$\delta[x(t)] = f_{nom}^{-1}\{F[x(t)]\} - x(t), \tag{6}$$

where $x(t)$ is the actual value of the signal at the input of the technical means of measurement; f_{nom}^{-1} is the inverse of the nominal statistical characteristic of the conversion of the measuring instrument; $F[x(t)]$ is the unknown real dynamic conversion function.

It is not possible to use expression (6) in modeling the transformation process $x(t)$, because the functional $F[x(t)]$ and function $x(t)$ are unknown.

Obviously, this identity will not be violated if it presents as follows:

$$\delta[x(t)] = f_{nom}^{-1}\{F[x(t)]\} - F^{-1}\{F[x(t)]\}, \quad (7)$$

where f^{-1} is the inverse of the real dynamic transformation function.

It follows from (7) that the error $\delta[x(t)]$ is determined by the difference between the two transformation functions:

$$f_{nom}^{-1} \neq F^{-1}, \quad (8)$$

Let us express in (6) the unknown functional $F[x(t)]$ by the mathematical model, using the estimate of the inadequacy of the model $\Delta(y)$ as follows:

$$\Delta(y) = F_m[x(t)] - F[x(t)] \quad (9)$$

where $F_m[x(t)]$, designated as $F_m(\bullet)$ is the direct dynamic conversion function model of a technical measuring instrument.

In view of (9), expression (7) is transformed to the following form:

$$\delta[x(t)] = \left\{f_{nom}^{-1} - [F_m(\bullet) - \Delta(y)]^{-1}\right\}\{F_m(\bullet) - \Delta(y)\} \quad (10)$$

After transformations (10), we finally get:

$$\delta[x(t)] = f_{nom}^{-1}[F_m(\bullet)] - x - f_{nom}^{-1}[\Delta(y)] = \delta^*[x(t)] - f_{nom}^{-1}[\Delta(y)] \quad (11)$$

Thus, when modeling the transformation process using models $F_m(\bullet)$ and $f_{nom}(\bullet)$, the calculated error value according to (11) will have a residual error equal to $\eta = f_{nom}^{-1}[\Delta(y)]$.

The numerical characteristics of the distribution of the error in estimating the error $\delta^*[x(t)]$ substantially depend on the parameters of the nominal characteristics of the conversion of the technical measuring instrument and the numerical characteristics of the model inadequacy distribution. The parameters depend on the distribution law *x(t)* and its numerical characteristics. Therefore, in the simulation procedure of a direct transformation that is close to real, a simulation of the input process is required.

Recovery of an unknown input process from a known output process using inverse models is an incorrectly posed problem. However, if the implementation of the output process with the known real correlation function and the first moment of distribution *y (t)* is represented by a first or second order autoregressive model, for example, in the form:

or

$$y(k) = a_{11}\xi(k) + d_{12}y(k-1) + m_{13}, \quad (12)$$

$$y(k) = a_{21}\xi(k) + d_{22}y(k-1) + \gamma_{23}y(k-2) + m_{24}, \quad (13)$$

then the error condition can be eliminated if we pass from discrete values of $y(k)$ generated by (12) or (13) to differentiable smooth functions that deviate from $y(k)$ on a segment divided into pieces that are glued together by piecewise polynomial functions of j^{th} order.

In other words, the values of $y(k)$ can be used in the future as interpolation nodes with a uniform grid to form an interpolation differentiated (smooth) polynomial spline, the values of which are denoted by $y^*(t_s)$.

Using the inverse model of a differential equation, for example, of the second order, we restore the input process:

$$x(t_i) = \left\{ y^*(t_i) + a_1 y'^*(t_i) + a_2 y''^*(t_i) - B_0 \right\} A_0^{-1}, \quad (14)$$

where $y'^*(t_i)$ and $y''^*(t_i)$ are first and second derivatives of the output process at time t_i; $A_0, B_0, a_j (j = 1, 2)$ are differential equation parameters.

In essence, it follows from (1.8) that a known output process is transformed into a previously unknown input process with a correlation function and distribution times and can be different from the real process $x(t)$. This difference depends on the adequacy of Eq. (1.8) and can be determined if we pass from the differential equation to its difference analogue, forming from (1.8) a system of equations with covariances between $x(k-i)$ and $y^*(k-i)$ and taking mathematical expectations from both again formed sides parts of equations.

Turning to (14) and (6), we note that the result of the transformation $\{F_{nom}(\bullet) - \Delta(y)\}^{-1}\{F_m(\bullet) - \Delta(y)\}$ in (11) corresponds to the true value of x(t) from (1.1), while the result of a transformation of the form $f_{nom}^{-1}\{F_m(\bullet) - \Delta(y)\}$ is practically used.

Substituting the direct model (14) in (6), and also, taking into account (11), we obtain:

$$\delta[x(t)] = \left\{ x(t)[A_0 - A] + [B_0 - B] - a_1 y'^* - a_2 y''^* \right\} A^{-1} - \eta. \quad (15)$$

It can be seen from (15) that the error $\delta^*[x(t)]$ is systematic, including dynamic error, and is formed due to differences in the parameters of the real static characteristic of the dynamic conversion of the technical measuring instrument (i.e., parameters A_0 and B_0) from the corresponding parameters of the nominal conversion characteristic (i.e., parameters A and B), as well as due to the lack of a dynamic component in the nominal characteristic conversion. Taking into account the above relations, it is formed a structural scheme for calculating the expected measurement errors that are close to the actual operating conditions of the technical measuring device. As it follows from the block diagram, the procedure for modeling the measured process is based on the well-known output process $y^*(t)$, which, according to the model of the inverse transformation of the original measuring instrument, is converted into the input unknown process $x(t)$.

Changes in the parameters during the functioning of a technical measuring instrument (the influence of external environmental factors ξ1, ξ2), with a probabilistic distribution of the measured quantity $x(t)$, form a deformed distribution law of the resulting measurement error according to (13), to which, in principle, the concept of probability distribution density cannot be correctly applied, since the irregularity property of the collective is violated due to the heterogeneity of the operating conditions of the technical measuring instrument.

In other words, the necessity of correlating the distribution law of the resulting measurement error $\delta[x(t)]$ with constant external conditions, characterizing the internal statistical stable interactions of random events, describes the correctness of the applicability of probability-statistical methods in practice.

Change in the accuracy of technical measuring instruments at the required level in a changing environment is possible only by the transition from a nominal conversion function to an adaptive one in a limit that differs from the actual conversion function by no more than η.

The implementation of this requirement can be a measure of correctness in the approach to the possibility and expediency of using adaptive identification of technical measuring instruments.

Let us determine the relationship between the numerical characteristics of the distribution of the error in calculating the Q-factor and the numerical characteristics of the distribution of the error in the frequency measuring. To do this, we use the mathematical expectation and variance of the error distributions and the relationship between them.

When deriving the analytical dependencies, we make the assumption that the error in measuring the frequency is random, additive and independent, and the mathematical expectation of errors in the frequency measuring is zero, i.e. $m\xi f = 0$.

Equate

$$Q_{nom} = \frac{f_0}{f_2 - f_1}, \quad (16)$$

where $f_2 - f_1$ is the bandwidth of the resonance curve at half power level; f_0 is the resonance frequency:

$$Q_{nom}\xi k + \xi z = \frac{f_0 + \xi_0}{(f_2 - f_1) + (\xi_1 - \xi_2)}, \quad (17)$$

where ξ_k is the multiplicative calculation error; ξ_z is the adaptive calculation error of Q_{nom}.

The mathematical expectation of the multiplicative error:

$$m\xi_k = -\frac{mf_0(mf_2 - mf_1)}{mQ_{nom}\mu_k(\xi_1 - \xi_2) - mf_0(mf_2 - mf_1)}, \quad (18)$$

Since the errors ξ_0, ξ_1, ξ_2 relate to one measuring instrument, then designating them through ξ, we obtain

$$m\xi_k = -\frac{mf_0(mf_2 - mf_1)}{2mQ_{nom}\mu_z(\xi) - mf_0(mf_2 - mf_1)}, \quad (19)$$

where mQ_{nom} is the mathematical expectation of Q-factor.

The total value of the mathematical expectation of the error in calculating the Q-factor of the resonator:

$$m\Sigma Q\xi = mQ_{nom}(m\xi_{nom} - 1) + m\xi_z. \quad (20)$$

The total variance of the error in calculating the Q-factor of the resonator:

$$\mu_2(\varDelta\Sigma_\xi) = \mu_2(Q_{nom})\left[\mu_2(\xi_k) + m^2\xi_k - 2m\xi_k + 1\right] + \mu_2(\xi_z) + m^2Q_{nom}\mu_2(\xi_k). \quad (21)$$

Thus, the above calculation formulas make it possible to express the dependence of the numerical values of the distribution of the error in calculating the Q-factor of the resonator on the numerical characteristics of the error in measuring the frequency, then at $\mu_2(Q_{nom}) = 0$ the last formula takes the following form:

$$\mu_2\left(\Delta\Sigma_\xi\right) = \mu_2\left(\xi_z\right) + m^2Q_{nom}\mu_2(\xi_k). \quad (22)$$

The table shows the data establishing the relationship between the relative values of the error in calculating the Q-factor of the resonator in percent and the errors of the frequency measuring instruments, also expressed in relative values:

$$(I)\frac{\sigma_1(\xi f_0)}{\sigma(f_0)}\% \text{ and } (II)\frac{\sigma_2(\xi f_2 - f_1)}{\sigma(f_2 - f_1)}\%. \quad (23)$$

In this case, the relative value of the error in calculating the Q-factor of the resonator was determined by the formula $\sqrt{\frac{\mu_2(\Delta\Sigma\xi)}{\mu_2(Q_{nom})}}\%$ (diagonal elements of the Table 1).

When assessing the error in calculating the Q-factor of the resonator in relative limit values, it follows that the error of 1.05% is ensured by the accuracy class of the

Table 1. Calculation of the Q-factor of the resonator

II%, I%	0.5	1.0	3.0	6.0	10.0	20.0
0.5	0.6					
1.0		1.33				
3.0			4.01			
6.0				8.06		
10.0					13.53	
20.0						28.06

frequency meter not lower than 0.52, the error of 2.1% – by the accuracy class not lower than 1.04, and of 6.2% accuracy class is not lower than 3.12.

The implementation of the computational correction of systematic errors at the computer information complex, the measuring part of which is designed to determine the resonant frequency and Q-factor of the resonators, is shown in the structural diagram.

The signal level correction for directional couplers DC1 and DC2 is carried out according to three input measures Pi.

Prior to the measurements, the amplitude-frequency characteristics of the directional couplers (DC1 and DC2) of the complex are equalized so that the ratio of the output signals in the directional couplers in the entire range of operating frequencies is equal to unity.

The difference between the input values of ADC1 and ADC2 in a tabular form is stored in the PC memory and is used in further calculations.

3 Results and Discussions

The implementation of the principle of adaptability of graded characteristics made it possible to solve the problem of improving the accuracy of the measurement results of the radio parameters of resonators of automated control systems in determining the moisture content of materials.

4 Conclusions

1. The block diagram of an automated material moisture control system is considered. This system is based on the principle of separation and direct detection of incident and reflected wave signals.
2. Improving the reliability of control and the effectiveness of controlling the drying process of materials by increasing the accuracy of measurements of technological parameters leads to the need to consider the initial concept in the metrological support of the technological operation as a system task.
3. It has been considered the need to determine the conditions under which the applicability of probabilistic-statistical methods to the estimation of measurement error is observed and the security of control reliability indicators in modern technologies is guaranteed.
4. The signal level correction for directional couplers DC1 and DC2 is carried out according to three input measures *Pi*.

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Mathematical Modeling of Gas and Water Cone Formation at an Oil Well

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Abstract. The study considers the three-phase problem of cone formation of a well drilled in an oil reservoir with bottom water and a gas cap. Equations for water-gas-oil factors are derived. Proportions for calculating the average heights of the liquid columns at given values of their saturations are obtained. The formula for calculating the effective radius of the well is obtained. A mathematical model that allows calculating technical and economic indicators of a well, such as net present value, cumulative oil, gas and water production, oil recovery coefficient, etc., in the form of a function of control parameters, such as the size of the perforation interval and its location according to the formation thickness, and control such functions as $Q_d(t)$ and $q_{nf}(t)$ is proposed.

Keywords: Well cone formation problem · Net present value · Cumulative oil production · Oil recovery coefficient · Control function of parameters · Perforation interval · Reservoir thickness

1 Transformation of the Equation of Motion

The three-phase cone formation problem at a well drilled in an oil reservoir with bottom water and a gas cap is considered (Fig. 1).

It is assumed that the well is opened (perforated) in the oil zone. The sole and roof of the formation, as well as the initial position of the gas-oil and water-oil contact surfaces are horizontal planes. In Fig. 1, the following notation is accepted:

- H_{ft} – power (thickness) of the reservoir;
- H_{go}, H_{wo} – the initial position of the gas-oil and water-oil contact surface, measured from the roof.

The size and placement of the perforation interval are determined through

- H_{pt}, H_{pb} – the depth of the top and bottom of the interval of perforation of the well, measured from the roof;
- $h_{pf} = H_{pb} - H_{pt}$ – the length of the perforation interval.

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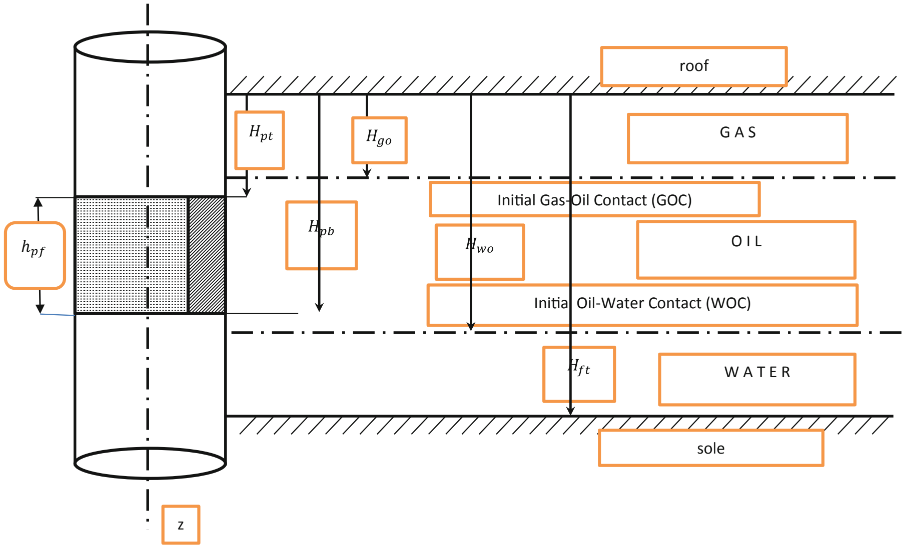

Fig. 1. The initial position of the contact surfaces and the location of the perforation section of the well in the reservoir

The flow of fluids in the reservoir is described by the following partial differential equations [1]:

$$\frac{1}{r}\frac{\partial}{\partial r}\frac{K_h \cdot K_{of}}{\mu_f} r \frac{\partial}{\partial r}(P_f - \rho_f g z) + \frac{\partial}{\partial z}\frac{K_v \cdot K_{of}}{\mu_f}\frac{\partial}{\partial z}(P_f - \rho_f g z) = m\frac{\partial S_f}{\partial t}, \quad (1)$$

$$\frac{1}{r}\frac{\partial}{\partial r}\frac{K_h \cdot K_{of}}{\mu_f} r \frac{\partial}{\partial r}(P_f - \rho_f g z) + \frac{\partial}{\partial z}\frac{K_v \cdot K_{of}}{\mu_f}\frac{\partial}{\partial z}(P_f - \rho_f g z) = m\frac{\partial S_f}{\partial t}, \quad (2)$$

$$\frac{1}{r}\frac{\partial}{\partial r}\frac{K_h \cdot K_{of}}{\mu_f} r \frac{\partial}{\partial r}(P_f - \rho_f g z) + \frac{\partial}{\partial z}\frac{K_v \cdot K_{of}}{\mu_f}\frac{\partial}{\partial z}(P_f - \rho_f g z) = m\frac{\partial S_f}{\partial t}, \quad (3)$$

where the phase "f" for case (1) means oil, for case (2) – water, for case (3) – gas.

These equations are written in a cylindrical coordinate system (Fig. 1) and are valid for any of the three phases under consideration. In (1)–(3), the following notation is accepted:

- K_h and K_v – permeability of the formation horizontally and vertically;
- K_{of} – the relative permeability of the phase "f";
- ρ_f, P_f, μ_f и S_f – the density, pressure, viscosity, saturation phase "f" in the formation;
- *m* is the porosity of the reservoir.

It is assumed that the phases do not mix, and the formation is a cylinder of radius r_e, in the center of which there is a well of radius r_w, and the side surface is a supply circuit. The flow obeys the following boundary conditions:

1. The flow of each phase is set on the power circuit:

$$\int_0^{H_g} \frac{K_{og}K_h}{\mu_g}\frac{\partial P_g}{\partial r}dz = -\int_0^{H_g} u_g dz = \frac{q_g B_g}{2\pi r_e},$$

$$\int_{H_g}^{H_w} \frac{K_{oo}K_h}{\mu_o}\frac{\partial P_o}{\partial r}dz = -\int_{H_g}^{H_w} u_o dz = \frac{q_o B_o}{2\pi r_e},$$

$$\int_{H_w}^{H_{res}} \frac{K_{ow}K_h}{\mu_w}\frac{\partial P_w}{\partial r}dz = -\int_{H_w}^{H_{res}} u_w dz = \frac{q_w B_w}{2\pi r_e}.$$

Here:

- H_g and H_w – the depths of the contact surfaces of gas-oil and water-oil;
- u_f – the flow of phase "f" from the reservoir;
- B_f – volumetric coefficient of the phase "f" in reservoir conditions;
- q_f – the flow rate of the phase "f".

2. The influx into the wellbore occurs only in the range of perforations:

$$(z \le H_{pt}) \vee (z \ge H_{pb}) \Rightarrow u_f = 0.$$

3. On the perforation interval, the potential is constant:

$$(H_{pt} \le z \le H_{pb}) \Rightarrow F_f(r_w) = const.$$

4. The roof and sole of the formation are impermeable:

$$(z = 0) \Rightarrow \frac{\partial P_g}{\partial z} - \rho_g g = 0, \;\; (z = H_{ft}) \Rightarrow \frac{\partial P_w}{\partial z} - \rho_w g = 0.$$

5. For arbitrary r, vertical equilibrium is maintained:

$$P_f(r,z) = P_f(r,0) + \rho_f g z, \tag{4}$$

where $P_f(r,0)$ – is the pressure on the roof of the reservoir ($z = 0$).

Integrating Eqs. (1)–(3) over z, we can obtain a vertical averaged equation for the flow of each phase:

$$\int_0^{H_{ft}} \frac{1}{r}\frac{\partial}{\partial r}\frac{К_г К_{оф}}{\mu_ф} r \frac{\partial}{\partial r}\left(P_f - \rho_f g z\right)dz = \int_0^{H_{ft}} m\frac{\partial s_f}{\partial t}dz; \tag{5}$$

$$\frac{1}{r}\frac{\partial}{\partial r}\frac{К_г r}{\mu_f}\int_0^{H_{ft}} К_{of}\frac{\partial}{\partial r}\left(P_f - \rho_f gz\right)dz = m\frac{\partial}{\partial t}\int_0^{H_{ft}} S_f dz; \tag{6}$$

$$\frac{1}{r}\frac{\partial}{\partial r}\frac{К_г r - \overline{К_{of}}}{\mu_f}\frac{\partial P_f(r,0)}{\partial r} = m\frac{\partial \overline{S_f}}{\partial t}. \tag{7}$$

Depending on the specific phase, the index "f" for case (5) can be replaced by "g" (gas), (6) - "o" (oil) and (7) "w" (water). In (5)–(7)

$$\frac{\partial P_f(r,0)}{\partial r} = \frac{\partial}{\partial r}\left(P_f - \rho_f gz\right).$$

Here, relation (4) is used and the notation is accepted:

$$\overline{К_{of}} = \frac{1}{H_{ft}}\int_0^{H_{ft}} К_{of}dz\,, \overline{S_f} = \frac{1}{H_{ft}}\int_0^{H_{ft}} S_f dz.$$

From (4), considering the vertical equilibrium conditions, it is possible to determine the pressure differences between the phases at any radius:

$$\begin{cases} P_o(r,z) - P_g(r,z) = P_o(r,0) - P_g(r,0) + \left(\rho_o - \rho_g\right)gz, \\ P_w(r,z) - P_g(r,z) = P_w(r,0) - P_o(r,0) + \left(\rho_w - \rho_o\right)gz. \end{cases} \tag{8}$$

On the power circuit on the contact surface, the phase pressures should be equal to:

$$\begin{cases} \left(z = H_g\right) \wedge (r = r_e) \Rightarrow P_o\left(r_e, H_g\right) = P_g\left(r_e, H_g\right), \\ (z = H_w) \wedge (r = r_e) \Rightarrow P_w(r_e, H_w) = P_o(r_e, H_w). \end{cases} \tag{9}$$

It is assumed that relations (9) are valid not only for $r = r_e$, but also for all r. Then the left-hand sides of Eqs. (8) written respectively for $z = H_g$ and $z = H_w$ will be equal to zero. From here:

$$P_g(r,0) = P_o(r,0) + \Delta\rho_{go} g H_g, \tag{10}$$

$$P_w(r,0) = P_o(r,0) - \Delta\rho_{wo} g H_w, \tag{11}$$

where $\Delta\rho_{go} = \rho_w - \rho_o$ and $\Delta\rho_{wo} = \rho_o - \rho_g$. Substituting (11) in (7) and (10) in (5) (case (7) is the equation written for water, case (5) is written for gas), system (5)–(7) can be given the following form:

$$\frac{1}{r}\frac{\partial}{\partial r}\frac{К_g r\overline{К_{ow}}}{\mu_w}\left(\frac{\partial}{\partial r}P_o(r,0) - \Delta\rho_{wo} g\frac{\partial H_w}{\partial r}\right) = m\frac{\partial \overline{S_w}}{\partial t}, \tag{12}$$

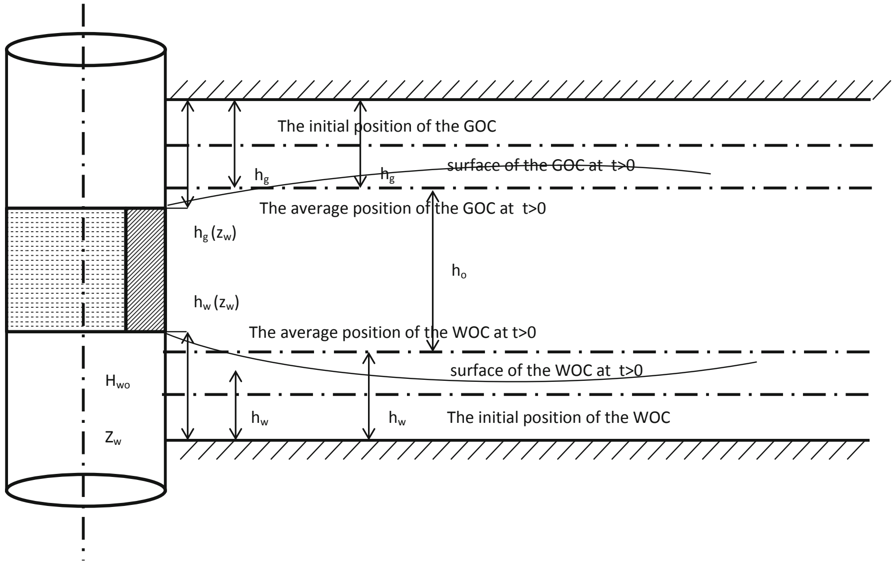

Fig. 2. Geometry of the cone and phase distribution model

$$\frac{1}{r}\frac{\partial}{\partial r}\frac{\text{K}_g r\overline{\text{K}_{og}}}{\mu_g}\left(\frac{\partial}{\partial r}\text{P}_o(r,0)-\Delta\rho_{go}g\frac{\partial \text{H}_g}{\partial r}\right)=m\frac{\partial\overline{S_w}}{\partial t}, \tag{13}$$

$$\frac{1}{r}\frac{\partial}{\partial r}\frac{\text{K}_g r\overline{\text{K}_{oo}}}{\mu_o}\frac{\partial \text{P}_o(r,0)}{\partial r}=m\frac{\partial\overline{S_o}}{\partial t}. \tag{14}$$

Thus, due to the assumption of vertically equilibrium, values of $\text{P}_g(r,0), \text{P}_w(r,0)$, and K_w are excluded from consideration. This assumption near the well will not be fulfilled, since there must be a flow of gas (down) and water (up) to the perforation interval, as a result of which the contact surfaces are deformed and take the form shown in Fig. 2. As a result, the solution obtained by the derived equations near the well may differ from the actual one. In the following presentation, the concept of the effective radius and the correction for taking this phenomenon into account will be derived.

Under the assumption made above about the immiscibility of various phases, the average permeability of each phase can be expressed as a function of the height of the gas and water columns h_g and h_w.

$$\overline{\text{K}_{og}}=\frac{1}{\text{H}_{ft}}\left[\int_0^{\text{H}_{go}}dz+\int_{\text{H}_{gw}}^{h_g}\text{K}_{oo}^{o}dz\right]=\frac{1}{\text{H}_{ft}}\left[\text{H}_{go}+\text{K}_{og}^{o}\left(h_g-\text{H}_{go}\right)\right].$$

$$\overline{\text{K}_{ow}}=\frac{1}{\text{H}_{ft}}\left[\int_{\text{H}_{wo}}^{\text{H}_{ft}}dz+\int_{\text{H}_{ft}-h_w}^{\text{H}_{wo}}\text{K}_{oo}^{o}dz\right]=\frac{1}{\text{H}_{ft}}\left[\text{H}_{ft}-\text{H}_{pt}+\text{K}_{ow}^{o}\left(\text{H}_{pb}-\text{H}_{ft}+h_w\right)\right].$$

$$\overline{\text{K}_{oo}}=\frac{1}{\text{H}_{ft}}\left[\int_{h_g}^{\text{H}_{ft}-h_w}\text{K}_{oo}^{o}dz\right]=\frac{\text{H}_{ft}-h_w-h_g}{\text{H}_{ft}}\text{K}_{oo}^{o}.$$

Similarly, you can express the average saturations of each phase "f" as a function of h_g and h_w:

$$\begin{aligned}\overline{S_g} &= \frac{1}{H_{ft}}\left[\int_0^{H_{go}} dz + \int_{H_{go}}^{h_g}(1-S_{oog})dz + \int_{h_g}^{H_{ft}-h_w} S_g^K dz\right]\\ &= \frac{1}{H_{ft}}\left[H_{go} + (1-S_{oog})(h_g - H_{go}) + S_g^K(H_{ft} - h_w - h_g)\right]\\ &= \frac{1}{H_{ft}}\left[H_{go} - (1-S_{oog})H_{go} + S_g^K H_{ft} + \left(1 - S_{oog} - S_g^K\right)h_g - S_g^K h_w\right].\end{aligned}$$

$$\begin{aligned}\overline{S_w} &= \frac{1}{H_{ft}}\left[\int_{h_g}^{H_{ft}-h_w} S_g^K dz + \int_{H_{ft}-h_w}^{H_{wo}}(1-S_{oow})dz + \int_{H_{wo}}^{H_{ft}} dz\right]\\ &= \frac{1}{H_{ft}}\left[S_w^K(H_{ft} - h_w - h_g) + (1-S_{oow})(H_{wo} - H_{ft} + h_w) + H_{ft} - H_{wo}\right]\\ &= \frac{1}{H_{ft}}\left[H_{ft}(S_w^K - 1 + S_{oow} + 1) + H_{wo}(1 - S_{oow} - 1) + h_w(1 - S_{oow} - S_w^K) - S_w^K h_g\right]\\ &= \frac{1}{H_{ft}}\left[H_{ft}(S_w^K + S_{oow}) - H_{wo}S_{oow} + h_w(1 - S_{oow} - S_w^K) - S_w^K h_g\right].\end{aligned}$$

$$\begin{aligned}\overline{S_o} &= \frac{1}{H_{ft}}\left[\int_{H_{go}}^{h_g} S_{oog}dz + \int_{h_g}^{H_{ft}-h_w}\left(1 - S_w^K - S_g^K\right)dz + \int_{H_{ft}-h_w}^{H_{ft}} S_{oow}dz\right]\\ &= \frac{1}{H_{ft}}\left[S_{oog}(h_g - H_{ft}) + \left(1 - S_w^K - S_g^K\right)(H_{ft} - h_w - h_g) + S_{oow}(H_{wo} - H_{ft} + h_w)\right]\\ &= \frac{1}{H_{ft}}\left[H_{ft}\left(1 - S_w^K - S_g^K - S_{oow}\right) + S_{oow}H_{wo} - S_{oog}H_{wo} + h_w\left(S_{oow} + S_w^K + S_g^K - 1\right) + \right.\\ &\quad \left. h_g\left(S_{oog} + S_w^K + S_g^K - 1\right)\right].\end{aligned}$$

Here S_g^K and S_w^K are the critical saturations of gas and water, S_{oog} and S_{oow} are the residual oil saturations in the gas and water zones. Note that $\overline{S_g} + \overline{S_o} + \overline{S_w} = 1$, which is easily verified by substituting the corresponding values.

As shown in [2], in the study of cone formation problems, transient processes can be neglected, since they proceed quickly. Therefore, we can confine ourselves to considering the quasi-stationary case, neglecting the values of the right-hand sides of Eqs. (5)–(7). Then you can get the first integrals of these equations:

$$-r_w\overline{u_w}(r_w) = \frac{K_g r \overline{K_{ow}}}{\mu_w}\left(\frac{\partial P_o}{\partial r} - \Delta\rho_{wo} g\left(\frac{\partial h_g}{\partial r} + \frac{\partial h_o}{\partial r}\right)\right); \quad (15)$$

$$-r_w\overline{u_g}(r_w) = \frac{\text{K}_g r\overline{\text{K}_{og}}}{\mu_g}\left(\frac{\partial \text{P}_o}{\partial r} - \Delta\rho_{go} g \frac{\partial h_g}{\partial r}\right); \tag{16}$$

$$-r_w\overline{u_o}(r_w) = \frac{\text{K}_g r\overline{\text{K}_{oo}}}{\mu_o}\frac{\partial \text{P}_o}{\partial r}. \tag{17}$$

Here $\overline{u_w}(r_w), \overline{u_g}(r_w)$ and $\overline{u_o}(r_w)$ are the average values of the flows of water, gases and oil at the radius of the well. These values can be expressed in terms of flow rates:

$$\begin{aligned} q_o\text{B}_o &= -2\pi r_w \text{H}_{ft}\overline{u_o}(r_w); \\ q_w\text{B}_w &= -2\pi r_w \text{H}_{ft}\overline{u_w}(r_w); \\ q_g\text{B}_g &= -2\pi r_w \text{H}_{ft}\overline{u_g}(r_w). \end{aligned}$$

Substituting Eqs. (15), (16) and (17), we can exclude the average values of the flows:

$$\frac{q_o\text{B}_o}{2\pi r_w \text{H}_{ft}} = \frac{\text{K}_g r\overline{\text{K}_{oo}}}{\mu_o}\frac{d\text{P}_o}{dr}; \tag{18}$$

$$\frac{q_w\text{B}_w}{2\pi r_w \text{H}_{ft}} = \frac{\text{K}_g r\overline{\text{K}_{ow}}}{\mu_w}\left(\frac{d\text{P}_o}{dr} - \Delta\rho_{wo} g\left(\frac{dh_g}{dr} + \frac{dh_o}{dr}\right)\right); \tag{19}$$

$$\frac{q_g\text{B}_g}{2\pi r_w \text{H}_{ft}} = \frac{\text{K}_g r\overline{\text{K}_{og}}}{\mu_g}\left(\frac{d\text{P}_g}{dr} - \Delta\rho_{go} g\frac{dh_g}{dr}\right). \tag{20}$$

Equation (18) can be solved for $\frac{d\text{P}_o}{dr}$:

$$\frac{d\text{P}_o}{dr} = \frac{q_o\text{B}_o\mu_o}{2\pi r_w \text{H}_{ft}\text{K}_g r\overline{\text{K}_{oo}}}.$$

Now this can be put into Eqs. (19) and (20), and after some algebraic transformations, given that $h_o + h_g = \text{H}_{ft} - h_w = h'_w$

$$\frac{q_w\text{B}_w\mu_w}{\overline{\text{K}_{ow}}} = \frac{q_o\text{B}_o\mu_o}{\overline{\text{K}_{oo}}} - 2\pi\text{H}_{ft}\text{K}_g\Delta\rho_{wo} g\frac{dh'_w}{dr}r, \tag{21}$$

$$\frac{q_g\text{B}_g\mu_g}{\overline{\text{K}_{og}}} = \frac{q_o\text{B}_o\mu_o}{\overline{\text{K}_{oo}}} + 2\pi\text{H}_{ft}\text{K}_g\Delta\rho_{go} g\frac{dh_g}{dr}r. \tag{22}$$

Now we know that:

$$\begin{cases} \overline{K_{og}} = \frac{1}{H_{ft}}\left(H_{go} + K_{og}^{o}\left(\overline{h_g} - H_{go}\right)\right); \\ \overline{K_{ow}} = \frac{1}{H_{ft}}\left(\left(H_{ft} - H_{wo}\right)(1 - K_{ow}^{o}) + K_{ow}^{o}\overline{h_w}\right); \\ \overline{K_{oo}} = \frac{\left(H_{ft} - \overline{h_w} - \overline{h_g}\right)K_{oo}^{o}}{H_{ft}}, \end{cases} \tag{23}$$

where K_{og}^{o}, K_{ow}^{o} and K_{oo}^{o} is the relative permeability of gas, water and oil in the oil zone.

Expressions (23) can be used in Eqs. (21) and (22). From (21)

$$\frac{q_w B_w \mu_w H_{ft}}{(H_{ft} - H_{wo})(1 - K_{ow}^{o}) + K_{ow}^{o} h_w} = \frac{q_o B_o \mu_o H_{ft}}{(H_{ft} - h_w - h_g)K_{og}^{o}} - 2\pi H_{ft} K_g \Delta\rho_{wo} g \frac{dh'_w}{dr} r.$$

From here after algebraic transformations:

$$\frac{dr}{r} = \frac{-2\pi K_g \Delta\rho_{wo} g K_{0o}^{o}(H_{ft} - h_w - h_g)\left[(H_{ft} - H_{wo})(1 - K_{0w}^{o}) + K_{0w}^{o} h_w\right] dh'_w}{q_w B_w \mu_w K_{0o}^{o}(H_{ft} - h_w - h_g) - q_o B_o \mu_o\left[(H_{ft} - H_{wo})(1 - K_{0w}^{o}) + K_{0w}^{o} h_w\right]}. \tag{24}$$

From (22)

$$\frac{q_g B_g \mu_g H_{ft}}{H_{gw} + K_{0g}^{o}(h_g - H_{go})} = \frac{q_o B_o \mu_o}{(H_{ft} - h_w - h_g)K_{0o}^{o}} + 2\pi H_{ft} K_g \Delta\rho_{wo} g \frac{dh_g}{dr} r.$$

After some transformations, we have:

$$\frac{dr}{r} = \frac{2\pi K_g \Delta\rho_{go} g K_{0o}^{o}(H_{ft} - h_w - h_g)\left[H_{go}(1 - K_{0g}^{o}) + K_{0g}^{o} h_w\right] dh_g}{q_g B_g \mu_g K_{0o}^{o}(H_{ft} - h_w - h_g) + q_o B_o \mu_o\left[H_{go}\left(1 - K_{0g}^{o}\right) + K_{0g}^{o} h_g\right]}. \tag{25}$$

Analysis of Eqs. (24) and (24) yields the following: $\frac{dh_g}{dr} \sim \frac{1}{r}$ and $\frac{dh_w}{dr} \sim \frac{1}{r}$, which show, for large values of «r», values of $\frac{dh_g}{dr}$ and $\frac{dh_w}{dr}$ are small. This is an important result, showing that the cones are wide and flat, with the exception of the immediate vicinity of the well.

With the result of the above analysis integrating Eqs. (21) and (22), $\overline{K_{ow}}$, $\overline{K_{oo}}$ and $\overline{K_{0g}}$ retaining constant. Consider the Eq. (21):

$$\int_{r_w}^{r}\left[\frac{q_w B_w \mu_w}{\overline{K_{0w}}} - \frac{q_o B_o \mu_o}{\overline{K_{0o}}}\right]\frac{dr}{r} = -\int_{r_w}^{r} 2\pi H_{ft} K_g \Delta\rho_{wo} g\, dh'_w; \tag{26}$$

$$\left[\frac{q_w B_w \mu_w}{\overline{K_{0w}}} - \frac{q_o B_o \mu_o}{\overline{K_{0o}}}\right]\ln\frac{r}{r_w} = 2\pi H_{ft} K_g \Delta\rho_{wo} g\left[h_w - h_w(r_w)\right]. \tag{27}$$

Consider the Eq. (22):

$$\int_{r_w}^{r}\left[\frac{q_g \mathrm{B}_g \mu_g}{\overline{\mathrm{K}_{0g}}} - \frac{q_o \mathrm{B}_o \mu_o}{\overline{\mathrm{K}_{0o}}}\right]\frac{dr}{r} = \int_{r_w}^{r} 2\pi \mathrm{H}_{ft}\mathrm{K}_g \Delta\rho_{go} g dh_g;$$

$$\left[\frac{q_g \mathrm{B}_g \mu_g}{\overline{\mathrm{K}_{0g}}} - \frac{q_o \mathrm{B}_o \mu_o}{\overline{\mathrm{K}_{0o}}}\right]\ln\frac{r}{r_w} = 2\pi \mathrm{H}_{ft}\mathrm{K}_g \Delta\rho_{go} g\left[h_g - h_g(r_w)\right]. \tag{28}$$

These equations are valid everywhere except in the vicinity $r = r_w$. To obtain the relationship between the average values, we multiply the above equations by $2r/\left(r_e^2 - r_w^2\right)$ and integrate from от $r = r_w$ to $r = r_e$:

$$\left[\frac{q_w \mathrm{B}_w \mu_w}{\overline{\mathrm{K}_{0w}}} - \frac{q_o \mathrm{B}_o \mu_o}{\overline{\mathrm{K}_{0o}}}\right]\overline{\ln r} = 2\pi \mathrm{H}_{ft}\mathrm{K}_g \Delta\rho_{wo} g\left[\overline{h_w} - h_w(r_w)\right] \tag{29}$$

And

$$\left[\frac{q_g \mathrm{B}_g \mu_g}{\overline{\mathrm{K}_{0g}}} - \frac{q_o \mathrm{B}_o \mu_o}{\overline{\mathrm{K}_{0o}}}\right]\overline{\ln r} = 2\pi \mathrm{H}_{ft}\mathrm{K}_g \Delta\rho_{go} g\left[\overline{h_g} - h_g(r_w)\right], \tag{30}$$

Where

$$\overline{\ln\ r} = \frac{2r}{r_e^2 - r_w^2}\int_{r_w}^{r} r \cdot \ln\left(\frac{r}{r_w}\right)dr = \frac{\ln\frac{r_e}{r_w}}{1 - \left(\frac{r_w}{r_e}\right)^2} - \frac{1}{2}, \tag{31}$$

$$\overline{h_w} = \frac{2r}{r_e^2 - r_w^2}\int_{r_w}^{r} r \cdot h_w(r)dr, \tag{32}$$

$$\overline{h_g} = \frac{2r}{r_e^2 - r_w^2}\int_{r_w}^{r} r \cdot h_g(r)dr. \tag{33}$$

2 Derivation of Equations for Water-Oil and Gas-Oil Factors

It is convenient to write Eqs. (29) and (30) through *WOR* and *GOR*, which are the development parameters: $WOR = \frac{q_w}{q_o}$ and $GOR = \frac{q_g}{q_o}$. Using these notations in Eqs. (29) and (30), we obtain:

$$\left[WOR\frac{\mathrm{B}_w \mu_w}{\overline{\mathrm{K}_{0w}}} - \frac{\mathrm{B}_o \mu_o}{\overline{\mathrm{K}_{0o}}}\right]\overline{\ln r} = \frac{2\pi \mathrm{H}_{ft}\mathrm{K}_g \Delta\rho_{wo} g(1 + WOR + GOR)\left(\overline{h_w} - h_w(r_w)\right)}{Q_d}; \tag{34}$$

$$\left[GOR\frac{\mathrm{B}_g \mu_g}{\overline{\mathrm{K}_{0g}}} - \frac{\mathrm{B}_o \mu_o}{\overline{\mathrm{K}_{0o}}}\right]\overline{\ln r} = \frac{2\pi \mathrm{H}_{ft}\mathrm{K}_g \Delta\rho_{go} g(1 + WOR + GOR)\left(\overline{h_g} - h_g(r_w)\right)}{Q_d}, \tag{35}$$

where $Q_d = q_o + q_g + q_w$.

Now assuming the separation of flows and adhering to the geometry of Fig. 2, we can derive an expression that relates *WOR* and *GOR* to the values $h_w(r_w)$ and $h_g(r_w)$ to the perforation interval:

$$WOR = \mathrm{M}_{wo}\frac{\mathrm{H}_{pb} - \mathrm{H}_{ft} + h_w(r_w)}{\mathrm{H}_{ft} - h_w(r_w) - h_g(r_w)}, \tag{36}$$

where $\mathrm{M}_{wo} = \frac{\mathrm{K}^o_{0w}\mu_o \mathrm{B}_o}{\mathrm{K}^o_{0o}\mu_w \mathrm{B}_w}$;

$$GOR = \mathrm{M}_{go}\frac{h_g(r_w) - \mathrm{H}_{pt}}{\mathrm{H}_{ft} - h_w(r_w) - h_g(r_w)}, \tag{37}$$

where $\mathrm{M}_{go} = \frac{\mathrm{K}^o_{0g}\mu_o \mathrm{B}_o}{\mathrm{K}^0_{0o}\mu_g \mathrm{B}_g}$.

From here we obtain the following system of equations:

$$\begin{cases} (WOR + \mathrm{M}_{wo})h_w(r_w) + WORh_g(r_w) = WOR\mathrm{H}_{ft} - \mathrm{M}_{wo}(\mathrm{H}_{pb} - \mathrm{H}_{ft}), \\ GORh_w(r_w) + (GOR + \mathrm{M}_{go})h_g(r_w) = GOR\mathrm{H}_{ft} + \mathrm{M}_{go}\mathrm{H}_{pt}. \end{cases} \tag{38}$$

Deciding on $h_w(r_w)$ and $h_g(r_w)$, we get:

$$h_w(r_w) = \frac{\mathrm{M}_{go}WOR(\mathrm{H}_{ft} - \mathrm{H}_{pt}) + (\mathrm{M}_{go} + GOR)\mathrm{M}_{wo}(\mathrm{H}_{ft} - \mathrm{H}_{pb})}{\mathrm{M}_{go}(WOR + \mathrm{M}_{wo}) + \mathrm{M}_{wo} + GOR}; \tag{39}$$

$$h_g(r_w) = \frac{GOR\mathrm{M}_{wo}\mathrm{H}_{pb} + (\mathrm{M}_{wo} + WOR)\mathrm{M}_{go}\mathrm{H}_{pt}}{\mathrm{M}_{wo}(\mathrm{M}_{go} + GOR) + \mathrm{M}_{go}WOR}. \tag{40}$$

Substituting (39) and (40) into Eqs. (34) and (35) after some algebraic transformations, we obtain:

$$\begin{aligned}&(J \cdot \mathrm{M}_{go} + \alpha \cdot \mathrm{H}_{w2} \cdot \mathrm{M}_{go})WOR^2 + (\alpha \cdot \mathrm{M}_{wo} \cdot \mathrm{H}_{t2})GOR^2 + (J \cdot \mathrm{M}_{wo} + \alpha \cdot \mathrm{H}_{w2} \cdot \\ &\mathrm{M}_{go} + \alpha \cdot \mathrm{M}_{wo} \cdot \mathrm{H}_{t2})WOR \cdot GOR + (J \cdot \mathrm{M}_{go} \cdot \mathrm{M}_{wo} - \mathrm{K} \cdot \mathrm{M}_{go} + \alpha \cdot \mathrm{H}_{w2} \cdot \mathrm{M}_{go} + \alpha \cdot \\ &\mathrm{M}_{go} \cdot \mathrm{M}_{wo} \cdot \mathrm{H}_{t2}) \cdot WOR + (-\mathrm{K} \cdot \mathrm{M}_{wo} + \alpha \cdot \mathrm{M}_{wo} \cdot \mathrm{H}_{t2} + \alpha \cdot \mathrm{M}_{go} \cdot \mathrm{M}_{wo} \cdot \mathrm{H}_{t2}) \cdot \\ &GOR + (-\mathrm{K} \cdot \mathrm{M}_{go} \cdot \mathrm{M}_{wo} + \alpha \cdot \mathrm{M}_{go} \cdot \mathrm{M}_{wo} \cdot \mathrm{H}_{t2}) = 0,\end{aligned} \tag{41}$$

And

$$\begin{aligned}&(-\beta \cdot \mathrm{H}_{t1} \cdot \mathrm{M}_{go})WOR^2 + (\mathrm{P} \cdot \mathrm{M}_{wo} + \beta \cdot \mathrm{H}_{w1} \cdot \mathrm{M}_{wo})GOR^2 + (\mathrm{P} \cdot \mathrm{M}_{go} - \beta \cdot \mathrm{H}_{t1} \cdot \\ &\mathrm{M}_{go} + \beta \cdot \mathrm{M}_{wo} \cdot \mathrm{H}_{w1})WOR \cdot GOR + (-\mathrm{K} \cdot \mathrm{M}_{go} - \beta \cdot \mathrm{H}_{t1} \cdot \mathrm{M}_{go} - \beta \cdot \mathrm{H}_{t1} \cdot \mathrm{M}_{wo} \cdot \\ &\mathrm{M}_{go}) \cdot WOR + (\mathrm{P} \cdot \mathrm{M}_{wo} \cdot \mathrm{M}_{go} - \mathrm{K} \cdot \mathrm{M}_{wo} + \beta \cdot \mathrm{H}_{w1} \cdot \mathrm{M}_{wo} - \beta \cdot \mathrm{H}_{t1} \cdot \mathrm{M}_{wo} \cdot \mathrm{M}_{go}) \cdot \\ &GOR + (-\mathrm{K} \cdot \mathrm{M}_{go} \cdot \mathrm{M}_{wo} - \beta \cdot \mathrm{H}_{t1} \cdot \mathrm{M}_{wo} \cdot \mathrm{M}_{go}) = 0,\end{aligned} \tag{42}$$

Where

$$J = \frac{B_w \mu_w}{K_{0w}} \overline{\ln r}, K = \frac{B_o \mu_o}{K_{0o}} \overline{\ln r}, P = \frac{B_g \mu_g}{K_{0g}} \overline{\ln r}, H_{t1} = \overline{h_g} - H_{pt}, H_{w1} = H_{pb} - \overline{h_g}, H_{t2} = H_{ft} - H_{pb} - \overline{h_w}, H_{w2} = H_{ft} - H_{pt} - \overline{h_w}, \alpha = \frac{2\pi H_{ft} K_g \Delta\rho_{wo} g}{Q_d}, \beta = \frac{2\pi H_{ft} K_g \Delta\rho_{go} g}{Q_d}. \quad (43)$$

The solution to this system of algebraic equations gives the values of *WOR* and *GOR* at different points in time $H_{pt} \leq \overline{h_g} \leq H_{pb}, H_{ft} - H_{pb} \leq \overline{h_w} \leq H_{ft} - H_{pt}$. However, if $H_{pt} < \overline{h_g}$ и $H_{ft} - H_{pb} > \overline{h_w}$, then $WOR = 0$ and (42) takes the form:

$$(P + \beta \cdot H_{w1}) GOR^2 + \left(-K + P \cdot M_{go} + \beta \cdot H_{t1} - \beta \cdot M_{go} \cdot H_{t1}\right) \cdot GOR + \left(-K \cdot M_{go} - \beta \cdot M_{go} \cdot H_{t1}\right) = 0.$$

Solving this quadratic equation with respect to *GOR*, we have different values of *GOR* at different points in time.

If $H_{pt} > \overline{h_g}$ and $H_{ft} - H_{pb} < \overline{h_w}$, then $GOR = 0$ and (41) takes the form:

$$(J + \alpha \cdot H_{w2}) WOR^2 + (-K + J \cdot M_{wo} + \alpha \cdot H_{w2} + \alpha \cdot M_{wo} \cdot H_{t2}) WOR + (-K \cdot M_{wo} + \alpha \cdot M_{wo} \cdot H_{t2}) = 0.$$

Solving this quadratic equation with respect to *WOR*, we obtain values of *WOR* at different points in time.

If $H_{pt} > \overline{h_g}$ and $H_{ft} - H_{pb} > \overline{h_w}$, then $WOR = GOR = 0$.

3 The Average Thickness of the Water and Gas Columns

In the foregoing, we showed that the average liquid saturations are expressed through the heights of the columns:

$$\overline{S_g} = \frac{1}{H_{ft}} \left[S_{oog} \cdot H_{go} + S_g^K \cdot H_{ft} + \left(1 - S_{oog} - S_g^K\right) \cdot \overline{h_g} - S_g^K \cdot \overline{h_w} \right];$$

$$\overline{S_w} = \frac{1}{H_{ft}} \left[S_w^K \cdot H_{ft} + S_{oow} \cdot \left(H_{ft} - H_{wo}\right) - S_w^K \overline{h_g} + \left(1 - S_{oow} - S_w^K\right) \overline{h_w} \right];$$

$$\overline{S_o} = \frac{1}{H_{ft}} \left[H_{ft}\left(1 - S_w^K - S_g^K - S_{oow}\right) + S_{oow} H_{wo} - S_{oog} H_{wo} - \overline{h_g}\left(1 - S_w^K - S_g^K - S_{oog}\right) - \overline{h_w}\left(1 - S_w^K - S_g^K - S_{oow}\right) \right].$$

Let

$А = S_{oog} \cdot H_{go} + S_g^K \cdot H_{ft}, B = S_w^K \cdot H_{ft} + S_{oow} \cdot (H_{ft} - H_{wo}), C = 1 - S_{oog} - S_g^K, Д = 1 - S_{oow} - S_w^K.$

Then the average gas and water saturation can be written as:

$$\begin{cases} \overline{S_g} \cdot H_{ft} = A + C \cdot \overline{h_g} - S_g^K \cdot \overline{h_w}, \\ \overline{S_w} \cdot H_{ft} = B - S_w^K \cdot \overline{h_g} + Д \cdot \overline{h_w}. \end{cases} \quad (44)$$

This system of linear equations can be solved with respect to $\overline{h_g}$ and $\overline{h_w}$:

$$\overline{h_w} = \frac{H_{ft} \cdot (S_w^K \cdot \overline{S_g} + \overline{S_w} \cdot C) - A \cdot S_w^K - B \cdot C}{Д \cdot C - S_g^K \cdot S_w^K}; \quad (45)$$

$$\overline{h_g} = \frac{H_{ft} \cdot \overline{S_g} - A + S_g^K \cdot \overline{h_w}}{C}. \quad (46)$$

These relations can be used to calculate the average heights of the columns of liquids at given values of their saturations.

4 Effective Well Radius

For a well partially penetrating into a formation with a hole, the expression for the potential is given by Musket [1], and Chappiler [2] gave a generalization of it taking into account arbitrary perforation and anisotropy. After some transformation of the results presented in [2], we obtain an expression for the potential for various z and small values of r:

$$\Phi = \frac{q\mu}{2\pi H_{ft} K_g} \left[\frac{H_{ft}}{2(H_{ft} - H_{pt})} \ln \left(\frac{H_{ft} - \overline{h_w} + H_{pb}}{H_{ft} - \overline{h_w} + H_{pt}} \left| \frac{H_{ft} - \overline{h_w} - H_{pt}}{H_{ft} - \overline{h_w} - H_{pb}} \right| \right) - \ln \frac{4H_{ft}}{r_e} \right].$$

For a purely radial flow, we have:

$$\Phi = \frac{q\mu}{2\pi H_{ft} K_g} \ln \frac{r_e}{r'_w}.$$

Equating the potentials and taking into account the influence of anisotropy for the effective radius, we obtain the expression:

$$\text{if } \mathrm{H}_{ft} - \overline{h_w} > \mathrm{H}_{pb}, \text{ то } r'_w = 4\mathrm{H}_{ft}\left[\left|\frac{\mathrm{H}_{ft}-\overline{h_w}-\mathrm{H}_{pb}}{\mathrm{H}_{ft}-\overline{h_w}-\mathrm{H}_{pt}}\right| \cdot \frac{\mathrm{H}_{ft}-\overline{h_w}+\mathrm{H}_{pt}}{\mathrm{H}_{ft}-\overline{h_w}+\mathrm{H}_{pb}}\right] \times \left(\frac{\mathrm{K}_g}{\mathrm{K}_w}\right)^{\frac{\mathrm{H}_{pb}-\mathrm{H}_{pt}}{\mathrm{H}_{ft}}};$$

$$\text{if } \mathrm{H}_{ft} - \overline{h_w} < \mathrm{H}_{pt}, \text{ then } r'_w = 4\mathrm{H}_{ft}\left[\left|\frac{\mathrm{H}_{ft}-\overline{h_w}-\mathrm{H}_{pt}}{\mathrm{H}_{ft}-\overline{h_w}-\mathrm{H}_{pb}}\right| \cdot \frac{\mathrm{H}_{ft}+\overline{h_w}-\mathrm{H}_{pb}}{\mathrm{H}_{ft}+\overline{h_w}-\mathrm{H}_{pt}}\right] \times \left(\frac{\mathrm{K}_g}{\mathrm{K}_w}\right)^{\frac{\mathrm{H}_{pb}-\mathrm{H}_{pt}}{\mathrm{H}_{ft}}};$$

$$\text{if } \mathrm{H}_{pt} \leq \left(\mathrm{H}_{ft} - \overline{h_w}\right) \leq \mathrm{H}_{pb}, \text{ then } r'_w = 0.$$

These expressions can be used in the reservoir model, and then the assumptions about the vertical balance and separation of flows that were used in the development of the model are removed. In this case, the main change occurs in Eq. (31), which takes the form:

$$\overline{\ln r} = \frac{\ln \frac{r_e}{r_w + r'_w}}{1 - \left(\frac{r_w + r'_w}{r_e}\right)^2} - \frac{1}{2}. \tag{47}$$

5 Calculation of Average Phase Saturations at Various Injection Modes

In the process of development, the values of saturations change over time, so we must have a relationship between the values of saturations of liquids in two consecutive time periods. These dependences can be obtained by considering the boundary conditions for the flow on the supply circuit and the material balance of the fluids in the reservoir. If Q_d defined as the total flow rate of liquids in a period of time Δt, then $Q_d = q_g + q_o + q_w$, where q_g, q_o and q_B flow rates of gas, oil and water, respectively. The value can be used to estimate changes in the volume of each fluid in the reservoir. For example, we can consider: (a) a volume Q_d is pumped on the formation supply circuit that is distributed between the formation fluids in proportion to their mobility and the heights of their posts on this circuit, or it can be assumed: (b) Q_d is equal the volume of water in flow caused by some process of active water displacement in the formation.

$$\text{Let } Д = \frac{\overline{\mathrm{K}_{0g}} \cdot h_g(r_e)}{\mu_g} + \frac{\overline{\mathrm{K}_{0o}} \cdot h_o(r_e)}{\mu_o} + \frac{\overline{\mathrm{K}_{0w}} \cdot h_w(r_e)}{\mu_w}.$$

Then in case

Gas injection:

$$q_{og} = Q_d \cdot \frac{\overline{\mathrm{K}_{0g}} \cdot \frac{h_g(r_e)}{\mu_g}}{Д}.\mathrm{a} \tag{48}$$

Oil injection:

$$q_{oo} = Q_d \cdot \frac{\overline{\text{К}_{0o}} \cdot \frac{h_o(r_e)}{\mu_o}}{\text{Д}} . \text{a} \tag{49}$$

Water injection:

$$q_{ow} = Q_d \cdot \frac{\overline{\text{К}_{0w}} \cdot \frac{h_w(r_e)}{\mu_w}}{\text{Д}} . \text{a} \tag{50}$$

During the time interval Δt, the formation is developed at flow rates of gas, oil and water q_g, q_o and q_w, therefore, these selections saturation change from one initial value S_g^n, S_o^n and S_w^n up to a final value S_g^{n+1}, S_o^{n+1} and S_w^{n+1}. These changes in the volume of fluids in the reservoir can be represented by the equation of material balance for each fluid. Then:

$$\begin{aligned} S_g^{n+1} &= S_g^n + \left(q_{og} - q_g^n\right)\Delta t/V \\ S_w^{n+1} &= S_w^n + \left(q_{ow} - q_w^n\right)\Delta t/V\text{a} \\ S_o^{n+1} &= S_o^n + \left(q_{oo} - q_o^n\right)\Delta t/V, \text{a} \end{aligned} \tag{51}$$

where the V – volume of the pores in the reservoir: $V = \pi r_e^2 m$.

In case (a), the amount of injected agent is determined from the expressions (48), (49), (50).

6 Definition of Net Income

Let P_o and P_g be the prices of oil and gas, and $TC(\Delta t)$ is a total cost associated with the development of the formation over time Δt^j. Then the net income for the time Δt^j will be

$$NI\left(\Delta t^j\right) = \int_{t_{j-1}}^{t_{j-1}+\Delta t^j} q_o^j(t)\text{P}_o dt + \int_{t_{j-1}}^{t_{j-1}+\Delta t^j} q_g^j(t)\text{P}_g dt - TC\left(\Delta t^j\right). \tag{52}$$

Here

$$TC\left(\Delta t^j\right) = \int_{t_{j-1}}^{t_{j-1}+\Delta t^j} q_w^j(t)\text{C}_w dt + \int_{t_{j-1}}^{t_{j-1}+\Delta t^j} q_g^j(t)\text{C}_g dt + Q_d^j \Delta t^j \text{C}_e + \Delta t^j \text{C}_0, \tag{53}$$

Where $q_o^j(t), q_g^j(t)$ и $q_w^j(t)$ are the rates of oil, gas, and water, which are constant over a period of time Δt^j.

C_w, C_g – costs of separating a unit volume of water and gas,
C_e – costs of raising a fluid of a unit volume from the formation to the surface,
C_0 – fixed operating costs,

Q_d^j – total flow rate established during Δt^j.

Combining (52) and (53), you can get net income for the time interval Δt^j:

$$NI(\Delta t^j) = \int_{t_{j-1}}^{t_{j-1}+\Delta t^j} \left(q_o^j(t)\mathrm{P}_o + q_g^j(t)\left[\mathrm{P}_g - \mathrm{C}_g\right] - q_w^j(t)\mathrm{C}_w \right) dt - \left(Q_d^j \mathrm{C}_e + \mathrm{C}_0\right)\Delta t^j, \tag{54}$$

So, if $PWHP^j$ and $PWHP^{j-1}$ are the accumulated values of hydrocarbons recovered to date, extracted by time t_j and t_{j-1}, respectively, then there is a relation between them:

$$\begin{aligned} PWHP^j &= PWHP^{j-1} + \left\{ \int_{t_{j-1}}^{t_j} \left(q_o(t)\mathrm{P}_o + q_g(t)\left[\mathrm{P}_g - \mathrm{C}_g\right] - q_w(t)\mathrm{C}_w\right)dt - \left(Q_d^j\mathrm{C}_e + \mathrm{C}_0\right)\Delta t^j \right\} e^{-dt_j} \\ &= PWHP^{j-1} + \left\{ \varphi\left(Q_d^j, \Delta t^j\right) - \left(Q_d^j \mathrm{C}_e + \mathrm{C}_0\right)\Delta t^j \right\} e^{-dt_j}, \end{aligned} \tag{55}$$

where d – corner discount factor $t_j = t_{j-1} + \Delta t^j$.

At the end of the last time period N, relation (55) takes the form:

$$PWHP^N = \sum\nolimits_{j=1}^{N} \left(PWHP^j - PWHP^{j-1}\right),$$

$$PWHP^0 = -C_0 \cdot Q_d, t_N = \sum\nolimits_{j=1}^{N} \Delta t^j, t_0 = 0,$$

where $PWHP^0$ represents the initial one-time capital investments for drilling and equipment of the well.

The proposed mathematical model allows calculating technical and economic indicators of a well, such as reduced net income, cumulative oil, gas and water production, oil recovery coefficient, etc., as a function of control parameters, such as the size of the perforation interval and its location by reservoir thickness, and such control functions as $Q_d(t), q_{nf}(t)$.

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Decision Support System for Road Transport Management in the Digital Age

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Abstract. The rapid development of information technologies and their widespread use in various sectors of the economy, including transportation, have led to a massive growth in data flows. However, the paradox of our time is that this data is not used to its full potential to provide companies with powerful impetus for their development. This is especially true at the strategic level, where company executives still mostly make decisions without relying on the recommendations of business intelligence systems. In the management of road transport, this phenomenon can be attributed to the fragmentation of data sources and the vague understanding of the relationships between them. This is also partially due to the diversity in opinions in the expert community on the efficiency of the transport processes. Thus, it is obvious that, without deciding on how to measure efficiency, it is hard to say where the data for calculations should be acquired from and what should be the architecture of a decision support system. Note that the diversity of data sources in the digital age creates prerequisites for various metrics that highlight different aspects of the transportation process.

Keywords: Road transport · Road transport management · Decision support system · Vehicle management system · Transportation businesses

1 Introduction

In the highly competitive market conditions that have developed in the global economic system in the recent years, the efficient transportation of goods has become an increasingly important factor. Consumer preference surveys conducted in different countries at different times revealed that customers understand efficiency as timely delivery, reliability, flexibility, low cost, high performance, etc. It is well-known that the material flows are accompanied by document flows, which are rapidly shifting towards electronic medium due to the contemporary information and communication

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technologies. Thus, it seems fair to say that information flows of electronic documents and messages are an integral part of the current transportation system [1].

In the context of information theory, these information flows are "raw data", which are not of high practical value for managers seeking to improve the efficiency of their transport companies. In order to become valuable in this regard, the data must go through the operational, tactical and strategic levels of decision making to achieve transformation: "DATA—INFORMATION—KNOWLEDGE—UNDERSTANDING" [2]. However, presently there is a paradox: with the growing variety of currently available data sources (GPS, sensors embedded in the vehicle systems, WEB, RFID, route sheets, orders, etc.), transport company managers do not get new management decision support capabilities. The data has virtually no effect on the improvement of the transportation process and the activities of the transport companies as a whole (Fig. 1).

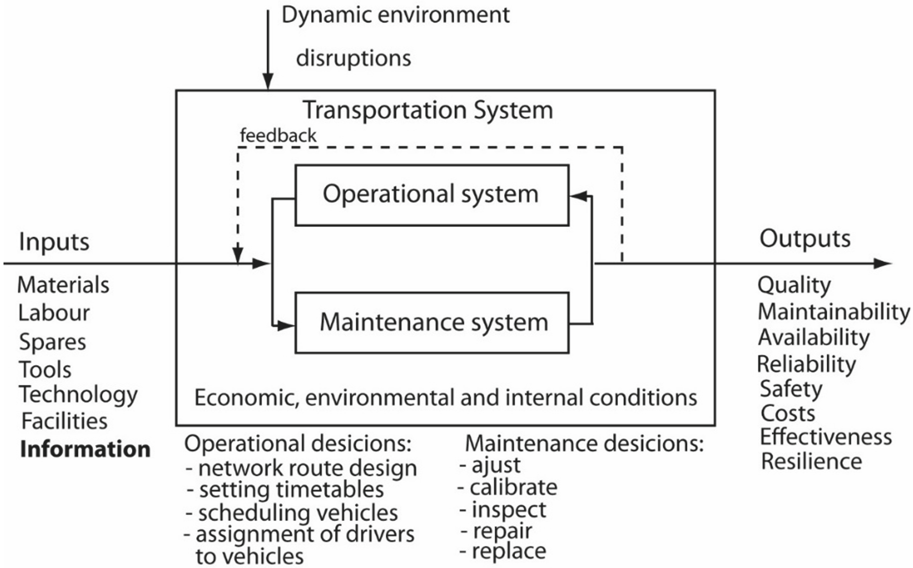

Fig. 1. The concept of the vehicle management system [1].

On the other hand, in practice, transportation businesses have contrasting ideas of work efficiency. For instance, a number of enterprises evaluate efficiency through maximum performance, which is achieved by the maximum utilization of vehicles [3, 4], and, therefore, by the growth of the transport services revenue. However, this significantly increases vehicle wear and tear, which managers in these enterprises consider to be a lower priority issue. In pursuit of greater profits, the vehicles are operated to the fullest capacity, to the detriment of maintaining their operational technical condition and despite the fatigue of drivers. What managers of these companies see as the optimal strategy is the restoration of lost operational capacity, i.e. repair when necessary. Other companies understand efficiency as minimization of the vehicle operating costs, primarily minimizing the wages funds by hiring less qualified drivers. However, despite the apparent savings in wages, such strategy is fraught with consequences, for example, a decrease in fuel efficiency due to unskilled operation on the part of the drivers (frequent braking, selection of non-optimal transmissions, etc.). From the scientific community standpoint, there are different approaches to the question of vehicle performance. Among other things, efficiency is linked to ensuring timely delivery, reducing idle runs, minimizing mileage, minimizing downtime, redundancy [5–7], etc. Many of these indicators are interconnected. In this regard, it is crucial to implement a flexible and adaptive analytical decision support system that allows the use of various data sources, enabling the user to transform data into information and knowledge on the fly (Fig. 2).

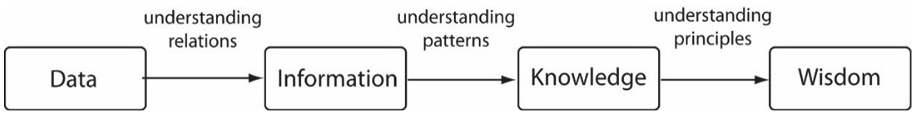

Fig. 2. The process of transforming data into knowledge [2].

2 The Classical Approach to Building Decision Support Systems for Road Transport

The classical data analysis approach in traditional decision support systems involves the preformulation and identification of the problem, extracting, transforming and loading (ETL) of data, and data visualization [8, 9]. In paper [10], a detailed classification of possible options for DSS (Decision Support System) in transportation and their intended tasks are given. The following tasks can be identified among them:

- analysis and forecasting of the situation on the transport services market;
- analysis and planning of optimal routes, schedule optimization;
- optimization of the number and types of vehicles in the fleet;
- optimization and prediction of rolling stock maintenance;
- analysis and optimization of costs and rates for transport services, etc.

Approaches to designing a decision support system for a typical TMS, the model of which is shown in Fig. 3, were considered in a number of papers, where, based on the classical method, data were loaded consistently through queries to an online database and visualized as OLAP cubes and summary graphs. For example, in paper [12], the BI-system Autobase-Expert is provided, wherein OLAP cubes are implemented, enabling managers to analyze fuel consumption by vehicle, driver, fuel brand, time (month, year). Other OLAP cubes were implemented as well, allowing the evaluation and analysis of the expenses in terms of types of repairs, vehicle brands, vehicle systems, as well as analysis of additional vehicle expenses, including fuel, drivers' wages, overhead costs, that is, main technical, operational and economic metrics.

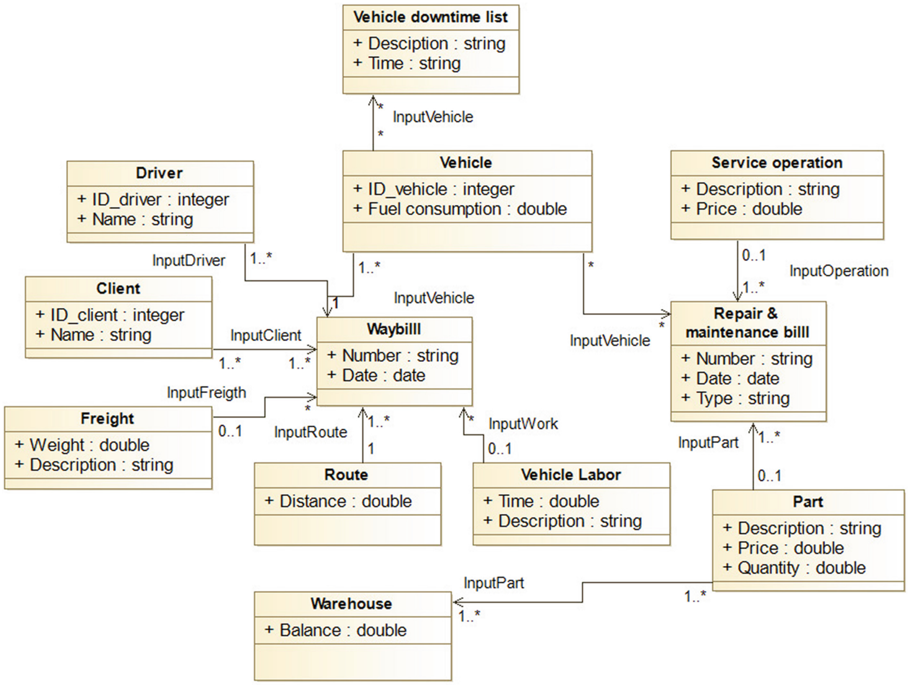

Fig. 3. Class diagram of the vehicle management system.

The disadvantage of this approach is that the transport manager needs to have the skills to query the database, as well as to understand the structure of the TMS database itself. At the same time, the need to consider new problems or previous problems from a different point of view implies additional database queries. Those would require the transport manager to spend a significant amount of time on their development, restricting opportunities for the business analysis. Not every company can afford having an IT specialist for this purpose, and the viability of this is questionable, since the tasks have to be defined for an IT specialist to solve them. The transport manager would be in charge of that, which once again leads to an unproductive use of their working time. Thus, the distinguishing feature of the new generation of decision support systems for transport management should be the possibility of forming arbitrary (ad-hoc) requests and data manipulations on the fly, immediately following the analyst's thoughts [13], as well as the ability to quickly process large data arrays and visualize them interactively (Figs. 4 and 5).

Cargo		As-	Sand			Pe	Total
Month			May	June	Total		
Customer	License	Ton	Ton	Ton	Ton	T	To
		Σ Sum	Σ Sum	Σ Sum	Σ Sum	Σ Sum	Σ Sum
		Σ Agg. value	Σ Agg. valu	Σ Agg. valu	Σ Agg. valu	Σ Agg.	Σ Agg. v
Stroykontakt LLC	X9550B99	4.00		21.63	21.63	22.0	47.6
	0945B097		12.0		12.0		12.0
	Total	4.00	12.0	21.63	33.6	22.0	59.6
Tekhservice CJSC	X9550B99	33.00					33.0
	0945B097	6.00					6.00
	Total	39.00					39.0
UM-7 CJSC				6.00	6.00	8.00	14.0
Dormost CJSC						5.00	5.00
Total		43.00	12.0	27.63	39.6	35.0	117.

Fig. 4. OLAP table with performance indicators of each vehicle for each customer [12].

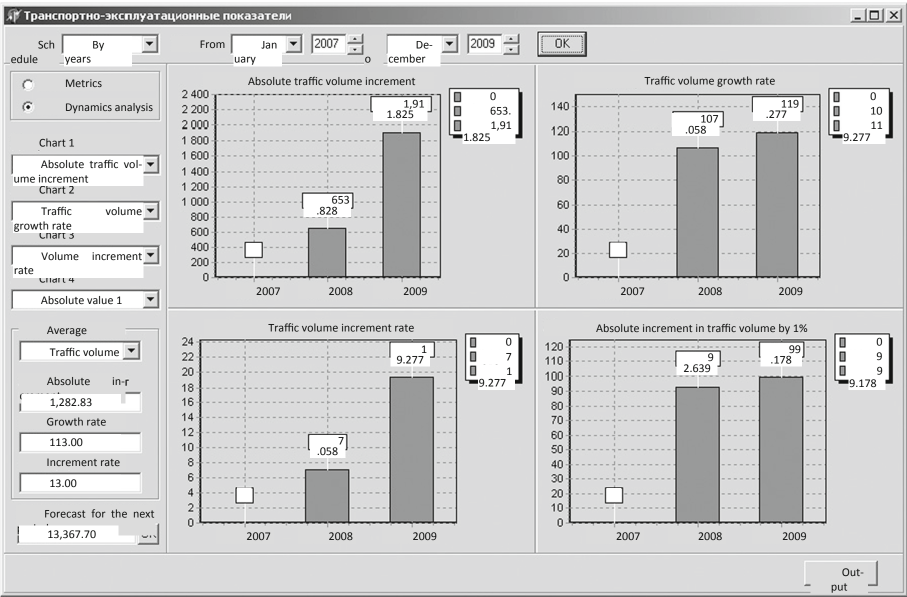

Fig. 5. Dashboard with the enterprise performance indicators [12].

3 Decision Support System for the Vehicle Management in the Digital Age

In the context of the digital transformation paradigm [14], the current concept of a decision support system for transport companies should, at the operational level, focus managers' attention on the work history of each individual vehicle and driver, identifying and noting all events, nuances and peculiarities, forming a personalized log. At the tactical level, the information identified at the operational level should be used to improve business processes. And at the strategic level, the decision support system should provide the managers with prerequisites for a reinterpretation and transformation of the business model. Accordingly, the digital transformation of the transportation process is understood as its improvement, possibly quite substantial, initiated through the use of information technologies, in particular, the decision support system. Thus, the main idea of the BI systems implementation for transportation in the digital age is not only the possibility of generating a set of various reports and graphs, however interactive. The DSS system should not just reflect the current state of the company and prompt "how" to act at a given moment [15, 16], but also show the current and potential bottlenecks, which will hinder the development of the company, and the areas where the company can succeed. In fact, the answers to these questions are prerequisites for the transformation of the company's business model (Fig. 6).

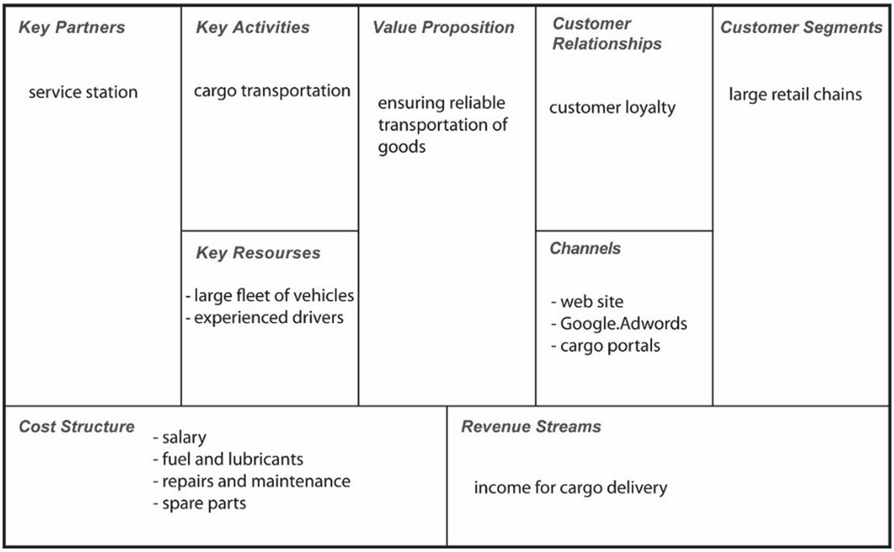

Fig. 6. The Osterwalder's business model canvas for a transport company [18].

Thus, based on the known framework of A. Osterwalder, Business Model Canvas, consisting of 9 elements (Customer Segments, Value Proposition, Channels, Customer Relationships, Revenue Streams, Key Resources, Key Activities, Key Partners, Cost

Structure), we propose the concept of the decision support system for transport enterprises of the digital age [17, 18]. Let us consider the data sources and their semantic links that allow forming indicators for the business model.

- Customer Segments. In the current conditions, a significant part of Russian carriers are looking for potential customers using online platforms, such as www.ati.su, www.perevozka24.ru, www.avtodispetcher.ru, etc. Accordingly, it is possible to use the APIs of such web-resources for data collection and analysis, identifying trends in freight traffic (cargo type, distance, direction of transportation, etc.).
- Value Proposition. In the highly competitive Russian freight market, a successful business needs to offer a balanced value proposition for transportation services that could interest potential customers. Many of the small carrier companies tend to attract customers with lower costs. However, today, the customers are starting to realize that the low freight rates may be due to the low quality of the service, which may be related to the carrier's violation of the contract terms: damage to the goods, failure to meet delivery deadlines, etc. Accordingly, the surveys and interviews of potential customers and the collection of search queries, reviews and opinions on the Internet allow the creation of a database, the analysis of which will provide information on the preferences of potential customers.
- Channels. In the digital age, the Internet is the main promotion channel. Therefore, the marketing data comes from the company's website logs, web-analytics data.
- Customer Relationships. Data array in this area can be generated using the CRM module in TMS. Previously, typical TMS solutions discussed above generally did without CRM, having only accounting modules for vehicle maintenance operations. However, this meant that only the business matters related to the changes in the financial status of the enterprise were recorded in the information system. But in contemporary conditions, the analysis of information from customer calls, emails, reviews in social media is also needed.
- Revenue Streams. For this aspect, data can be acquired from the contract register, invoices, payment orders.
- Key Resources. Obviously, the key resources for a transportation company are vehicles and drivers. Accordingly, data from the operational activity subsystem and the maintenance and repair system will be required for data analysis here. This way, it is possible to identify the individual characteristics of each vehicle.
- Key Activities. Here, the main source of data may be the GPS monitoring subsystem, as well as vehicle onboard sensors. Based on the vehicle location data, it will be possible to evaluate the efficiency of the route, the actions of the driver, etc.
- Key Partners. Here, one can use TMS data on the business partners of the transport company: car service centers, fuel and spare parts suppliers. Data sources are bills of lading, orders for fuel and material supplies.
- Cost Structure. The company's expenses database is formed with the information from the operating activity subsystem and the rolling stock maintenance subsystem.

4 Conclusion

The provided concept of forming a TMS and a TMS-based decision support system focuses on the development of efficient company activities on the operational, tactical and strategic levels. Focusing TMS on the development and support of the business model is meant to ensure its deep integration into key business processes, thereby creating the prerequisites for a digital transformation of transportation activities. As a result, the decision support system becomes a strategic key asset of the company, thereby creating a competitive advantage.

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Economic and Mathematical Evaluation Model of Interaction Between Container Transportation System and Russian Regions

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Abstract. The purpose of the article is to develop an economic and mathematical evaluation model of interaction between the container transportation sector and a region. The topicality of the research is evidenced by the lack of coordination mechanisms between the development programs for container transportation system and other branches of regional economy. This leads to a disproportionate development of the terminal capacities in the region, inefficient transportation flows with empty containers, suboptimal use of the rolling stock. The article establishes an outline for interaction analysis that considers multi-faceted, reciprocal effect the container transportation has on a region. To estimate the economic development of a region due to the interaction with the container system, the notion of regional wealth will be used. The main factors affecting regional wealth and their numerical indicators are provided in the article. The lagging nature of the influence of individual factors on the regional wealth is noted, and a general method for determining this time lag is designed. A linear evaluation form for regional wealth is provided, which considers its dependence on the factors of the container transportation development. The practical significance of the research results lies in the model's potential to predict the wealth growth of a region, to evaluate the priorities for the structural and technical development of the container transportation system, to design strategies for social and economic development of the region and its transportation sector, to generate optimal investment flows.

Keywords: Container system · Containerization · Regional growth · Evaluation of interaction

1 Introduction

Currently, container transport is the most desirable and fastest developing type of cargo transportation. Today, the containerization rate for dry cargo is estimated to be as high as 60–70% [1] worldwide. In Russia, this indicator is below the global level at 6.2%, but demonstrates fast growth. The railroad containerization rate more than doubled in the last decade. The development of the container transport sector in Russia is fueled by the growing volumes of production, increased trade with Asia-Pacific countries,

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redistribution of the cargo traffic in favor of containers. In addition, containerization processes go beyond the transportation of so-called container-suitable cargo. Today, specialized containers carry a wide range of raw materials, including metals, liquid and bulk cargoes, and liquefied gas.

Note that switching goods to container transportation from other modes of transport and increasing the level of containerization is one of the priority tasks of the economic development of the Russian Federation. Thus, in accordance with the Presidential Decree "On National Goals and Strategic Tasks of the Development of the Russian Federation for the Period until 2024", the goal was set to increase the volume of rail container transportation by four times by 2024.

This has resulted in a heightened need for regional infrastructure for container transportation and development of a competitive market.

At the same time, there are no mechanisms for coordinating development programs of the container transport system and other sectors of a regional economy; there is no common coordinated approach to estimating regional demand for the container transportation infrastructure development. In these conditions, the container transportation market forms spontaneously. This leads to an imbalance in the development of regional terminal capacities, wasteful empty container flows, inefficient use of rolling stocks. In its turn, the inefficient container transportation system negatively affects the development of individual economic sectors and the region as a whole.

This confirms the topicality of this work and defines its overall objective: to study the interaction between the container transportation sector and a region, and to design an economic and mathematical model of this interaction.

The model is based on the contemporary research in modeling and evaluation of individual aspects of interaction between transportation system and a region. For instance, papers [2–10] are dedicated to this subject. In particular, papers [2–4] examine methods of modeling, predicting and estimating economic and social development of regions, resulting from the implementation of transport infrastructure projects. Paper [4] offers an integrated indicator for assessment of regions in terms of their transport infrastructure development. Studies [5–7] are dedicated to designing regression models that demonstrate the influence of different macroeconomic performance indicators of a region on the transport infrastructure development. Papers [8, 9] develop mathematical models of interaction between major companies (using RZD OJSC as an example) and subjects of the Russian Federation. It also offers methods of assessing the wealth of a region from the point of view of a major company.

By analyzing existing studies, we can infer that the effect the transportation has on a region is reciprocal. Depending on the current economic situation, the direction of influence may change. So, during periods of intensive economic growth, the primary influence is the economy, which initiates the development of the transport system to meet consumer demand. But when implementing large transport projects, the primary influence is behind the transport system, which will stimulate the intensive economic development of the regions and the country's economy as a whole for many years to come. Thus, the interaction of the transport industry and the region is bi-directional, dynamically changing, and has a stochastic character. Nowadays, certain aspects of this interaction have been studied. However, an economic-mathematical model reflecting the mutual dynamic influence of these subsystems is not represented.

2 Developing the Evaluation Model for Interaction

The proposed model is based on the following concept: the regional container transportation system is one of the subsystems of a region, so the growth of containerization will influence its development. At the same time, changes in other regional subsystems can affect the development of container transportation. Thus, the reciprocal influence between a region and its container transportation system is assumed. However, this interaction cannot be measured directly, as it has a lagged effect and can be affected by various stochastic parameters. The social and economic development of a region will be evaluated in the context of lowering expenses for cargo owners, increasing economic indicators of the region, as well as various social and economic factors that indirectly affect the containerization. Of course, the reverse influence is present as well —the economic growth of a region promotes structural and technical development of the container transportation system (due to the growing production levels, trade expansion, investments and rising appeal of the sector).

The reciprocal influence of the mentioned factors can be represented by the following flow-chart (Fig. 1).

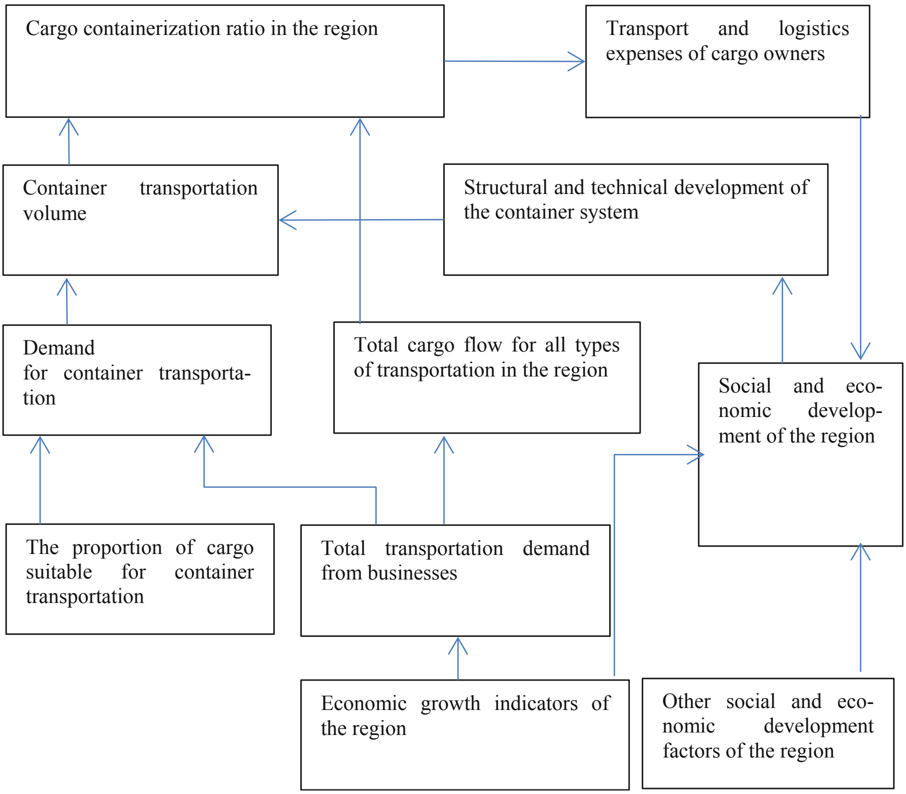

Fig. 1. The interaction flow-chart between factors of container transportation and region development

Thus, the interaction of a region and container transportation system is multi-faceted and reciprocal.

This work details one direction of the mentioned interaction—the effect container transportation has on the region development. Studying such an influence and developing quantitative evaluations of the influence of the container transportation development on the economic and social life of a region is necessary to predict the wealth growth of the region, to eliminate the “bottlenecks” in this interaction, to evaluate the priorities in the structural and technical development of the container transportation system, to develop regional strategies for the transportation sector development, and to generate the optimal investment flows.

To estimate the economic development of a region due to the interaction with container system, we will use the notion of regional wealth [8, 9]. The regional wealth indicator $\Omega(t)$ in the reviewed period t is defined in [9] as the following linear evaluation form:

$$\Omega(t) = \alpha_1 w_1 x_1 + \alpha_2 w_2 x_2 + \ldots + \alpha_n w_n x_n \quad (1)$$

where $x_1, x_2, \ldots, x_n$ are the considered parameters of the region’s development;

$\alpha_1, \alpha_2, \ldots, \alpha_n$ are the equalization factors,

$\alpha_i = \frac{1}{\max\{x_i\}}$, for each $i = 1, \ldots, n$; $w_1, w_2, \ldots, w_n$ are the weighting factors, determining the importance of a parameter. The parameters $x_1, x_2, \ldots, x_n$ that affect regional wealth can be, for instance, region’s population, regional budget revenue, cargo loading/unloading volume in the region, railroad track mileage, etc.

This work aims to set $W(t)$ as the integrated indicator of the region’s economic growth that considers the influence of container transportation development.

To achieve the objective of this work, the regional wealth evaluation model should include the following parameters among others (t is the considered point in time):

- cargo containerization ratio $k(t)$ in the region, ratio;
- container transportation volume $Q(t)$, tons;
- total cargo flow $G(t)$ for all types of transportation in the region, tons;
- total transportation demand $S(t)$ from businesses, tons;
- container transportation demand $D(t)$ from businesses, tons;
- throughput $R(t)$ of the container infrastructure, tons;
- total logistics and transportation expenses $J(t)$ for cargo owners, ratio.

A functional or correlative dependence is assumed between these indicators, which can be explained as follows.

Containerization ratio in a region is the ratio of the containerized cargo volume in the region to the total cargo transportation volume. The container transportation volume depends on two factors: the container transportation demand from businesses and structural and technical development (throughput) of the container transportation infrastructure. In turn, the container transportation demand increases with the growth of economic indices of the region, if the type composition of the transportation sector remains the same. The container transportation system development, reflected in the containerization ratio increase, allows cargo owners to lower their expenses due to logistics savings from cargo handling, faster shipping, improved rolling stock turnover, and increased cargo safety.

The parameters of interaction between container transportation and the region can be represented as follows.

Region containerization ratio $k(t)$ is the containerized portion $Q(t)$ of the total cargo volume $G(t)$ in the region in the t time period:

$$k(t) = \frac{Q(t)}{G(t)} \tag{2}$$

The total containerized cargo volume $Q(t)$ depends on the demand $D(t)$ from the region's businesses for such transportation and is limited by the throughput $R(t)$ of the container transportation system at the time t:

$$Q(t) = \min\{D(t), R(t)\} \tag{3}$$

The region's demand $D(t)$ for the container transportation is modeled in [10] based on the index method, regression modeling and the Monte Carlo method.

$$D(t) = w(t) \cdot G(t-1) \cdot I_G(t) \tag{4}$$

$$I_G(t) = f(I_1(t), I_2(t)\ldots I_n(t)) \tag{5}$$

where $w(t)$ is the portion of cargo suitable for container transportation in the region; $I_G(t)$ is the growth index of the total cargo flow in the region;

$I_1(t), I_2(t)\ldots I_n(t)$ are economic growth indicators of the region. These can be indicators of GRP by volume, goods and services output indices, production indices, trade turnover indices, and more. The choice of indices in the suggested regression model is determined by GRP structure of the region, the information availability for the parameters in question, specifics of the region's economy. The decision to include or exclude a parameter is made based on the regression significance analysis.

To find the regression equation, it is advisable to use a step-by-step algorithm, the essence of which is to select a small group of variables that make the greatest contribution to the variation of the dependent variable (in our case, the index of growth in freight traffic in the region I_G) from a large number of factor indicators (in our case, the economic development indices of the region I_i).

For instance, the regression model for the Sverdlovsk Region defined in [10] is as follows:

$$I_G = 0.8067 I_1 + 0.3016 I_2 - 7.5712, \tag{6}$$

where I_1 is the GRP volume index in manufacturing, %; I_2 is the GRP volume index in wholesale and retail trade, %.

It is also necessary to take into account the fact that a change in the growth indices of economic indicators of the region $I_i(t)$ is a random variable, which is determined by a large number of difficultly predicted external factors. Therefore, it is advisable to express each index I_i as a random variable with the established distribution law.

For example, for the Sverdlovsk region, in accordance with the algorithm of the Monte Carlo method, laws and distribution parameters for the variables I_1, I_2 are established, the calculation is performed using the STATISTICA software product:

- I_1 is a random variable distributed according to the normal law with mathematical expectation μ = 103.05 and standard deviation: σ = 8.43.
- I_2 is a random variable distributed according to the lognormal law with a median Me = 101.31 and a standard deviation of σ = 12.71.

The $k(t), Q(t), S(t), J(t)$ factors do not affect the regional wealth $\Omega(t)$ immediately, but, evidently, with some time lag. To determine the time lag of each factor, the following (presumably, original) general method is proposed.

The factors $k(t), Q(t), S(t), J(t)$ and the regional wealth $\Omega(t)$ are considered to be discrete random variables. The actual values of those random variables are taken at each sample point (for instance, each month) for a sufficiently large observation period and put into columns.

Next, the column of values for the parameter in question is shifted step-by-step against the $\Omega(t)$ column to find the point of the highest correlation. After each shift by one line (one month), the correlation ratio is calculated between the data column for the parameter and the $\Omega(t)$ column. Additionally, at each step the columns for the parameter in question and $\Omega(t)$ have to be shortened by one value that is left without a pair after the shift, as shown in Fig. 2.

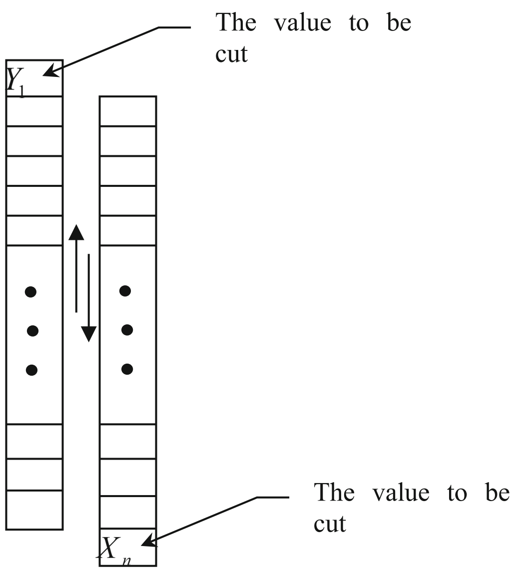

Fig. 2. Column shifting and value cutting

Clearly, the initial amount of data (the number of values in each column) should be large enough (several years) to still have a significant random sample after each cut.

Evidently, the time lag of the parameter effect on the regional wealth equals the shift length (in months) that produces the highest correlation between the parameter in question and the regional wealth.

In conclusion, to express the regional wealth *W(t)* at the time t in the context of container transportation, the following linear evaluation form is proposed for the regional wealth that reflects the influence of container transportation development and considers the time lag for the parameters in question:

$$W(t) = \Omega(t) + w_k k(t - t_k) + w_Q Q(t - t_Q) + w_S S(t - t_S) + w_J \frac{1}{J(t - t_J)} \quad (7)$$

where w_k, w_Q, w_S, w_J are weighting factors; t_k, t_Q, t_S, t_J are the time lag intervals for each corresponding parameter.

The presented assessment model is formed on the basis of the following principles.

First, since the value of the form *W(t)* should be the greater, the better is the estimated parameter for the development of the region, then each term of the form should increase monotonically with an improvement in the corresponding indicator.

Therefore, when conducting assessments, sometimes, as the values of the variables in the evaluation form *W(t)*, it is necessary to use not the indicators themselves, but some suitable functions of them. In our case, it is obvious that the lower the transport and logistics costs of cargo owners *J(t)*, the better it is for the development of industries. Therefore, it is reasonable to imagine: $x_i = \frac{1}{J(t - t_j)}$, i.e. take the value inverse to the value of the costs of the cargo owners as the corresponding variable.

Secondly, the model includes weighted normalization coefficients that perform two functions. The first is equalization of the terms' dimensions. The dimensions of the coefficients are chosen so that they equalize the dimensions of the terms of the form so as to obtain a dimensionless quantity. This requirement is satisfied automatically if the coefficient is assigned the dimension inverse to the dimension of the corresponding evaluation parameter. The second is to give corresponding weights to the indicators in the interests of the region conducting the assessment in accordance with its strategic goals and objectives.

The method has been verified by computer simulations. Simulation data and the results of interaction evaluation with the provided method are being generated and will be published in future works.

3 Conclusion

The overall objective of studying the interaction between container transportation and regional economy has been stated. The topicality and practical significance of the objective stem from the potential to coordinate regional development programs for individual economic branches and container transportation, to predict regional wealth growth, to evaluate priorities for the structural and technical development of the container transportation system, and to generate optimal investment flows.

The general outline has been established for studying the interaction characterized by multi-faceted, reciprocal effect of container transportation on regional development. The impact of containerization on the growth of the regional economy is considered from the perspective of reducing transport costs for cargo owners. At the same time, the fact that the increase in the containerization coefficient is limited by the development of the transport infrastructure of the region and the structure of the cargo base is taken into account. In this regard, the opposite effect arises - economic growth stimulates investment in the transport industry, which creates the preconditions for a further increase in container traffic.

The concept of regional wealth has been suggested for the evaluation of economic development of a region. The main factors of container transportation affecting the regional wealth have been highlighted. Their quantitative characteristics have been proposed. The proposed method can be used not only in the framework of this study, but can also be useful for solving a wide range of tasks related to studying the influence of lagging indicators on the development of various economic processes.

The general method has been proposed for determining the time lag of a parameter's effect on the regional wealth. It involves step-by-step shifting of the data column for the parameter in question against the regional wealth column in order to find the point of the highest correlation.

A linear evaluation form for regional wealth is presented, which considers its dependence on the factors of the container transportation development.

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Algorithmization of Decision-Making in the Construction of Logical Structures of Databases of Functional Information Systems

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Abstract. Decision-making is the creative process of identifying alternatives and choosing among them a satisfactory solution based on the values and preferences of the decision maker (LPR). This person at present can be directly to the man himself, and, - directly computer. And the methods of decision-making - can be both individual and group. An important factor of difficulties in making decisions is that very often the target function is not set, or its description is a difficult task. There are situations when the researcher himself does not clearly know what exactly he wants to achieve as a result of research, what result to get. It is obvious that in the conditions of computer decision-making, such a process must be formalized on the basis of a deep logical analysis of the probable outcomes of the problem to be solved. This work directly intersects with research in the field (Big Data)". In the literal sense of the term Big Data, means large in volume (in terabytes, petabytes and etc.,) data. A more precise definition of the term could be "complex data". The present work is devoted to the search for methods of decision - making formalization of complex data on the basis of database structuring. Model logical database structures were based on the concepts introduced in the text and defined by the author.

Keywords: Economic system · Information system · Logical structure · Database · Logical analysis · Decision algorithm · Register · Value · Object · Indicator · Time · Restructuring · Connectivity · Relationships

1 Introduction

Eric Bern: «No problem, there are only wrong decisions». The living conditions of the modern economic systems of the world market are very strict, and the competition in these systems is very big. In such conditions, when different companies and organizations have similar technologies, a big role in success, in competitive confrontation and in achieving goals is played by highly effective, correct and rational decisions at all levels of management.

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With the development and implementation of modern information technologies it became possible to create complex information systems based on modern database management systems (DBMS). The most important stage of this work is the design of the database itself. And first of all, the construction of its logical structure. It is the logical structure that ultimately determines the efficiency of the information system.

This article develops and substantiates the methods of construction and analysis of logical database structures under the assumption that the information model of these structures has previously identified all the necessary elementary and group data, as well as objectively existing information and logical relationships between them.

The database model will be based on the concept of "registers", the development of which is one of the directions in the creation of functional subsystems.

Under the definition of "register" we mean a set of objects of statistical observation with a set of qualitative, quantitative and reference features for each observed object. For example, private construction companies, various businesses, different geographical areas, etc. of Course, that information about objects can be very diverse in content and in their relationships. This variety of information leads to many possible variants of the final logical structures of the designed databases. Therefore, there is a need to analyze these structures in order to choose the most effective. Consider the options of examples of existing structures are implemented in modern DBMS.

2 Materials and Methods

Option 1. The numerical value (quantity) of each indicator K_it information base of the register is characterized by:

Q_i - code of the object of observation (construction, enterprise, territory, country, etc.), $i = 1 \cdots i^*$;

P_j - index code characterizing the state of the system (production activity) of the object of observation (productivity, investment, etc.), $j = 1 \cdots j^*$;

T_t - observation time (year, quarter, etc.), $\mathrm{t} = 1 \cdots t^*$.

Thus

$$K_{ijt} = f(Q_i P_j T_t) \equiv f(i,j,t) \tag{1}$$

In the future, we will use the following terminology using terms such as: - "value", "object", "indicator", "time". If the indicator P_1 matter for objects Q_1, Q_3, Q_5 and indicator P_2 values for objects of Q_1 and Q_2 the indicator P_4 matter for objects Q_1 and Q_3, these relations can be represented by sets at the instance level (Fig. 1).

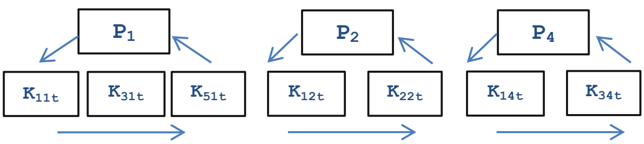

Fig. 1. Levels of «Instances»

Where the owner of these values is the indicator itself, and the elements of this set are actually its values. The scheme of this connection is shown in Fig. 2.

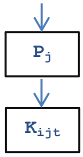

Fig. 2. Context «Indicators»

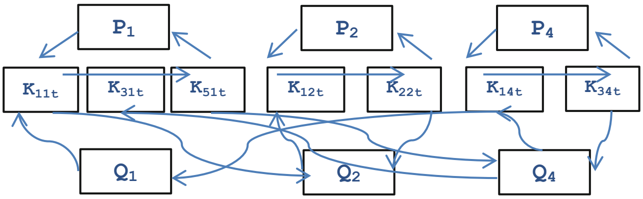

Fig. 3. Elements of "Sets" and logical connections between them

Now let's connect the objects with the values of the indicators belonging to them (Fig. 3). The owners of new instances of sets are objects, elements are their values. The scheme of the given structure is shown in Fig. 4.

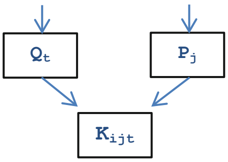

Fig. 4. Linking objects to their own values

By associating in the same way the previously mentioned characteristic "time" with its "value", we can obtain the corresponding structure both at the instance level and at the scheme level (Fig. 6). (In the diagram, the letters N, M, L denote the names of the sets).

Built so the structure is very simple in relation to the value of the index K_{ijt}, as there is equally easy access through the "object", "rate" and "time".

Access through the "object of observation" provides a choice of values of any set of indicators for this object for any period of time

$$\{K_{i^{\sim},j,t}\} \in \{\{K_{ij,t}\}, i^{\sim} \in_{\overline{1,i^*}} \tag{2}$$

Access through the "indicator" allows you to select the values of this indicator for any set of objects for any period of time

$$\{K_{i,j^{\sim},t}\} \in \{\{K_{ij,t}\}, j^{\sim} \in_{\overline{1,j^*}} \tag{3}$$

Access through the "observation time" provides a choice for a given time period values of any set of indicators to any set of objects.

$$\{K_{i,j,t^{\sim}}\} \in \{\{K_{ij,t}\}, t^{\sim} \in_{\overline{1,t^*}} \tag{4}$$

This structure of the relationship of indicators meets the information needs of the various functional subsystems of statistics (Fig. 5).

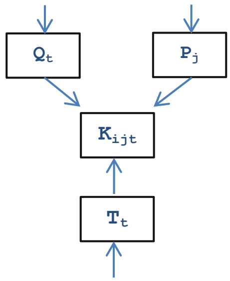

Fig. 5. Diagram of the structure of relations between objects

Individual tasks, or a set of tasks, or subsystems, can organize access to data through the "accounting object", "time" or "indicator", if these criteria are predominant for obtaining output information.

The structure under consideration does not contain duplication of features. Codes of objects, indicators and time periods are repeated only once, and the value characterized by these three criteria lies at their intersection.

The structure does not require restructuring when adding any number of objects, indicators and time periods.

Structure 2. Let the object of observation is characterized by a subset of indicators: information about the belonging of the object to a certain territory, industry, Ministry or Department, as well as a number of information specific to individual subsystems.

In turn, the following aggregation is possible in the subsets of indicators that characterize the different States of the objects of observation:

- according to the method of obtaining indicators, for example, design and regulatory, planned, actual;
- on the indicators characterizing the separate party of activity of object, for example, indicators on sections: "Capital investments", "Input of fixed assets", "Commissioning of production capacities";
- according to any other required user level of classification of indicators, different frequency: annual, quarterly, monthly. Values of monthly frequency are usually repeated in the values of the quarterly and annual periodicity, or only annual, and the values of the quarterly - annual.

You can enter other periods - monthly accumulating, quarterly accumulating, semi-annual, etc., depending on the conditions and requirements of the user.

In all the structures discussed below, all these requirements are easily met, and the repetition of the value at different intervals does not in any way lead to a repetition of the indicator code. Aggregation depends on the needs of the subsystem. So, if the percentage of output forms in the context of "General contractor" is high, it should be allocated in a separate set, then all construction will be tied to its General contractor and the time of their search will be significantly reduced.

If the percentage of output for the "General contractor" is low, you can mark its code as an element in the record to the "object". This will simplify the structure, although it will create duplication in this indicator. If the need for a first link is low, it may not be organized to simplify the structure. Other relationships can be analyzed in the same way.

Structure 3. In addition to the values of the basic indicators directly stored in the database, there is a need to have the values of derived indicators, which are calculated by formulas using the basic indicators. Derived indicators can be calculated both by means of DBMS and application programs. Analysis of a specific information system allows to identify a number of commonly used derived indicators that should be obtained by means of DBMS. Derived indicators can be defined as real results, and their values must be stored in a database and recalculated automatically by the system when the underlying indicators on which they were calculated change. Derived indicators defined virtually are not stored in the database, but are calculated when a request is received from the application. Let's build another scheme that differs from the previous one and reflects the values of derived indicators, assuming that all derived indicators are obtained using a single procedure, quite complex and capable, depending on the conditions, to implement calculations using different formulas.

To determine the value of K^*_{ijt} derived indicator construct the set D^* arguments - i.e. the values of basic indicators. So, as the same base value K^*_{ijt} can be used in the calculation of several derived indicators, construct a set D^* that contains multiple copies of the argument. As a result, we obtain the scheme shown in Fig. 6.

Here and further the relations between values and corresponding objects, indicators and time periods without levels of their aggregation as they do not influence these] relations are considered. Entering D u D* sets increases the percentage of structural information (the percentage of references that provide links across sets), but these sets are used to calculate derived measures, allowing the average user to retrieve them directly from the database without additional programming. The higher the percentage

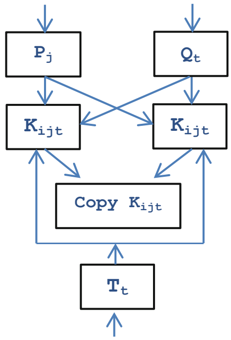

Fig. 6. Relations between objects

of structural information in a record, the more complex the structure and the shorter the record. But, in turn, the more complex the structure and the more fully taken into account all levels of data aggregation and the links between them, the better access to the data.

Before moving on to the new structures, note that the three database structures described above allow you to store and store only those values for which records are defined and, therefore, the use of external memory is very efficient.

Consider now structures in which the length of records is increased by reducing relationships. This is how the structures 4 and 5 shown in Figs. 7 and 8.

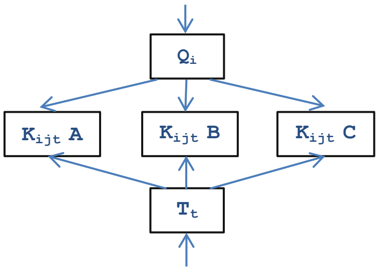

Fig. 7. Combining indicator values for variants of schemes A, B, C

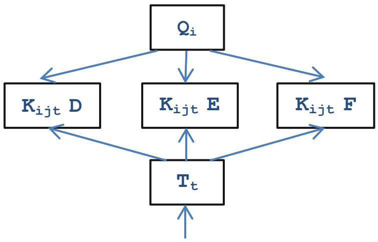

Fig. 8. Combining indicator values for variants of schemes D, E, F

Structure 4. Let's combine the values of indicators into record types according to the following principle: the values of indicators of the same periodicity for one enterprise for one time period are combined into one record. So, record type A (Fig. 7) can contain all the values of annual frequency that correspond to a specific company and time period, where a specific year, e.g. 2019. Similarly, a type B record can include all quarterly periodicity values that correspond to a particular business and time period, where a certain quarter of a particular year, such as the 1st quarter of 2019.

A type C record contains the monthly periodicity values for a given enterprise for a specific month of the year, for example, August 2019.

These records are combined into sets N and L. The set N contains records of values related to this enterprise for all stored time periods. Thus, if we store annual data for the entire construction period for any construction site, and quarterly and monthly data for the last year, then the set N will contain records of type A - one for each past year, type B - one for each past quarter of the current year, type C - one for each past month of the current year. With the onset of a new time period, the next records of the corresponding type can be included in the set.

Let the set L contain the records of all recorded sites for this time period.

Then, for example, if the owner of the set L is "year 2019", then it will include records of type A, i.e. the values of all indicators for all objects for 2019.

And if the owner of the set L is "February 2019", the set will include records of type C, i.e. the values of all indicators for all objects for February 2019.

As a result, the amount of useful information in the records $K_{ij,t}$ will increase dramatically, as the records will store the values of all (not one) indicators for the corresponding time. As the calculations show (for 100 enterprises and 200 indicators stored for different time periods in such a way that each enterprise is characterized by 2400 values of indicators), the efficiency of using external memory in the application of this structure in comparison with the previous ones increases by 5 times.

In this structure it is possible to define values of other various derived indicators by means of DBMS. Within a record, the values of derived measures over the same time period are calculated using simple individual procedures that use any element of the record. In addition, the set N can be used to calculate various object summary data for different time periods, using the necessary values from the records of this set. You can get this summary data in the "Record", i.e. - the owner of this set.

Having aggregate data for the object, you can anticipate them getting territorial, administrative or industry types. The structure provides access to the values of indicators through the "object" and "time". "Indicator" takes a fixed place in the record, so the composition of indicators should be defined in advance, and if it is required, then with a margin. The addition of a new group of indicators or the cancellation of the old one leads to a restructuring of the structure that can be carried out by means of the system. Restructuring in this case is not affected and applies only to the composition $K_{ij,t}$. This database can be used in subsystems where a thorough analysis of the information model base, well-defined set of indicators on the objects of monitoring and identifies the range of tasks which will be decided on the basis of these indicators.

Structure 5. The principle of constructing this structure is similar to the previous one: - that is, increasing the length of the record by reducing the links.

In this structure, the records combine the values of one indicator for one object for a certain time period. In this case, the records are divided into types, depending on the nature of the time period. Record of type D (Fig. 8), which combines annual (e.g. 10 years) value of some indicator on a single object; a record type E - all quarter (for example, for the four quarters of the current year), a record type is F - all monthly (e.g., 12 months) value of some indicator on one object.

In a set of N merged records that contain the values of all indicators of the same object for all time periods of storage of these indicators, and a set of M entries containing the values of one indicator for all observed objects for temporary periods of storage in this indicator. The structure provides access to the data through the “Indicator” and “Object”. “Time” takes a fixed place in the record, so the composition of time series must be defined in advance. It is not difficult to do this, and therefore it is possible to avoid restructuring of time periods.

In such structures the DBMS can be defined inside records derivative values of this indicator in the enterprise series, it’s stored in this record. You can also get derived (for example, totals) data for all objects for one indicator (using the M set) or derived (for example, aggregated) data for one object for different indicators (using the N set).

The efficiency of using external memory here as well as in structure 4 is very high.

3 Results

Thus, we have analyzed five variants of the register database structures. The basis of their construction was based on the following principles:

- easy to build;
- ability to access data on various aspects (via “object”, “indicator”, “time”);
- de-duplication;
- storing data in a dynamic way (with any retention periods of information);
- resistance to adding new objects, indicators, time periods;
- availability of aggregation levels and their structural connectivity;
- the effectiveness of the use of external memory;
- the possibility of obtaining by means of DBMS derived indicators.

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Determination of Factors of Professional Health Risk of Engineering Workers

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Abstract. The article presents the regularities of the formation of risk of occupational diseases of the working population in the engineering of individual forms of professional pathology. The calculations were performed using the methodology developed using the principles of the International Labour Organisation and World Health Organization on study of adverse workers health effects, caused by exposure of harmful and dangerous factors of the production environment. There are also used approaches to occupational risk assessment. It was found that the total occupational risks among workers of surveyed sectors are high enough. There was used a methodology based on a systematic approach to technology assessment of health risk from occupational exposure. The object of the study was typical for this industry engine-building association in one of the Russian cities. The greatest number of healthy employees was found in the group III (ETW) without the influence of unfavorable factors of production, which is characteristic for members of groups I and II. Using the methodology of risk assessment, it is possible to determine the safe working period under the influence of adverse factors of industrial environment.

Keywords: Occupational diseases · Occupational hazards · Coal industry · Engineering · Risk

1 Introduction

Recently, there have been more information about the harmful production factors that adversely affect on the health of workers, but the level of research and accordingly safety measures which are taken, are on improper level. Such factors include, for example, biological, which accompany processes in the metal-working enterprises. The source of their appearance are aqueous technological greasing-cooling liquids which are used in large quantities in processes of treating metal articles by drilling, grinding and others. Improving occupational safety and health management system in such enterprises should be happen taking into account these factors and the potential negative consequences of their impact on the work [1–8]. State of labor protection is a component of the international situation, which is monitored by International Labour Organization (ILO). According to ILO experts to 2.8 billion working-age population in the world each year accounting for up to 2200000 accidents fatal work-related. At average, 5000 people die every day from injuries at work. In general, the number of accidents in the workplace is about 270 million a year. The number of diseases,

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caused by unfavorable working conditions, is reaching 160 million cases. From 30 000 000 000 000 dollars world GDP 4% are losses associated with accidents at work. Low levels of literacy and poor training in safe working methods lead to high death rates from fires and exposure to hazardous substances [7].

Global GDP losses due to death and illness of workers in 20 times more than all official development assistance which is provided to developing countries. 440 000 of people die in all of the world from exposure of harmful substances annually. Only one asbestos is about 100 000 lives. In general, the proportion of cardiac diseases and musculoskeletal system is accounted for half of the costs associated with the disease, received at work [2].

The highest category of evidence is "a proven professional risk" - based on epidemiological health studies submitted contingents using the health monitoring data, periodic medical examinations, study of morbidity with temporary disability, professional and professional due to morbidity, mortality, disability, and others. The methodology of the analysis and the results of epidemiological studies risk calculations can have two main models. These models are considered from the perspective of risk analysis of the events that have already taken place in order to predict their in subsequently, depending on the existing risk factors for a variety of submitted selected populations, as well as the second model, which involves the potential risk of the use of new chemicals, hardware, etc., have not been used yet, so the real data about the events that cause damage to health, yet, but for these funds should be calculated the expected potential risk based on similar materials, or based on experimental studies of these factors.

By using the two models there is most often calculated absolute (AR) or relative (RR) risk indicators. If possible, it is advisable to use both of these indicators, but for researching of professional risk the most informative is the relative risk. In addition, in the Clinical Epidemiology calculations is used etiological share (ES), which is defined as the percentage of certain diseases in population, which is due to the influence of occupational risk factors and allows to assess the degree of conditionality of diseases of this factor.

According to State Statistics Committee, area of economic activity "Manufacture of machinery and equipment "has about 5.6% of the account number of full-time workers in economic industries activity, where there are harmful and dangerous working conditions [1].

In the engineering industry there is exposure in the workplace employees of all harmful and dangerous factors of production environment, mainly: noise (12,1% of workers), harmful chemical substances of the 1–4 classes of danger (11,1%), dust predominantly fibrogenic action (8,4%), unfavorable microclimate parameters (7,5%), forced working posture (7,1%), tension (4.1%) and the weight (3.3%) labor, and the others. However, in comparison with the other investigated sectors of economic activity, the level of relative risk of influence of harmful and dangerous factors in the workplace's workers of machinery industry is lower in almost all factors ($RR < 1.0$)

and excluding exposure to harmful chemicals of 1–4 class of danger (RR = 1,27). The contribution of the investigated etiological factors in the occurrence of work related and occupational pathology among workers in the engineering industry is estimated at 39.8–79.7%. Ultra-high levels of the relative risk are observed (RR > 5,0) morbidity in workers with musculoskeletal diseases system and connective tissue (RR = 9,07, EF = 89,0%); sensorineural hearing loss (RR = 6,13, EF = 83,7%) and high levels (R = 2,0–4,9) - disease of the peripheral nervous system (mono-, PN) (RR = 2.57 m, EF = 61,1%) and vibration disease (RR = 3,03, EF = 67,0%). There are also risks of accidents. Their causes are shown in Fig. 1.

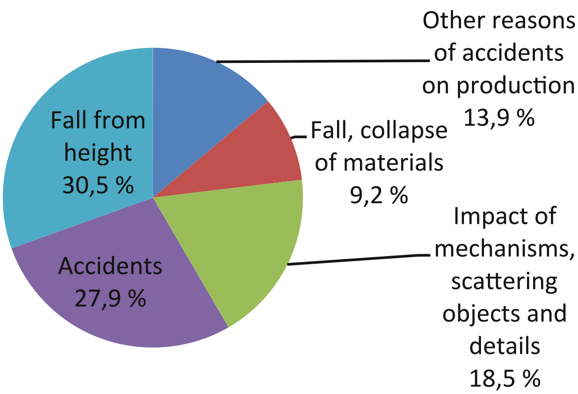

Fig. 1. Causes of accidents on production

2 For Professional Risk Management the Assessment Methods are Required

There was used a methodology based on a systematic approach to technology assessment of health risk from occupational exposure. To this end, are study: risk framework, risk, prognosis, likelihood of disease, the categorization of risk [6, p. 700]. There are used a common criteria: hygienic classes of conditions; biomedical; DWTD (Diseases with temporary disability); production due to morbidity (Table 1). The methodology is developed based on years of research and studying adverse effects of worker's health caused by exposure to harmful and dangerous factors of production environment. During the development of guidelines is also used experience of the Finnish Institute of occupational health in the qualitative assessment and management of occupational risks in the workplace (recommended ILO) and department experience of epidemiological studies on quantifying occupational hazards in the workplace [9, 10].

Table 1. Criteria for occupational exposure in health

Index	Level of professional risk					
	Minimum	Low	Medium	Above average	High	Super-high
Class of working conditions	2	3.1	3.2	3.3	3.4	4
The index of occupational morbidity	<0.05	0.05–0.1	0.12–0.24	0.25–0.5	0.51–1.0	>1,0
Morbidity		<1.5	1.6–5.0	5.1–15.0	15.1–50	>50
DWTD-cases	66.4–72.3	72.4–84.6	84.7–90.7	90.8–96.8	96.9–102.9	>102.9
DWTD-days	867–938	939–1081	1082–1153	1154–1225	1226–1281	>1281

Results of research. It is established that the index of occupational diseases is an inverse value of the product risk categories (RC) and the category of gravity (CT) occupational diseases:

$$\text{IOD} = 1/(\text{RC} \times \text{CG}),\ \text{where the OD - occupational diseases.}$$

To predict the probability of developing diseases the following three indicators of risk are used:

- odds ratio, i.e. the ratio probability (OR):

$$\text{OR} = \text{ad}/\text{bc};$$

- relative risk, i.e. the ratio of the frequencies of the disease (RR):

$$\text{RR} = \text{af}/\text{ce};$$

- etiological fraction, i.e. proportional to the risk brought (EF):

$$\text{EF} = (\text{RR} - 1)/\text{RR}.$$

For the calculation of these indicators the notation system based on contingency tables is used (Table 2).

Table 2. Generalized notation system of table with four fields

Index	Level of professional risk					
	Minimum	Low	Medium	Above average	High	Super-high
Class of working conditions	2	3.1	3.2	3.3	3.4	4
The index of occupational morbidity	<0.05	0.05–0.1	0.12–0.24	0.25–0.5	0.51–1.0	>1.0
Morbidity		<1,5	1.6–5.0	5.1–15.0	15.1–50	>50
DWTD-cases	66.4–72.3	72.4–84.6	84.7–90.7	90.8–96.8	96.9–102.9	>102.9
DWTD-days	867–938	939–1081	1082–1153	1154–1225	1226–1281	>1281

The object of the study was typical for this industry engine-building association in one of the Russian cities. Surveyed employees were divided into 3 groups. Group I included 68 (36 males and 32 females) fitters and washing machine machinists of section engine assembly machines, contacting with gasoline, acetone, benzene, exposed to occupational noise, which do not exceed the MPC and MPL. Group II was amounted to 68 (44 males and 24 females) mechanical works locksmiths motors assembly section testers. Group III (control) was included 68 (14 males and 54 females engineering and technical workers (ETW): heads of sections, technologists, economists, engineers, without the influence of unfavorable factors of production. The average index of occupational diseases was equal to 0.96, which corresponds to a high level of professional risk (Table 1). Occupational diseases accounted for 5.5 per 10,000 employees, which corresponds to the professional level of risk is above average (Table 1).

Incidence per 100 employees across all diseases is equal to 54.1 cases of disability and disability 1123.9 days, which corresponds to the average level of professional risk (Table 1). Combining health data surveyed groups, we can say that the groups I and II of the staff have a professional level of risk is above average, although the working conditions of all groups surveyed employees considered acceptable. This once again confirms the requirement of professional risk assessment on integral indices and indicators of health.

Diseases of different organs and systems identified in 88,2 ± 3,2% of the patients, while among employees of groups I and II statistically significantly more often than in group III (ETW) (Table 5). The majority of staff (78,9 ± 2,9%) had pathology in two or more organs or systems. The greatest number of healthy employees was found in the group III (ETW) without the influence of unfavorable factors of production, which is characteristic for members of groups I and II (Tables 3 and 4).

Table 3. Analysis of occupational risk for fitters (group I)

Index	Level of professional risk					
	Minimum	Low	Medium	Above average	High	Super-high
Class of working conditions	2	3,1	3,2	3,3	3,4	4
The index of occupational morbidity	<0,05	0,05–0,1	0,12–0,24	0,25–0,5	0,51–1,0	>1,0
Morbidity		<1,5	1,6–5,0	5,1–15,0	15,1–50	>50
DWTD-cases	66,4–72,3	72,4–84,6	84,7–90,7	90,8–96,8	96,9–102,9	>102,9
DWTD-days	867–938	939–1081	1082–1153	1154–1225	1226–1281	>1281

Table 4. Analysis of occupational risk for fitters (group II)

Production factor	Category of risk, C_r	Category of gravity (C_g)	The index of occupational diseases, I_{od}
Local vibration	1	2	0,5
Noise	2	3	0,17
Abrasive aerosol	2	2	0,25
All the factors	–	–	0,92

Nosological profile of the identified diseases are shown in Table 6. The first place in the structure of the identified diseases are of the circulatory system, the nervous system and diseases of locomotor apparatus.

Table 5. The state of health of workers by major groups (% of total surveyed) (M ± m)

Production factor	Category of risk, C_r	Category of gravity, (C_g)	The index of occupational diseases, I_{od}
Local vibration	1	2	0,5
Noise	2	3	0,17
Abrasive aerosol	2	2	0,25
All the factors	–	–	0,92

Table 6. Nosological profile diseases in workers surveyed groups (in % to the total number surveyed) (M ± m)

Production factor	Category of risk, C_r	Category of gravity, (C_g)	The index of occupational diseases, I_{od}
Local vibration	1	2	0,5
Noise	2	3	0,17
Abrasive aerosol	2	2	0,25
All the factors	–	–	0,92

3 Discussion and Conclusions

The relative risk for developing hypertension in the group I is in 2.1 times more than the in the control and immediate risk is amounted to 28 new cases per 100 employees. The etiological share of group I is 52%, which is indicating about a high degree of professional conditionality. In the second place were diseases of the nervous system, muscle and connective tissue. The relative risk of polyneuropathy in group I is above 14 times compared to the control group in the group II - in 11.5 times. Special interest is a hearing loss, which is more common in groups I and II. Coefficient disease probability in the group I was 9.3 in the group II - 11,9. The probability of sensorineural hearing loss was increased 7.3-fold in group I and 8.7 times in the group II compared with the control group. The etiological share was 87% in group I and 89% in Group II of, almost complete professional degree of conditionality, is a professional nature of the disease.

Analysis of the situation shows that the underlying causes of the workers disease are: violation of the requirements and regulations, lack of preventive inspections; lack of remedies or fault condition. The great importance is the human factor, which determines the unwillingness to comply with sanitary regulation employee, and sometimes unwillingness to know them and remember, much less perform [5]. Also it should be noted that the use of equipment for personal use, non-compliance with the labor protection requirements leads to the ingress of harmful substances in the body and the body human. The great importance is the control of the administration of the implementation requirements and rules in the workplace. Failure analysis of the system shows that serviceability of ventilation systems, machine tools, pumps, pipelines, their wear, breakage and the like are very important, determines the penetration of harmful substances into the working zone as aerosols, drops, spills, etc. [4].

4 Conclusion

Using the methodology of risk assessment, it is possible to determine the safe working period under the influence of adverse factors of industrial environment. These data predict the incidence of diseases of the circulatory system, to assess the effectiveness of measures to improve working conditions and the quality of the clinical examination, planning volumes and priority treatment and preventive care. Monitoring occupational exposure is a prerequisite for risk management and assessment its effectiveness [3]. The results of these studies show the need for continued cooperation with the Social Insurance Fund against accidents and occupational diseases in terms of the overall analysis of the results activities, development of preventive measures and risk management, joint conducting ongoing actuarial calculations for the respective industries.

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Application of Cosinor Analysis for Modeling Time Series of Traffic Accidents

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Abstract. In connection with a variety of road conditions and traffic characteristics in each particular locality, a more general approach to evaluation of influence of external factors on road safety is required. Therefore, development of a mathematical model based on a time series of road traffic accidents is of great importance for determining the influencing factors. Using the example of the road traffic in Yakutsk, mathematical modeling of the time series of road crashes was performed using a technique of sequential application of cosinor analysis. Their rhythmic structure has been revealed and the factors influencing the road safety have been identified.

Keywords: Road traffic accident · Road safety · Cosinor analysis · Mathematical modeling

1 Introduction

When designing the roads, their operation and traffic management, consideration must be given to the numerous factors specific to the particular locality and affecting the road safety. It is necessary to take into account changes in traffic intensity by seasons, weekdays and time of day, the seasonal changes in the road conditions, natural and climatic factors [1]. The Far North is characterized by the variety of extreme climatic impacts on a human body and environment. The natural and climatic factors of a permafrost territory have the impact on operational properties of the roads, the road conditions and psychophysiological states of people. When there are violations of the psychophysiological states of road users, their attentiveness decreases, coordination of movements worsens, the response time to a signal increases, and speeds of mental processes change, including those that control decision-making in dangerous road situations. It has been established [2] that the days with an increased number of the road accidents in Yakutsk are associated with the sharp changes in air temperatures and atmospheric pressure, perturbations of Earth's magnetic field and unfavorable combinations of these factors.

To study the road safety, statistical information of the traffic police of Yakutsk about the road accidents was entered into a database "Road Accidents". In this paper, analysis of the road crashes in 2014–2015 has been performed. In 2014, there were 492 accidents with victims, and in 2015 – 481.The analysis of these accidents showed that the largest number of the road crashes had occurred for the following reasons: failures

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to comply with road rules at an intersection – 187 (19.2%), the violations of the traffic rules at a crosswalk – 131 (13.5%), pedestrian crossings of a carriageway outside the crosswalk – 113 (11.6%), drivers lost control – 75 (9.5%), wrong-way driving – 62 (6.4%), the drunk driving – 54 cases (5.5%). Despite the harsh climatic conditions, no road accidents occurred in Yakutsk during this period due to a technical malfunction of vehicles.

In order to reveal hidden periodicities, the statistical information about the road accidents is distributed over time intervals, such as months. A diagram of the time series of the road crashes is shown in Fig. 1.

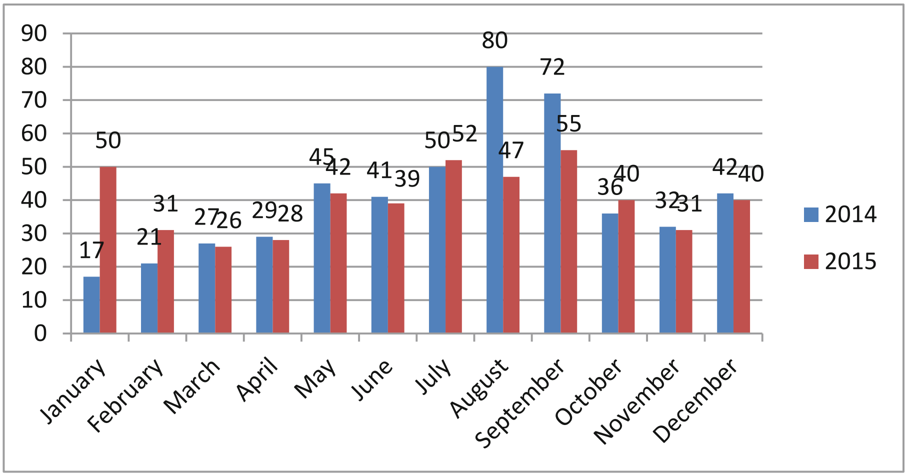

Fig. 1. Diagram of time series of road accidents in Yakutsk by months of year.

Someone can see repeatability of the accident time series in 2014 and 2015 in the diagram. On average for the two years, the highest number of the traffic accidents happened in August and September, and the lowest ones in February and March. The largest differences between the monthly numbers of the road crushes in 2014 and 2015 are observed in January (the difference between the accident numbers was 33), August (33), September (17) and February (10). In the remaining eight months, deviations of the traffic accident numbers in the different years did not exceed 4. Taking into account the significant differences between the numbers of the road accidents in January and August, it can be assumed that there were some random factors in January 2015 and August 2014. Thus, it can be concluded that there is the annual periodicity in distributions of the traffic accidents by month, i.e. road accident dynamics in Yakutsk are influenced by the seasonal factors.

2 Research Methods

Due to complexity of a road traffic system and variety of the influencing factors and their combinations, the systems approach to a road safety estimate is needed. One of the most important procedures of the systems analysis of technical objects is creation of the mathematical model that characterizes the investigated object taking into account the specific operation conditions. The research of the mathematical model of the road accident dynamics will allow one to define regularities of the distributions of the road accidents in the time. For the analysis, the time series of the road crashes are created on the basis of statistical data on the traffic accidents that occurred in the traffic conditions of the specific locality. Terms of the time series represent the total number of the road crashes in the given time interval (the week, the month and year) and form a chronological sequence of random values. The obtained time series of the accidents have a periodic component, so for the development of the mathematical model we use the technique of the sequential application of the cosinor analysis with a linear trend, proposed in [3]. The application of the cosinor analysis in the various fields of knowledge was developed in [4]. When implementing the technique at a first stage, the time series of the road accidents $(U_1, U_2, \ldots, U_n)$ of length n is approximated by a continuous function $U_1(t)$, consisting of one harmonic and linear trend:

$$U_1(t) = A_1 \cos(\omega_1 t - \phi_1) + h_1 + p_1 t, \tag{1}$$

where t is the time in months; ω_1 is an angular frequency, A_1 is an amplitude, φ_1 is an initial phase, h_1 is an average level of the harmonic of the studied process and p_1 is a trend coefficient. Here, the trend shows an increase of the road crash number, depending on the time: $h(t) = h_1 + p_1 t$, where $h(t)$ is the level of the harmonic at the time t. When calculating parameters of the function $U_1(t)$, it is necessary to give in advance the period T_1, the value of which determines the angular frequency of the harmonic: $\omega_1 = \frac{2\pi}{T_1}$. The other parameters are determined by the method of least squares: $I = \sum_{i=1}^{n} \{U_1(t_1) - U_i\}^2 = \min$. From the system of four algebraic equations the values of unknowns x_1, y_1, h_1, p_1 are found. The amplitude A_1 and acrophase φ_1 of the first harmonic are calculated from the obtained values of x_1 and y_1:

$$A_1 = \sqrt{x_1^2 + y_1^2},$$
$$\phi_1 = \begin{cases} arctg\left(\frac{y_1}{x_1}\right), & \text{if } x_1 \geq 0 \\ arctg\left(\frac{y_1}{x_1} + \pi\right), & \text{if } x_1 < 0 \end{cases} \tag{2}$$

After finding the confidence interval δ_1 for the amplitude A_1, the following periodicity criterion is used: if $\delta_1 < A_1$, then the periodicity exists at the corresponding frequency ω_1; if $\delta_1 > A_1$, then there is no periodicity at this frequency and calculations are repeated, giving another period. The period T_1 satisfying the periodicity criterion defines the function $U_1(t)$. The next recommendations should be followed in selecting this period. The value of T_1 must be greater than or equal to the time series length n. It is reasonable to calculate the determination coefficient R^2: the greater the value of this coefficient, the more appropriate is the corresponding value of the period T_1. This coefficient shows a degree, to which the model matches the original data. To determine the next periodic component of the time series of the road accidents, we subtract the corresponding values of the approximating function $U_1(t)$ at the times $t_i\,(i = 1, 2, \ldots, n)$ from the values of the original time series.

At the second stage, the obtained time series of residuals will be approximated by the function of form (1), selecting the period T_2 (satisfying the periodicity criterion), which is smaller in the value than the first period T_1. For the value of the angular frequency corresponding to the period T_2, we calculate the average level h_2, the trend coefficient p_2, the coefficients x_1 and y_1, then the amplitude A_2 and acrophase φ_2, according to above formulas. Thus, we get the function $U_2(t)$, which approximates the time series of residuals. This allows us to determine the additive function $U_S(t) = U_1(t) + U_2(t)$, approximating the initial time series of the road accidents. For this additive function, the determination coefficient R^2 is calculated.

To calculate the next periodic function of form (1), we find the differences between the terms of initial time series and values of the additive function in the approximation nodes and repeat an algorithm of the second stage of the calculations. The recurrent calculations are repeated until the maximum possible value of the determination coefficient R^2 for the additive function is reached, when the hidden periodicities of the original time series are exhausted (i.e. the calculation process stops, when the determination coefficient R^2 decreases). The additive function $U_S(t)$ is obtained by adding to this function defined at the previous stage of the calculations the function of form (1) found at the current stage.

As a result of the recurrent calculations, we obtain the mathematical model of the time series of the experimental data as a superposition of the functions of form (1), reflecting the influence of the different destructive factors:

$$\begin{aligned} U_1(t_1) \ &= A_1 \cos(\omega_1 t - \phi_1) + h_1 + p_1 t + A_2 \cos(\omega_2 t - \phi_2) + h_2 + p_2 t + \ldots \\ &\quad + A_m \cos(\omega_m t - \phi_m) + h_m + p_m t. \end{aligned} \tag{3}$$

Implementation of the described technique of the application of the cosinor analysis in the form of a program in mathematical software MathCad makes it possible to study the rhythmological structure of the time series under consideration.

3 Data and Discussion

We will make the calculation of the mathematical model according to the above technique for the time series of the road accidents in Yakutsk for 2014 and 2015. We will set in advance the period T_1 (in months) equal to the length of the investigated time series n = 24. The angular frequency (in radians) of the first harmonic is calculated according to the formula: $\omega_1 = \frac{2\pi}{T_1} = \frac{2\pi}{24} = 0.262$. Using the method of least squares, we obtain the system of four algebraic equations and calculate the values of the unknowns $x_1 = -7.043$; $y_1 = 14.169$; $h_1 = 21.319$ and $p_1 = 1.538$. The amplitude of the first harmonic $A_1 = 15.823$ and acrophase $\varphi_1 = 2.032$ are determined from the values of the coefficients x_1 and y_1. After finding the amplitude confidence interval $\delta_1 = 8.582$ and checking it by the periodicity criterion ($\delta_1 = 8.582 < A_1 = 15.823$), we obtain the approximating function $U_1(t) = 15.823\ cos(0.262t - 2.032) + 21.319 + 1.538t$ and calculate the determination coefficient $R^2 = 0.296$. A chronogram of the traffic accidents for 24 months and graph of the function $U_1(t)$ are presented in Fig. 2.

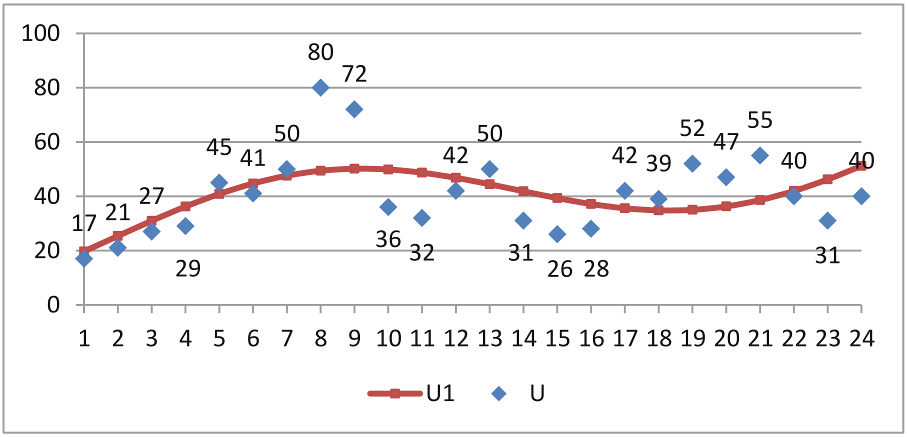

Fig. 2. Chronogram of road accidents for 24 months and graph of function $U_1(t)$.

It should be noted that the similar calculations with the periods exceeding 24 months give the slightly larger value of the determination coefficient at the initial stage, but later lead to a decrease in its value for the final mathematical model of the time series of the road accidents. To proceed to the second stage of the calculations, the time series of residuals is compiled by subtracting from the terms of the initial time series the values of the approximating function $U_1(t)$ in the corresponding nodes. To approximate the obtained series by the function of form (1), the value of the period T_2 satisfying the periodicity criterion is selected. As the result, the period of 12 months was chosen, which is consistent with the preliminary considerations of presence of the annual repeatability of the road crashes. The time series of residuals after the first approximation and graph of the approximating function ($U_2(t) = 11.565\ cos(0.524t - 3.983) + 3.192 - 0.255t$) are presented in Fig. 3. The additive function is defined as a sum of the approximating functions: $U_{S1}(t) = U_1(t) + U_2(t)$. Its graph is shown in Fig. 4, and the determination coefficient R^2 is equal to 0.601.

The function $U_2(t)$ has maximums of the road accident number in August and minimums in February, which corresponds to the time series regularities of the traffic accidents in Yakutsk observed for the many years. Thus, the function $U_2(t)$ is the seasonal component of the time series of the road accidents and expresses the influence of the seasonal changes in the traffic intensity.

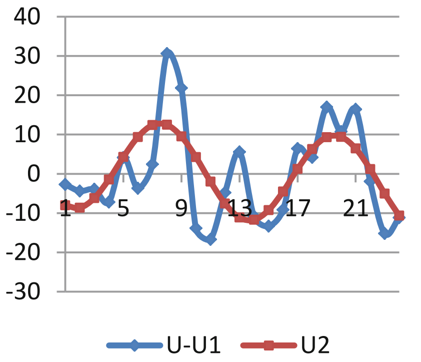

Fig. 3. Time series of residuals after first approximation and graph of function $U_2(t)$.

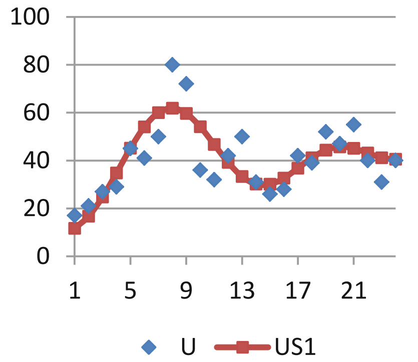

Fig. 4. Chronogram of road accidents for 24 months and graph of additive function $U_{S1}(t)$ after second approximation.

Similarly, we obtain the time series of residues after the second approximation by calculating the differences in the nodes $i\,(i = 1, 2, \ldots, n)$: $U_i - U_{S1}(t_i)$. The function $(U_3(t) = 7.658\ cos(1.047t - 1.924) - 1.969 + 0.157t)$ approximating this time series has the period of 6 months. The determination coefficient of the additive function $U_{S2}(t) = U_1(t) + U_2(t) + U_3(t)$ is 0.735. The graphs for this stage are shown in Figs. 5 and 6.

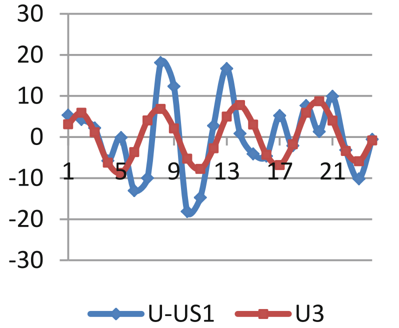

Fig. 5. Time series of residuals after second approximation and graph of function $U_3(t)$.

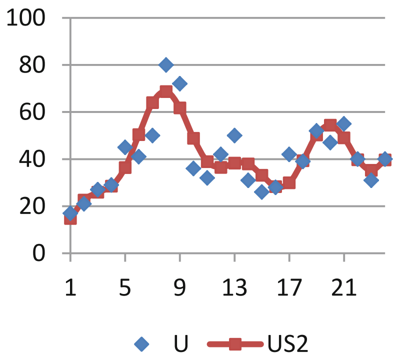

Fig. 6. Chronogram of road accidents for 24 months and graph of additive function $U_{S2}(t)$ after third approximation.

The function $U_3(t)$ with the period of 6 months has the maximums in February and August and minimums in May and November. This harmonic is most likely associated with the significant changes in the road conditions. The road conditions include the climatic factors, the carriageway states and visibility. The difficult road conditions in Yakutsk are typical for February. If at the beginning of February, as the rule, frosty weather with the fogs is observed, then at the end of the month slipperiness increases on the roads. This is due to the fact that under an effect of the pressure on crystals of ice its melting point increases [5], therefore, during warming of the weather a liquid-like (transition) layer on a surface of the ice or compacted snow appears under the pressure from wheels, which immediately freezes. This leads to the increase in the road slipperiness. In August, the road traffic intensity increases significantly due to mass returns of citizens from summer vacations, preparations for the school year and visits of rural residents to Yakutsk for sales of seasonal agricultural products and purchases of goods for schoolchildren. The minimum of the function $U_3(t)$ in May is associated with seasonal improvement in the road conditions, since in April glaze and black ice are observed on the roads, as well as puddles of atmospheric precipitation and melt water. The minimum of this harmonic in November can be explained by the fact that the frosty weather is established, and the road conditions are stabilized: there is the decrease in the winter slipperiness on the road surface due to an appearance of the layer of the compacted snow on the ice deposits that arose on the road surface during the formation of the glaze and black ice in October.

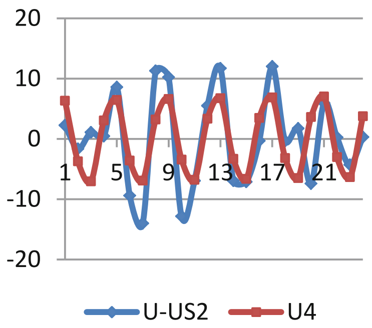

Fig. 7. Time series of residuals after third approximation and graph of function $U_4(t)$.

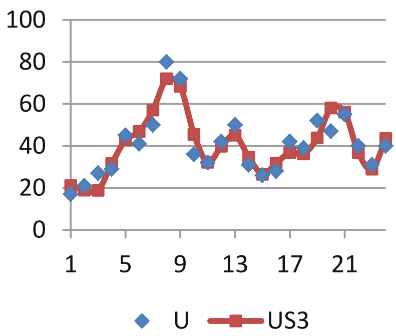

Fig. 8. Chronogram of road accidents for 24 months and graph of additive function $U_S(t)$ after fourth approximation.

The next harmonic function of the time series of the road crashes has the period of 4 months. The determination coefficient of the additive function $U_{S3}(t) = U_1(t) + U_2(t) + U_3(t) + U_4(t)$ is 0.869. The graphs obtained at this calculation stage are shown in Figs. 7 and 8. At this stage, the hidden periodicities of the time series of the traffic accident are exhausted.

The function $U_4(t)$ with the period of 4 months has the maximums in January, May and September and minimums in March, July and November. The second harmonic of the time series of national holidays of Russia in 2014 and 2015, obtained by this technique with the use of the cosinor analysis has the same period of 4 months and extremes in the same months. The longest national holidays in Russia are in January and May, and in September there are no official holidays. The minimums of the function $U_4(t)$ take place in the months with the one-day national holidays (8 March – International women's day, 4 November – National Unity Day), and in July there are no national holidays. Thus, it can be assumed that there is a statistical relationship between the systematic component of the time series of road accidents with the period of 4 months and distribution of the national holidays in the year.

The final mathematical model of the time series of the traffic accidents in Yakutsk is the additive function $U_S(t) = U_1(t) + U_2(t) + U_3(t) + U_4(t)$ containing four harmonics and trend equations. Some characteristics of the approximating functions are given in Table 1.

Table 1. Main characteristics of approximating functions.

Function	Period T, months	Amplitude A	Trend coefficient p	Month with maximum	Month with minimum
U_1	24	15.823	1.538	September	July
U_2	12	11.565	−0.255	August	February
U_3	6	7.658	0.157	February, August	May, November
U_4	4	7.517	0.035	January, May, September	March, July, November

After simplification we get the resulting equation of the trend $y = 1.475t + 22.103$. The positive value of the coefficient of the trend equation allows on the basis of the road accident data in 2014 and 2015 someone to conclude that there has been the trend towards the increase in the road crash number, most likely associated with growth of motorization in Yakutsk and appearance of the novice drivers on the roads.

4 Conclusion

The technique of the consistent application of the cosinor analysis allows one to evaluate rhythmology of the changes in the number of the road accidents by the time and to detect the hidden periodicities and trends. The constructed dynamic model of the time series of the road accidents in Yakutsk for 2014–2015 contains the several harmonic components and linear trend equation. The main harmonic with the period of 24 months allows somebody to better approximate the time series by the additive function, but its period does not affect the other harmonics. The harmonics with the periods of 12 and 6 months reflect the influence of the seasonal changes in the traffic intensity and conditions on the roads of Yakutsk. The harmonic with the period of 4 months correlates with the distribution of the national holidays of Russia in 2014 and 2015. Thus, it is possible to conclude that the dynamics of the road accidents in Yakutsk are due to the effect of the periodically changing external factors.

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Economic Optimization and Evolutionary Programming When Using Remote Sensing Data

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Abstract. The article considers the issues of optimizing the use of remote sensing data. The following method can be used for the methods of the evaluation of remote sensing approaches. Remote sensing approaches are used in many applications for example for solutions of the complicated problems of transport management and construction of new transport arteries. A mathematical model to describe the economic effect of the use of remote sensing data is built. Here is also given a numerical method of solving this problem. Also discusses how to optimize organizational structure by using genetic algorithm based on remote sensing. The methods considered allow the use of remote sensing data in an optimal way. The proposed mathematical model allows various generalizations for optimization of decision making in the presence of remote sensing data. The approach associated with evolutionary programming is an effective solution when optimizing economic structures in the presence of remote sensing data.

Keywords: Transportation management system (TMS) · Remote sensing · Economical optimization · Earth monitoring

1 Introduction

When using remote sensing data of the Earth there are various the problem of economic optimization of the use of these data [1] what can be used in the economic research of remote system efficiency. Remote sensing approaches are used in many applications for example for solutions of the complicated transport management problems and construction of new transport arteries. This is especially important for Russia including Siberia with its long spaces and distances. This problem has various causes [2]. First, the use of satellite imagery and thematic processing can be economically costly. In addition, in this case, we find that the economic effect has a certain damping, since the information derived from satellite imagery is quickly becoming obsolete. Second, the use of satellite images in monitoring of projects may lead to structural changes in economic planning. In this case, there occurs a problem of evolutionary programming to assess structural changes when using the data of space images. The close topic is discussed in [3, 4].

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In the present work we consider two economic goals: optimizing the use of satellite images during the implementation of projects and the method of evolutionary programming to optimize economic structures. The research is based on works [5–8].

2 Optimization of Economic Efficiency

We consider a mathematical model of space imagery on the enterprise. The purpose of this model is the calculation of the optimal use of satellite images in such a way as to maintain a predetermined level of effectiveness in the use of space services.

We will consider some venture P. The management of these enterprises is to use space images. The aim of business management is a generalized indicator of efficiency of enterprise activity. Under performance, you can understand the different indicators, for example: profit; the level of innovativeness; competitiveness and etc.

We introduce the corresponding notation. We will consider a mathematical model with continuous time, which we will denote by t.

The distribution of the use of space services, we will describe the function u(t), while we assume that this function is a linear combination of generalized functions, because of its economic sense – the intensity of the use of space services is the impulse function.

Performance indicator we will denote by I(t). On the economic meaning of the function u(t) and I(t) are nonnegative. To specify the relationship of the functions u(t) and I(t) must enter the transfer function K(t), which will show the result of the contribution to the impact function I(t) under the pulsed action of the function u at time t = 0. Using the transfer function, the relationship between the function of the use of space services and performance possible to record in the form of integral equations

$$I(t) = \int_0^t K(t-s)u(s)ds \tag{1}$$

The transfer function has the following properties

1. $K(t) \geq 0$
2. $K(t) = 0,\ t \leq 0$
3. $K(t) \to 0,\ t \to \infty$

The first property shows that the impact of the use of space services for the performance cannot be negative. Of course, in some real situations, this property can be violated, but in our model, we believe that this influence cannot be negative. The second property shows that the past does not depend on the future. This is a natural condition that the use of satellite images only affects the future but not the past. The third property reflects the fact that the effectiveness of the use of space images has a finite duration of the performance, and over time their influence is eroding.

Equation (1) is a linear integral equation of the first kind.

3 The Optimization Problem

As we have noted, in economic situations, we must consider not a continuous function of space services, and pulse function. We will consider the use of space snapshots at specific points in time

$$0 < t1 < t2 < \ldots < tN$$

In each of the moments tk the level of use of satellite services will be denoted using uk. Using the formalism of δ-functions, the impulse function of the use of space services can be written as follows.

$$u(t) = \sum_{k=1}^{N} u_k \delta(t - t_k)$$

Substituting this function in integral Eq. (1), we get the following equation.

$$I(t) = \sum\nolimits_{k=1}^{N} K(t - t_k) u_k \tag{2}$$

Suppose we have a desired level of performance of our company, which is expressed as a function J(t). Then the problem reduces to finding such values

$$u * 1, u * 2, \ldots, u * N$$

After the substitution these values in Eq. (2), we get the identity

$$\mathrm{J(t)} = \sum_{\mathrm{k}=1}^{\mathrm{N}} \mathrm{K(t - t_k) u_k^*}$$

From a mathematical point of view this problem is incorrect because it does not have an exact solution, may not be the only solution, and it can be unstable with respect to perturbations.

4 The Method of Calculating an Optimal Plan for Use of Space Services

We introduce the next values

$$u1,\ u2, \ldots, uN$$

These values we call the plan of use of space services. To optimize the plan that we are thus to minimize the following value

$$D(t, u_1, \ldots, u_N) = \int_0^T |I(t) - J(t, u_1, \ldots, u_N)|^2 dt \rightarrow \min$$

Thus, we have a problem of minimizing functions of N variables.

As we have already noted, this task is incorrect, therefore, for numerical calculations it is necessary to use regularization by Tikhonov. To do this, we modify the original problem by adding to D a new function with a small parameter

$$D(t, u_1, \ldots, u_N) + \alpha\Omega(u_1, \ldots, u_N) \rightarrow \min$$

Here $\alpha > 0$ is a small parameter, and the function Ω is called a stabilizer, which is calculated by the following formula

$$\Omega(u_1, \ldots, u_N) = \sum_{k=1}^{N} u_k^2$$

The use of the stabilizer allows to regularize the original problem.

For the numerical determination of the optimal plan is to use the method of swarming particles, which is effective for multidimensional optimization for no smooth functions. Consider a model example of optimizing the use of space services. We will consider funding for N = 10. We consider the situation where we need to ensure the performance of dimensionless quantities.

$$I(t) = 10$$

As of the transition function consider the following function.

$$K(t) = \frac{t}{1 + t^2}$$

It is easy to see that this function satisfies the necessary conditions. In addition, it can be shown that this function reflects the economic effect of the use of space services.

We give the results obtained. Optimal use of space services is shown in Fig. 1.

Accordingly, the graph of performance is shown in Fig. 2.

You can see that the proposed plan for the use of space services leads the performance to the desired values, and then supports the desired mode of performance.

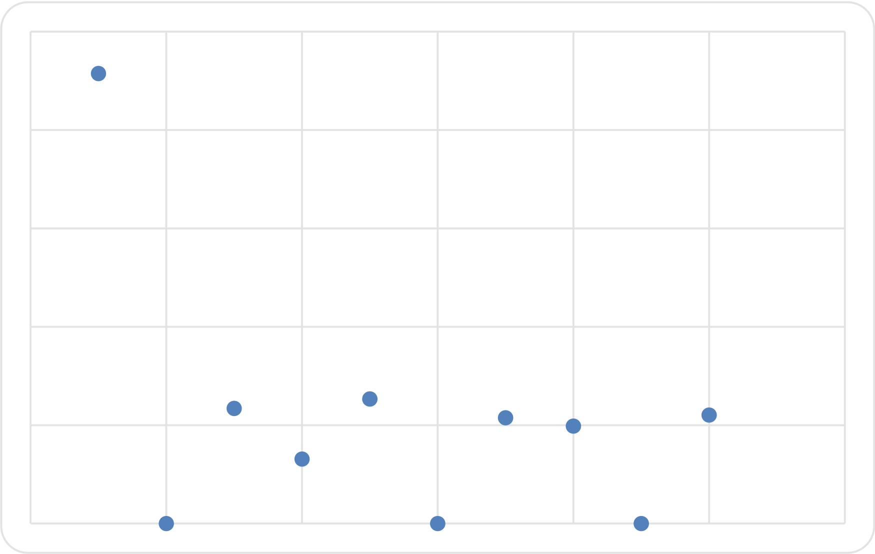

Fig. 1. The optimal plan.

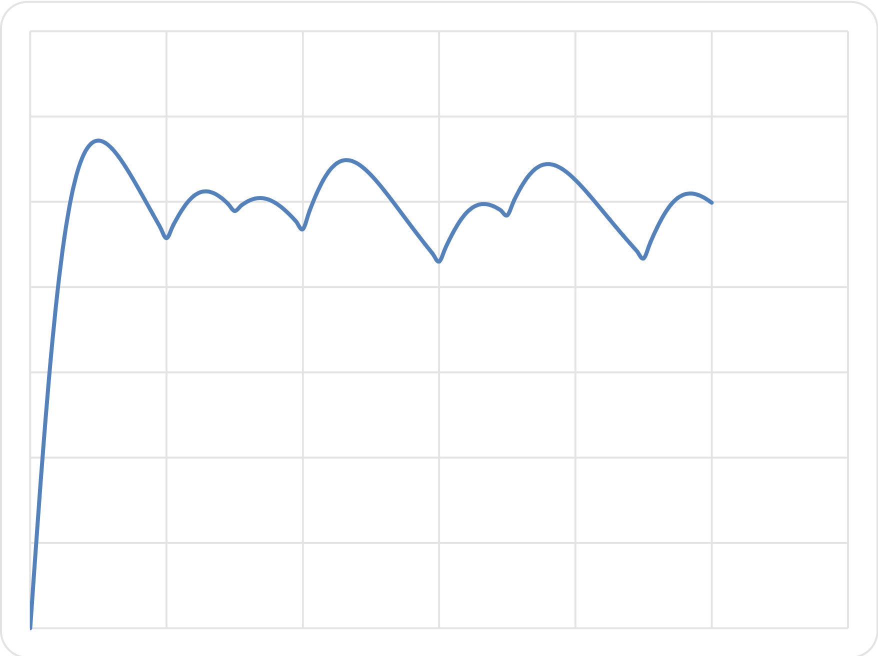

Fig. 2. The performance.

5 The Use of the Evolutionary Method in the Task of Using Space Services

Consider the task of optimizing the structure of enterprise on the basis of the results of the use of space services. This problem can be solved by using evolutionary methods. Let the considered enterprise has a complex structure, which was considered as a directed graph

$$G = <V, E>$$

where V is the vertex set of the graph and E is the directed arcs. In the vertexes there may be structural unit of the enterprise, and arcs of the graph Express the subordination of these structural units in the organization.

A fundamental point for the use of economic-mathematical models of optimization is determining the objective function. We consider the following objective function.

$$H = H(G, \xi)$$

The function H accepts numeric values which make sense of economic efficiency of the enterprise. Units of measure this efficiency are irrelevant, because the evolutionary optimization methods do not depend on the actual values of the optimized functions.

Here as the vector ξ, we consider the random parameters that affect efficiency.

We introduced a function depends essentially on the own structure of the organization, i.e., from the selected graph G.

The scheme of using the evolutionary method is the application of genetic algorithms to optimize functions of H. In this case, we vary the graph G. This graph is the structure of your organization. As an elementary change of the graph we will consider the following operations on directed graphs:

- adding vertices;
- delete vertices;
- adding arcs;
- deletion of arcs.

These operations we will consider as basic changes of the graph. These changes are application to an existing structure (the graph G) one of these operations.

When used in practice, evolutionary methods of optimization of structure of the enterprise, questions arise regarding the calculation function of efficiency relative to the proposed structure (the graph G). To resolve this issue, you can use two fundamental methods

- simulation;
- practical application of the changes.

Simulation is a classical way of evaluating the effectiveness of the organization. An important advantage of this method is the fact that we can carry out this estimate "on the computer" without the involvement of material resources and risks. However, this approach is limited by the quality of the simulation, since many factors influence of organizational structure on efficiency are not continuous parameters, i.e. for a slight change in the structure, the efficiency can change dramatically. Thus, the construction of an adequate simulation model is difficult.

Another approach is more radical because it implies that the changes in the company structure implemented, and then it turns out the change (improvement or worsening) performance of the enterprise. Of course, this approach can be implemented is not always, therefore, requires a certain amount of moderation when you change the structure of the enterprise. At the same time, it should be noted that to calculate the real values of the function H may require lots of time.

Recently, more and more are becoming the methods of artificial intelligence in problems of Economics and management. The use of deep machine learning in conjunction with the construction of expert systems and knowledge bases will allow us to find more accurate methods of evaluating the effectiveness of the structure of the enterprise.

6 Conclusion

The paper presents an original mathematical model for performance evaluation of space imagery data application for enterprises. With this extreme model is formulated an optimization problem to describe the optimal scheme of using satellite images for maintaining a given level of productivity of the enterprise.

Considered a model of optimization of structure of the enterprise based on data derived from remote sensing. This model is based on evolutionary programming. This model can be used for the planning of different enterprises, including transport area (building and maintaining the networks). Its implementation and verification can play a significant role in the dispersion of remote sensing approaches in the industry. The model can be used for the development of the method of the commercial efficiency evaluation of IT-applications for the space imagery data delivery. Nevertheless, its wide use will create the demand for more specific and quick computational methods.

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Development of the General Structure of the Knowledge Base for Neuro-Fuzzy Models

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Abstract. A key feature of the transition to a post-industrial and digital economy is the transition to "knowledge production". This process leads to an avalanche-like increase in the amount of data and complication of algorithms for their processing. Thus, the task of analyzing a large array of poorly structured economic information, identifying trends and anomalies and their subject interpretation is extremely important in many areas of the modern economy. To solve this class of problems, it is advisable to use the methods of machine learning and "soft computing", which together with the development of specialized expert systems and the use of heuristic algorithms will help to automate the process of identifying and interpreting knowledge in a wide range of areas. The article discusses the development and software implementation of the knowledge base for an intelligent system. The object of the study is the process of storage and fixation of heuristic knowledge, the subject of the study is the concept and structure of storage of rules of output and processing of dynamic information. The paper describes the problems encountered in the development and implementation of artificial intelligent systems, considers the use of neuro-fuzzy models for the formation of such systems, considers the definition of MIVAR and presents a universal storage scheme for the knowledge base in a wide range of areas.

Keywords: Artificial intelligence · Knowledge base · Intelligent systems · MIVAR

1 Introduction

The emerging post-industrial economy has a fundamental impact on the dominant type of society and its needs, the basic resources, activities, the approach to R&D and the predominant form of knowledge. A key feature of the transition to a post-industrial and digital economy is the transition to "knowledge production". In [1] the following features of such transition are distinguished:

– Increasing the knowledge part in the cost of goods and services. For such goods and services as software development, analytics and consulting, the contribution of knowledge and skills becomes decisive; the activity on creation, storage and use of

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knowledge becomes more and more demanded, so the role of education systems changes. Investments in education are considered as investments in human capital;
– The speed of knowledge obsolescence increases significantly. By the time you receive a diploma of graduation, most of the applied knowledge of the professional cycle (especially in the field of innovative technologies) are not relevant. This leads to the need of continuing the learning process throughout the working life;
– In the structure of the population, the share of workers engaged in the production, storage, transportation and use of knowledge is increasing, and competition among them is increasing too. High qualification and the corresponding level of knowledge are becoming more and more popular. Skilled workers provide benefit by using their the knowledge and skills;
– Excessive specialization in production is reduced. There is a growing need for personalization. These trends place high demands on the level of professionalism of the workforce.

All these prerequisites lead to an avalanche-like increase in the amount of data and complication of algorithms for their processing.

Thus, the task of analyzing a large array of poorly structured economic information, identifying trends and anomalies and their subject interpretation is extremely important in many areas of the modern economy, for example, in the study of logistics, as well as indicators of financial markets, management and optimization of production volumes, consideration of energy saving and resource consumption in housing and communal services. To solve this class of problems, it is advisable to use the methods of machine learning and “soft computing”, which together with the development of specialized expert systems and the use of heuristic algorithms will help to automate the process of identifying and interpreting knowledge in a wide range of areas. In solving this problem, in many cases, there are difficulties associated with the complexity of the applied mathematical apparatus and the considerable complexity of the subsequent software implementation of the developed algorithmic software. Therefore, the development of automated knowledge management systems (KMS) find significant application of artificial intelligence methods. In this case, the structure of such systems, as a rule, includes a knowledge base that provides the implementation of the developed algorithms for the analysis and synthesis of rules and knowledge.

The article discusses the development and software implementation of the knowledge base for an intelligent system. The object of the study is the process of storage and fixation of heuristic knowledge, the subject of the study is the concept and structure of storage of rules of output and processing of dynamic information.

To achieve the research goal it is necessary to solve a number of tasks:

– to examine different approaches to the description of knowledge bases;
– to propose a conceptual model of a universal knowledge base for an expert intellectual system.

2 Materials and Methods

Since the mid-XX century, were developed a variety of studies of artificial intelligence systems (AI) usage. In the history of the AI-formation as a scientific direction there are periods of optimism and expectations, rapid progress and stagnation, reducing the importance of already conducted research, when the results begin to seem unconvincing and investment in research work is sharply reduced.

When developing and implementing artificial intelligent systems, researchers and developers faced many problems [2]. The main problem was the extraction of experts' knowledge, their formalization and arrangement in the form of a set of rules. Most often, experts intuitively make decisions based on their extensive experience.

Another important problem associated with the use of such systems is the discrepancy between the complexity of the real domain and the binary logic of computing systems, which determines the natural use of the Boolean logic rules – "if-then".

Other problems include the following:

1. Problem of big data analysis.

Since many economic processes are dynamic and irregular, it is necessary to record various indicators over a long period for their successful registration. Therefore, the logistics of goods production can reach thousands of different names. Each name can be delivered to tens and hundreds of different points of attraction, and broken down by weekly dynamic sales forecasts. The database size can be further increased if data is accumulated from multiple primary document channels. Given the high computational cost of information processing algorithms and its dynamic nature, such calculations become resource-intensive and time-consuming.

2. Problem of generalization.

Existing approaches tend to suffer from high sensitivity to noise and anomalies included in the source data, as well as unreliability in working with various non-formalized input channels. Specialized algorithms capable of dealing with incomplete or ambiguous input patterns and suppression of anomalous data should be developed. For example, [3] is devoted to the analysis of possible anomalies.

Based on the above, for solving the information processing problems is currently actively used methods of data mining, which offer greater accuracy in forecasts compared to traditional computational methods. Data mining technologies are designed to search large amounts of data for non-obvious, objective and useful patterns that reflect the objective internal structure of the data compared to the subjective opinion of the expert. The main purposes of application of intellectual methods are:

- analysis of signals characterized by a high degree of uncertainty, for example, "non-stochastic" type;
- increasing the level of information support of industry specialists;
- identification of hidden patterns and extraction of new knowledge from the accumulated data, which will build specialized knowledge management systems.

Currently, the most common [4, 5] methodology for data research is CRISP-DM (The Cross Industries Standard Process for Data Mining). According to this CRISP standard, data mining is a continuous process with many cycles and feedbacks.

Among a wide range of different techniques, the authors propose to build a system of economic data analysis based on the methodology of fuzzy neural networks [8, 9]. Fuzzy neural networks are hybrid models that combine the main advantages of neural networks (the possibility of adaptive learning) and fuzzy systems (the interpretability of the result obtained with their help). A fuzzy neural network is similar to a fuzzy inference system. Fuzzy inference system is able to make decisions only based on expert-generated knowledge base, while fuzzy neural network forms a system of rules as a result of training itself.

The advantage of such models is that it is a neural network implementation of fuzzy inference. On the one hand, the parameters of the membership functions act as weights and can be adjusted via network training. On the other hand, each layer of the network is a fuzzy inference phase, which makes the operation of the network transparent - it becomes easy to correlate the outputs of a particular layer with the corresponding fuzzy inference phase. Currently, such structures as the Takagi-Sugeno-Kan model (TSK) or the Mamdani model are distinguished as classifiers based on fuzzy inference with the possibility of adjusting the parameters of membership functions [6–8]. However, these models in the classical version use the full rule base, which limits their application for problems with a large number of input variables and terms.

Therefore, it is important to choose a flexible fuzzy-productive model of knowledge representation in the system. Practical application of neuro-fuzzy models in such systems requires the development of a scheme of their permanent storage. However, the work on this subject is mainly focused on the application of a class of neuro-fuzzy models to the solution of specific applications [9] or the synthesis of teaching methods of such models [10]. The developed software systems include databases of models or databases and knowledge, but the scheme and means of their storage are not disclosed, and calculations on models are implemented by the application.

3 Results

In this regard, the authors propose a flexible scheme of permanent storage of neuro-fuzzy models in the database. At the same time, the goals of the system that will work with the specified database may be different, for example, to use the constructed model for forecasting and managing technical, social and other systems.

The general requirements for the permanent storage scheme in modeling systems are ease of use and efficiency of calculations on the model. Ease of use implies minimal effort to integrate neuro-fuzzy models into application systems. Computational efficiency is mainly related to the performance of such systems.

In order for the system to be able to learn, its subsystem of accumulation and processing data must have the property of adaptability, changeability, i.e. in a sense - evolution. If we move to the terms of automated information processing systems, the database and knowledge base of intelligent systems should be adaptive, and in a broader sense - evolutionary.

The term “knowledge base” is not correct, because in fact there are stored only rules, procedures and similar relationships of objects. The term “rule” is well formalized, and its meaning, in General, is most consistent with what is commonly called “knowledge”. Therefore, it is further advisable to use instead of the term “knowledge base”, in the same sense, another term - “rule base”, and as a generalization of the terms “database” and “rule base” will use the generic term - “database and rules”.

The traditional relational model of data representation is focused on the modelling of such subject areas, which can be described in the form of changing data and fixed structure. However, real-world objects involve semi-structured and unstructured data models.

Evolutionary databases (with a variable structure) - is a qualitative transition to the creation of trainable systems that will be more consistent with the term “intelligent”.

Let’s consider the application of the mathematical structure of N. Bourbaki, on the basis of which it is possible to synthesize a class of different evolutionary models [11]. The structure is defined as:

$$S = <\mathbf{M}, \mathbf{R}> \tag{1}$$

where $M = \{a, b, c, \ldots\}$ is the base set, a R = {R1, R2, R3,...} set of unary, binary and other relations.

The specified structure is static, to take into account the time factor, the sets should be translated into functions. Then this mathematical system will be described by the following Eq. (2):

$$S(t) = <\mathbf{M}(\mathbf{t}), \mathbf{R}(\mathbf{t})> \tag{2}$$

where t is the current time.

However, it is more expedient to consider discretized systems on the time interval [t0, t1]. After the end of this interval, the structure parameters change abruptly.

The obtained information about the subject area is accumulated in some system of data and knowledge representation. According to [12] it is possible to introduce three fundamental concepts: object (entity); property (attribute, feature); relation (communication, cooperation).

These three selected concepts-categories are sufficient to provide any information about any subject area. Especially note that such concepts as, for example: element, object, system, function, structure, organization and the like are secondary, derived from the three main, and therefore can be expressed through them.

Then any rule (procedure, communication, interaction, knowledge, etc.), regardless of the form of its representation, is just a special case of the relationship, and, therefore, there is no need for a special allocation in the storage systems of “rules” and the formation of a discrete “knowledge base”, since all this can be described and presented in a single formalism based on a universal approach.

It is possible to construct a three-dimensional discrete information space: <object, property, relation>, i.e. formally: <O, P, R>. According to [12] the smallest addressable point of three-dimensional space is called “MIVAR” (Multidimensional Informational Variable Adaptive Reality). For example, MIVAR is some particular thing with some particular property, which is presented in a specific relation in a specific time and in specific geographic coordinates.

It is very important that there are different detail levels of objects: from the description of all properties and relations to the representation of only the essence of the thing.

From the point of view of relational models, a MIVAR representation is a three-dimensional (or N-dimensional) relational table in three-dimensional space that contains all the usual relational tables. In addition to this, MIVAR data representation tables allow to effectively store rules and relationships between objects of the "many-to-many" type (M:N).

Thus, at the physical level, within the framework of the object-oriented concept, MIVAR can be considered as a special kind of class.

It should be noted that the modern concepts of class and object used in high-level programming languages that support the paradigm of object-oriented programming, quite accurately correspond to such classical concepts as the frame-sample and frame-instance. In this regard, the structure of the developed knowledge base is presented on the Fig. 1.

The knowledge base includes five classes (sample frames):

1. FrObject—a sample frame for storing an array of Objects [the frame has an ID and a name];
2. FrProperty—a sample frame for storing of a general description of the properties (with the ID and name it has field containing range of acceptable values - PrDomain);
3. FrRelation—a sample frame for storing relationship descriptions (attributes contain name, ID, and general description of the relationship);
4. FrDescription—a sample frame that implements the assignment of dynamic properties of objects (DscrObject – an array of objects, DscrProperty – an array of properties, DscrTime – the period of fixing properties, DscrValue – an array of values, can be of any type depending on the type of property);
5. FrMIVAR—frame sample, which stores MIVARs.

This data model is extremely flexible and can store almost any description and rules of the subject area and calculations on them. For example, the data model presented in [13] for storing ANFIS neuro-fuzzy models is transformed as follows (Fig. 2).

The disadvantages of the presented model include the computational complexity of data access with a branched structure of objects and relations in the subject area.

The practical importance of research is defined by possibility of usage the theoretical analysis results and scientifically well-founded recommendations about increase of efficiency of state regulation of economic development.

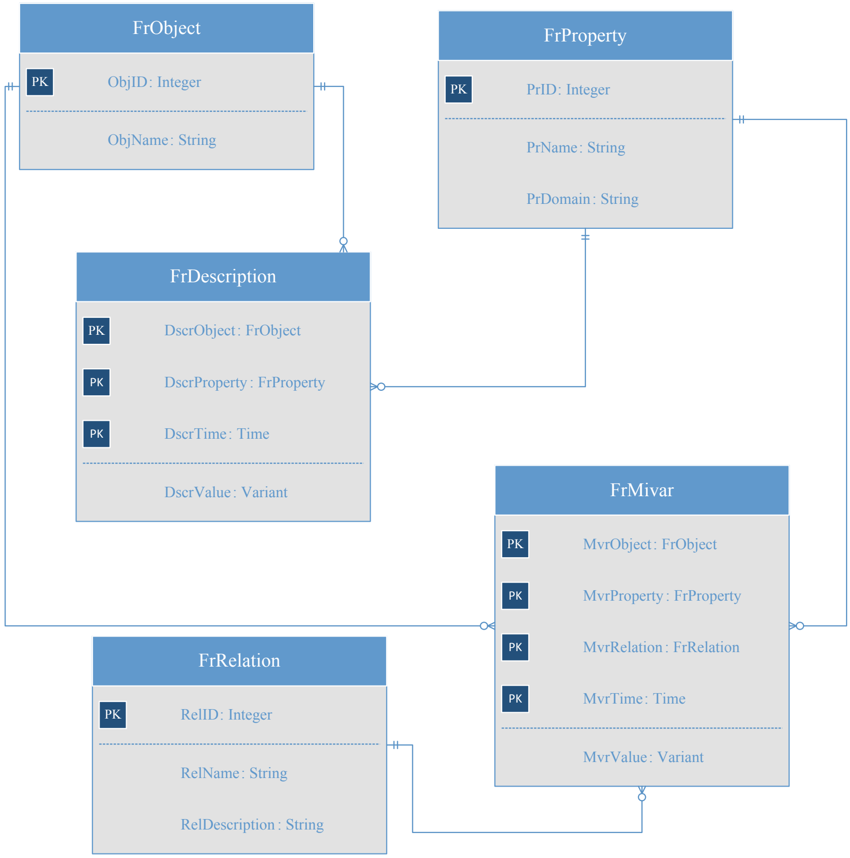

Fig. 1. The structure of knowledge base

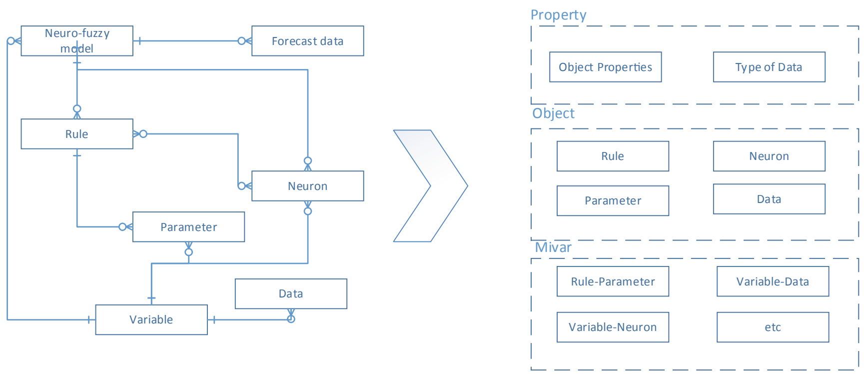

Fig. 2. The transformation of the ANFIS database storage

4 Conclusions

The paper describes the problems encountered in the development and implementation of artificial intelligent systems, considers the use of neuro-fuzzy models for the formation of such systems, considers the definition of MIVAR and presents a universal storage scheme for the knowledge base in a wide range of areas.

In the future, it is planned to develop an algorithm for detecting emissions based on economic time data using fuzzy logic and the developed model of the knowledge base.

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Modernization Concept of the Electric Power Industry as the Basis for Ensuring the Economic Growth of the Russian Federation

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Abstract. This study aims to consider the features of the electric power sector operation as the basis for increasing Russia's economic growth. As part of this study, a comprehensive analysis of statistical data and analytical indicators reflecting the current state of the electric power industry of the Russian Federation was carried out. The results of the study show that the electric power sector, which provides a relatively small share of GDP, has a huge impact on the country's economy. No goods and services can be produced without electricity, therefore stable and reasonable prices for electricity are absolutely necessary to restore, maintain and increase economic growth [1]. Unfortunately, to date, Russia has not paid enough attention to this issue [2]. Based on a study of the opinions of experts from the Russian energy market, the authors conclude that the price of electricity for industry in Russia is higher than in the United States and China, which have huge sales markets. Therefore, there was a need to create a doctrine of electric power security of the country by analogy to the doctrine of food security created in 2010. Further studies should be aimed at: eliminating the mistakes of the previous modernization; creating an understandable and transparent tariff policy; eliminating dependence on external supply of key technologies (in particular, critical dependence on western gas turbines); searching for sources of investment in the industry; developing information technologies that will help creating or saving value at each stage of the technological chain.

Keywords: Electric power industry · Capacity supply agreements (CSA) · Established capacity · Tariff policy · Infrastructure modernization

1 Introduction

In Russia, the first program of capacity supply agreements (CSA), an investment tool in the electric power industry aimed at modernizing the infrastructure, has been almost completely implemented. The program produced 130 generating units with a total capacity of about 30 GW and updated up to 15% of all installed capacity. However, today there are a number of problems associated with the implementation of this program:

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Firstly, the problem of the first CSA is the erroneous planning of the volume of demand for electricity, the location of facilities, and types of fuel used. As a result, many objects built under CSA work in the wrong mode or are not fully loaded.

Secondly, having implemented large-scale construction of new generation capacities, the companies did not withdraw the old facilities - and many units are operating under must run conditions, i.e. at a special rate that allows paying back the high costs of operating facilities built back in the 1950s. Heat reform dragged on in the country, heat supply costs are shifted to the electrical component. That is, Russian industry pays for the heat in each particular apartment.

Thirdly, another type of subsidization is kept - when the costs of low voltage networks are borne by medium and high voltage networks. At the beginning of 2018, the cost of electricity for industrial consumers reached 4 rubles/kWh. And in some regions of Central Russia, prices reach 5.5 rubles/kWh (or 10 US cents). At the same time, in the USA the price level for industry is 6–8 cents per kilowatt hour [3, 4].

These reasons led to the need to adopt specific policies aimed at promoting the development of the electric power industry. This issue is complex and very acute: now there is a need to develop a concept for the modernization of the country's electric power industry, in the development of which it is necessary to take into account past mistakes in the energy sector reform, but most importantly, make sure that prices for the vital resource of the entire economy – electricity - are a national competitive advantage, and not a brake for the entire economy [5].

2 Materials and Methods

The paper used an analytical approach based on an assessment of the current state of the electric power industry in the Russian Federation. The data used in this study are taken from the databases of the International Energy Agency (IEA), Russian Federal State Statistics Service (Rosstat), ATS JSC, NP Market Council Association, etc.

As part of this study, a comprehensive analysis of statistical data and analytical indicators reflecting the socio-economic and political factors affecting the adoption of investment decisions was carried out.

To identify trends in modernization, development and investment in the electric power industry of Russia, the following indicators were selected:

- Established capacity of the capacity supply agreements in Russia;
- Electricity prices in Russia;
- The impact of lowering electricity prices on economic growth;
- The cost of the planned modernization program for the electric power industry;

Forecasted growth of GDP and industrial production in the Russian Federation.

3 Results

The national economy is gradually embarking on a growth trajectory. Electric power industry is an industry on whose activity the stability of the economy's infrastructure directly depends. One of the key companies in this industry is Rosseti PJSC, which accounts for more than 75% of electric power transmission services in the Russian Federation. Rosseti is the flagship of the industry due to running events aimed at its modernization. Since its establishment in 2013, the company did a great job to increase efficiency, according to the results of which the accident rate decreased by up to 50%, the duration of technological disruptions was reduced by 30%, specific operating costs were reduced by 28%, the cost of technological connection was reduced more than twice, and electric power losses were reduced by 1%. However, the company's internal reserves are gradually exhausted. It is becoming increasingly difficult to constantly increase efficiency.

The country's leadership is faced with the task of creating conditions for enterprises in the electric power industry to maintain their growth rates without compromising the reliability of power supply and the availability of infrastructure for consumers. One way is to modernize the tariff policy.

Earlier there were different tariffs in the bulk power system for different regions. When the unified tariff was introduced, the part of consumers for whom it grew was unhappy, but there were those for whom tariffs were reduced. However, after a very short period of adaptation, everyone eventually won, since a single tariff is beneficial for business, especially interregional one, because now this indicator is not considered among the important ones when making investment decisions. Other indicators of the entity come to the fore: labor resources, roads, tax conditions, etc.

A single tariff is a real tool for macroeconomic regulation. For the industry, the introduction of a single tariff will become a stabilizing factor that allows not only replenishing production assets, but also modernizing them. To do this, the federal regulator must introduce a federal operating rate. Then, regions, if necessary, can establish local allowances for the development of the infrastructure of a particular entity. Creating an understandable and transparent tariff policy will give the industry an impetus for development, and simple and clear rules for tariff setting for consumers.

An important element should be agreements with regions on the introduction of regulated activities. They should have all the investment challenges that the regions pose for companies and guaranteed long-term tariffs. This practice is widespread abroad.

One of the defining indicators for a modern electrical grid infrastructure is its availability. In this regard, it is necessary to reduce the time for connecting consumers in terms of increasing customer service centers on the Internet portal, where the consumer can apply online and track its implementation.

To ensure the development and increase the efficiency of the country's economy, it is necessary to synchronize development plans for territories, industries and large businesses. Nowadays, the development of the integrated power grid is based on plans of regional authorities and consumer statements. As a result, not all projects are being implemented, which leads to the fact that the scarce investment potential of grid companies is not spent efficiently. Underloaded power centers remain in some places, while in others grids are overloaded. There is a need to introduce strict state control over the relevance of development plans. Closer interaction, cooperation of regional authorities, investors and networks for maintaining registers of regional investment projects may be of particular importance.

Another integral direction of modernization of the electric power industry should be an alternative to manual control - automation, in terms of introducing information technologies that will allow creating and saving cost at each stage of the technological chain. In terms of loss control in the grid and differences in the volume of services rendered, a transition to a new intelligent platform for the commercial accounting of electric energy is necessary. For this, it is necessary to build a system for collecting and transmitting information using modern metering devices that allow data to be transferred to a single center.

The European Union aims to equip 80% of metering points with remote collection by 2020, the current level is less than 10% [7]. The adoption of an appropriate federal program is required, including the necessary legal basis. No less important is the economic mechanism that motivates grid companies to automate accounting: the savings from the reduction of losses should remain with them.

One of the key problems of the Russian economy is the high level of transaction costs due to the large number of intermediaries. In the electric power industry, intermediaries are essentially a large number of grid companies. Electricity can be produced and consumed long ago, and payments for it along the entire chain can take years. In most cases, participants in these technological chains are state-owned companies of the federal, regional and municipal levels. The latter two account for more than 10% of the volume of transmission services [6]. A significant reduction in costs is possible due to the consolidation of assets on the basis of Rosseti. Now the main state assets in the electric power industry are concentrated in this company. This is especially important now, when modern smart grid technologies provide for an increasing independent role of the consumer and a special infrastructure role of grids. For this, grids should develop as a single technological and organizational complex along the entire chain. This requires special synchronization, which is impossible in an institutionally fragmented state.

On the agenda is the creation of a single federal customer service center and a technical customer center. Such a solution will make it possible to more effectively direct limited resources to address priority tasks - to ensure equal reliability of electric power supply and connection to networks at an affordable price for all consumers.

The above allows the author to propose a model for the sustainable development of the electric power industry as the basis for ensuring the economic growth of the Russian Federation (Fig. 1). The main content of the proposed model is a formalized description of:

– the main economic processes, problems and factors, the structure of which is determined by their objective properties, subjective target nature and affects the sustainable development of the electric power industry;
– goals, objectives, decisions, and measures of state policy in the field of electric power industry;

– procedures for clarification and possible adjustment of the timing for the implementation of the stages of the policy in the field of electricity;
– monitoring the progress of the implementation of the stages and control of execution in general;
– establishing (constituting) the interconnections and interactions of participants in the electric power sector.
– the subject-object structure of the participants in the electric power sector, including customers and contractors.

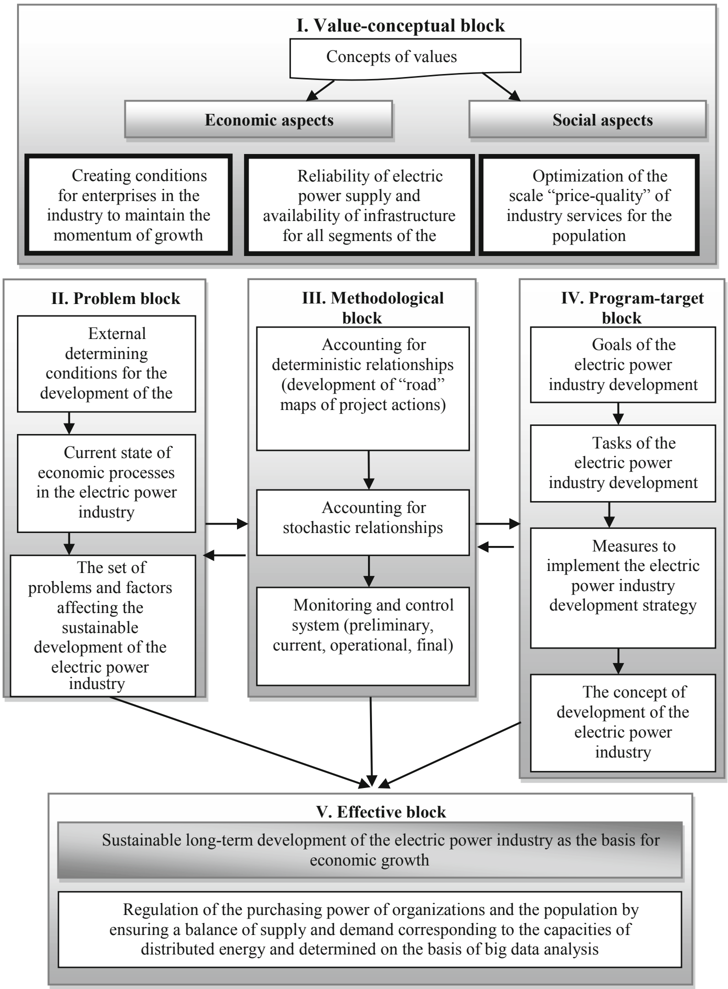

Fig. 1. Model for sustainable development of the electric power industry as the basis for ensuring economic growth of the Russian Federation

A specific feature of the proposed model is not only the sustainable development of determinism (functionality) of the established relations between phenomena and processes ("road" maps - the design algorithm of actions) of the electric power industry, but also in the implementation of a stochastic approach that takes into account probabilistic events ("wild" maps - the probability of floods, fires, as well as man-made and environmental disasters) in the socio-economic development of the country, which can affect the sustainable development of the industry.

4 Discussions

The graph of electricity prices in Russia (Fig. 2) shows that the main increase occurred from 2004 to 2011. During this time, real electricity prices rose by 60%, after which prices stabilized. But experts predict that they will go up again in the near future. In the electricity market, the state periodically distributes various types of subsidies – to renewable energy and waste incinerators; to thermal stations not included in the country's unified energy system; on the new construction of nuclear units; and subsidizes must run generation.

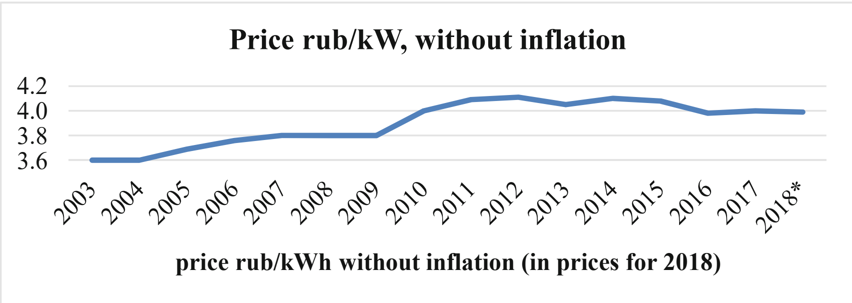

Fig. 2. Dynamics of electricity prices in the Russian Federation. Source: according to the official website of Rosstat http://www.gks.ru

There is a high probability that by the end of this year, the average price of electricity for industry will rise to 4.5 rubles/kWh. ($ 0.08). This is a very high price level, and it has an extremely negative effect on Russian industry. A high payment for electricity is the withdrawal of funds from industry, which needs its own modernization and which does not have special privileged tools to guarantee the return on production capacity [8]. While the new program, which is being discussed in the industry, called "CSA for modernization", assumes a guaranteed payback of generation facilities in 15–20 years.

At a forum in Davos in 2012, it was noted that the world is recovering from the global recession and financial crisis, countries are looking for opportunities to improve their economic indicators and return people to work. The energy sector provides a relatively small share of countries' GDP (other than those whose export revenues are based on oil and gas). However, the impact of energy on the economy is much greater. Most importantly, no goods and services can be produced without energy. Therefore, stable and reasonable energy prices are absolutely necessary in order to restore, maintain and increase growth [7, 8]. In Russia, this norm has not yet been taken into account.

The main increase in the price of electricity (Fig. 1) occurred in the period from 2008 to 2011. It is that time when the energy modernization program has begun under the CSA scheme. However, it cannot be unequivocally asserted that the stabilization of electricity prices after 2012 was not due to an excess of capacities that arose as a result of the CSA-1 program. But we can say with confidence: the fact that the electricity price for industry in Russia today is higher than in the US and China (6–8 cents per kilowatt hour and 4.5–7.5 cents per kilowatt hour, respectively). Even in Europe, for large industrial consumers, the price is not higher than in Russia. China, the US have incomparably large sales markets [9]. Our industry has expensive money, high taxes, a small sales market, and expensive energy. All this together excludes the possibility of economic growth. And we are mostly hearing from representatives of medium-sized businesses that the price of electricity is the most important limitation on investments in the new production.

That is why industrialists are looking for options for autonomous energy supply, which, due to the fall in prices for medium-sized power equipment, allows obtaining electricity 10–15% cheaper than centralized electric power supply. But useful to industry, this process destroys the financial stability of a centralized system, taking away solvent demand from it. And there is a vicious circle. The financial problems of large energy power industry make it demand higher prices or threaten the reliability of the system for ordinary consumers, and again, industrialists will pay for it. And so on to infinity. This circle can only be broken at a strategic level, striving for a concept that can ensure both the security of supply and the growth of industry.

The Energy Research Institute of the Russian Academy of Sciences made assessments of the impact of reducing electricity prices for industry on economic growth. Calculations showed that a 10% reduction in prices gives an additional 0.3–0.5% to the conservative GDP growth scenario of 3–3.8%, and in relation to industry, it would even overtake the innovation scenario (GDP growth up to 4.5%). Since there was no growth at all, relying on these estimates, it can be said that a decrease in electricity prices would make it possible not to fall into a recession, and by the end of 2017, to have an increase of 2–2.5% instead of the current 1.6%.

In its calculations, the Energy Research Institute relied on a very important factor - the level of profitability of energy companies, and showed that the level of profitability of energy companies is several times higher than that of industry. Therefore, it is logical that they sacrifice their profitability in the interests of the entire economy, and not vice versa.

Russia seeks to be competitive, and for this it is necessary to ensure the predicted price stability, or its reduction, then we will again become competitive in terms of electricity prices.

Another problem facing the electric power industry is the direction of technological changes within the framework of the planned modernization program, the total cost estimate of which varies from 1.5 trillion to 3.5 trillion rubles by 2035.

The modernization, which is being planned now, will actually extend the life of heating plants by 15–25 years at minimal costs. This will protect the consumer from high tariffs. But the HPP today has a conditional fuel consumption of 335 g for the production of 1 kW/h. These technologies were invented and massively introduced in the 40–50 s of the last century and, despite the progress, have not changed much. The modernization will not change this consumption in the future. Moreover, modern solutions in the form of combined cycle gas turbine (CCGT) can reduce fuel consumption to 180–190 grams per 1 kW/h. This, despite significant capital investments, still looks more preferable than just replacing old equipment with exactly the same new equipment [10].

The market already needs to be formed so that the equipment is in demand for the long term - until 2050. From this point of view, it is necessary to put such an indicator as the final price for the consumer at the forefront.

At the new stage of modernization of the country's energy sector, it is necessary to look at the costs for the entire equipment operation cycle. Otherwise, it turns out that today companies choose the lowest capital costs, but receive the highest costs over the entire life cycle. The equipment fleet is in such a state that sooner or later something will have to be done with it. This problem will arise at the same time in many companies.

The concept of modernization of energy sector is relevant and should be worked out to the utmost, taking into account the excess of available capacity. According to experts, in the country, up to 56 GW of excess capacity is in excess of the reserve, and the question is that the energy system has long ago upset the balance of economic interests. If you look at the structure of these capacities, we can see that the main problem is HPPs serving Russian cities with heat. On average, these plants are 50% loaded, and getting rid of excess capacity is a priority task that needs to be solved during the modernization. There should be an individual approach to each plant in each city separately, since each plant works both for heat load and for the city's energy system.

The main problem is that Russian mechanical engineering does not have technological solutions based on powerful gas turbines. And without a specific target program, powerful turbines (more than 100 MW) will hardly appear. Enterprises based on western technologies and built as part of the first wave of modernization of the energy sector require rather high maintenance costs. At the same time, Russian machine builders live only at the expense of the markets of Belarus, Kazakhstan, Mongolia, etc. There is great competition in the Russian market with foreign manufacturers. The largest European manufacturers have great interest in the Russian market, and dumping is from 30 to 40% in relation to prices of Russian manufacturers [11, 12]. This should be taken into account when developing the concept of modernization.

Figures 3 and 4 show the forecasted growth of GDP and industrial production in Russia. In accordance with these data, it can be said that the Russian energy sector needs a deep modernization with the replacement of all infrastructure: electrical equipment, auxiliary equipment, power distribution schemes, etc.

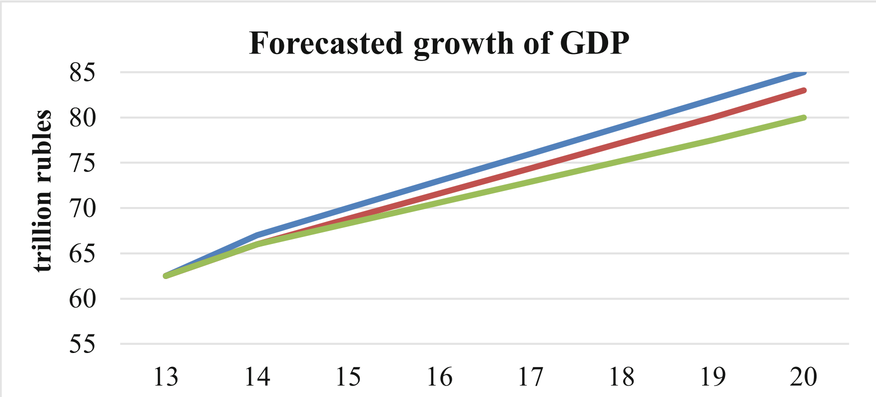

Fig. 3. Forecasted growth of GDP of the Russian Federation until 2020. Source: according to the Ministry of Economic Development http://economy.gov.ru/minec

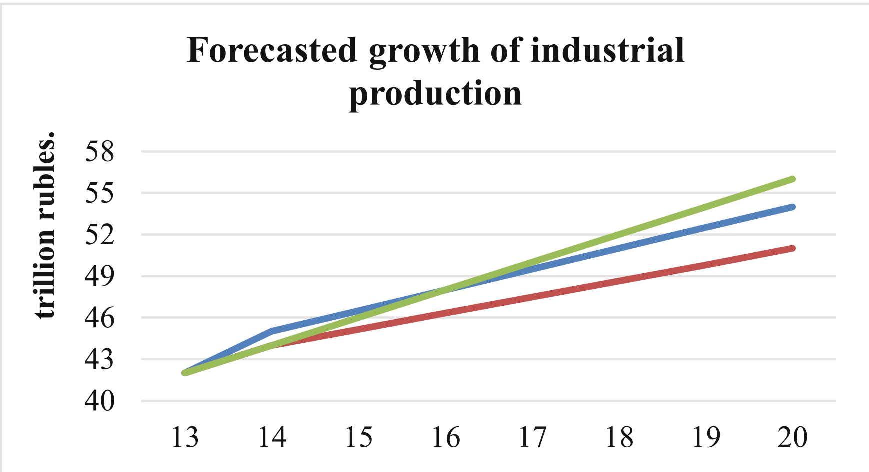

Fig. 4. Forecasted growth of industrial production in the Russian Federation until 2020. Source: according to the Ministry of Economic Development http://economy.gov.ru/minec

Systematizing the above, it can be said that the systemic challenges facing the Russian energy sector today are as follows:

- high electricity price with the cheapest gas in the world,
- dumping prices for western equipment in the presence of Russian solutions,
- non-optimal use of available capacities and their potential abrupt decommissioning in 10–20 years.

In developing the concept of modernization of the electric power industry, it is necessary to understand how we want to see the country's energy system in a few decades. It is very important to determine the sources of investment in the industry, and where the money paid for this modernization will go: to Russian machine builders and research institutes or to western corporations and patent holders. What technical solutions will eventually be applied in generation, grids and, possibly, in energy storage.

Now in the world, the electric power industry is at a completely different level of development: the market concept is changing, cardinal changes are taking place [13]. Smart grids are appearing, the electricity metering system is becoming more modern, while at the same time providing energy savings for the client and increasing the efficiency of markets [14]. The prerequisites for the Internet of energy are being formed, which is qualitatively changing the situation, and there are opportunities to store electric power in a completely different way than before. In the old concept, it was believed that electric power is produced and consumed simultaneously and it cannot be stored [15].

In developing the concept, a single federal customer service center and a technical customer center should become the center of effective development and responsible for preparing a set of measures to change the situation both according to the market model and organizational changes.

5 Conclusion

Choosing directions of development and working through the concept of modernization of the electric power industry and technological development of the industry, it is impossible to act haphazardly. It is necessary to fulfill the tasks set by the President of the Russian Federation without slowing down the pace: to increase the growth of reliability and a qualitative increase in the controllability of the industry, search for new potentials for reducing costs, and implement the concept of a new tariff policy. These solutions will also work in the second half of the XXI century. They cannot be based on technologies created and fully realized their potential in the middle of the XX century, because as experience with old technologies shows, the industry is not able to maintain a competitive price for energy. To simply return to US prices, Russia will be forced to work with new technologies and systematically relate to the structure of energy capacities.

One way to solve this problem is to increase gas prices. Such growth would reduce the margin of distributed energy and stimulate the development of alternative sources. However, rising energy prices will inevitably lead to the growth of prices for electricity and heat, and adversely affect the industry. The effectiveness of infrastructure solutions lies in interest rates on long-term investments and in the use of the best technologies.

Therefore, the concept of modernization of the electric power industry, aimed at maintaining a competitive energy price with the reliability of the system in the domestic market, is now particularly relevant. One of the main infrastructure sectors should have long-term benchmarks. It is necessary to exclude the situation when each participant in the energy market solves only his local problems. The systemically important indicator for the entire economy of the country should come to the forefront - the long-term price of electricity, a resource that will ensure the competitiveness of domestic industry. All this will make it possible to forecast prices for the next ten years and will give confidence in the country's energy security for this perspective.

This work is devoted to the study of the functioning of the electric power sector, the results of which allow formulating the following conclusions:

- The concept of modernization of the electric power industry of the Russian Federation is relevant and should be worked through as much as possible, taking into account the excess of available capacities. The current surplus of generating capacities in the country, the high cost of capital and unstable capital costs for imported equipment components limit medium and long-term investments in renewable energy sources.
- In the electric power market, the introduction of modern solutions is necessary. Despite significant capital investments, it will be much more effective than simply replacing old equipment with exactly the same new equipment. The market already needs to be formed so that the equipment is in demand for the long term - until 2050.
- At the new stage of modernization of the country's energy sector, it is necessary to look at the costs for the entire cycle of equipment operation. Otherwise, it turns out that today companies choose the lowest capital costs, but receive the highest costs over the entire life cycle.
- Creation of an understandable and transparent tariff policy will allow the industry to develop, and consumers will be provided with simple and clear rules for setting tariffs. This will become one of the stabilizing factors that allow not only replenishing production assets, but also modernizing them. To do this, the federal regulator must introduce a federal operating rate. Then, regions, if necessary, can establish local allowances for the development of the infrastructure of a particular entity.
- A total introduction of information technologies is needed, which is becoming an integral part of the new energy sector, allowing both creating and saving value at each stage by ensuring a balance of supply and demand corresponding to the distributed energy capacities and determined on the basis of big data analysis. Centralized asset data will allow for risk-based maintenance, and a user-friendly interface will facilitate the introduction of technology and contribute to the creation of added value. All this will increase the economic efficiency of the industry and the quality of provided services.

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Forming Ontologies and Dynamically Configurable Infrastructures at the Stage of Transition to Digital Economy Based on Logistics

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Abstract. Digitalization of all economic sectors results in continuously increasing load on corporate data processing centers. There is decrease of economic efficiency for using classic methods of developing information infrastructures of organizations. The purpose of this article is to provide the non-classical description of the current situation in the IT development conceptual field and the conceptual description of the intellectual computing platform of modern organization in the digital globalization context.

Keywords: Virtualization · Computing containers · Logistics · Multi-agent systems · Data center · Cloud computing

1 Introduction

Digitalization of almost all economic sectors and the related snowballing data production and accumulation results in the necessity for organization IT infrastructure to enable processing of more and more data of varying degrees of structuredness. Meanwhile, the emerging new technologies and tools are far ahead of the ontological fields development, which often results in confusion in concepts and definitions. The experience of the IT industry development clearly shows that this is quite an important point, since the rapid growth of the tools and technology park used in various digital economy areas by the huge number of occasional users leads to significant economic and technological collisions. Thus, an adequate description of new IT infrastructure types, as well as of their intellectual and tools' content, a priori needs a consistent conceptual framework. The second thing to notice is that currently IT infrastructures of organizations are still developing in a linear way [9]. The capacity of data processing centers (DPCs) in most cases calculated by classical formulas and expanded simply by purchasing additional racks and servers. This problem can be partly solved by modern

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server (cluster) platforms and systems. However, such systems cannot fully solve the problem of optimized and automatic distribution of DPC computing resources.

The purpose of this article is to provide the non-classical description of the current situation in the IT development conceptual field and the conceptual description of the intellectual computing platform of modern organization in the digital globalization context.

2 Materials and Methods

In the usual sense, an ontological approach is necessary for generating the logical system of concepts and definitions, based on which the knowledge in some subject area is conceptualized, structured and formalized. The concept of ontology is multi-valued but in the above sense ontology can be considered as a structured conceptual "dictionary" specifying a certain subject area. Ontology as an entity comprises quite a few defining concepts that are, first of all, the target, the covered area, the description language, the presence of axiomatics, types of relations, the knowledge presentation form, etc. Since the ontological approach often has applicable nature in generating various information and corporate knowledge systems, "the owner" concept is often introduced at present. This concept denotes someone who generates and uses such knowledge system for creating information product and the corresponding recognizable brand [2]. Ontology generation implies rigid structuring, interconnected hierarchical levels, and strictly stipulated relationship types. We do not purport to build the ontology representing the speed and diversity of the IT industry development, but to point out some aspects we consider important.

Firstly, one should note the rapid conceptual framework expansion of everything associated with economy digitalization, and the emergence of figurative (metaphorical) definitions. Such definitions, at high hierarchical level, include "digital transformation", "big data", "the Internet of things and the Internet of everything" [7], "cloud and fog computing", "digital twins" related to the technical and technological aspects of digitalization. We propose to expand the metaphoricity of fundamental concepts better reflecting the current state and development of IT.

Currently the IT subject area is a sufficiently complicated intertwining of entities, their corresponding substances, interacting objects, processes and data, which form the common intellectual information systems. Such state at the top level can be defined as "digital jungle". At the level of IT general (industry-specific) applications we can talk about the "forests" of IT technologies and technical means (IT TTM). The level of target IS constitutes a kind of "zoo" inhabited by different communities of technologies and tools (platforms, frameworks, applied libraries both interacting and conflicting with each other. And finally, at the corporate and user levels, there are "pet shelters" forming specific information infrastructures and specific "owners".

Note that in classical deployment diagrams of organization's information infrastructure, migration of methods, technologies and tools occurs, as a rule, downwards to the implementation level of a target system. Further system development is most often performed in the horizontal technological layer, and the heterogeneous system is developed linearly by integration methods. Service-oriented architectures (SOAs) provide more possibilities, but they are also not free from the classical approach disadvantages.

The “jungle” concept is more flexible, since the above-mentioned migration from layer to layer can be performed repeatedly in any direction. This migration is able to generate a hybrid, dynamically configurable information architecture and a corresponding infrastructure, not only at its “owner’s” request, but also according to quickly changing market conditions. The modern technologies of virtualization and containerization [6], the use of multi-agent systems provide such opportunities [10].

Note that the flexible transfer from level to level in the required direction and the required IT TTM selection for building target ISs, used to increase the organization’s profit, can be described as the corresponding logistic chain of creating the new value - from infrastructure generation and product design, up to product delivery to the end consumer. Such chain provides for more accurate selecting and agreeing of the necessary standards and technical - technological tools. These are used for building the required information infrastructure and developing the appropriate metrics to thoroughly measure the necessary product parameters during its design, development, market launch and branding. In the considered area there appeared such concepts as “food” corporate chain, hybrid systems, social branding, multi-agent systems based on virtualization and intelligent (neural) systems, branding intellectualization [2]. We consider the above logistic approach very productive, as it interlinks certain aspects of generating modern (distributed, mobile, adaptive) information infrastructure of any degree of complexity. We will illustrate it by the concepts of “financial logistics” and “virtualization-container logistics”.

2.1 Financial Logistic Approach

Methods of managing financial resources by using logistic tools have already been used for several decades [11]. Currently coming to the fore is the system-structural aspect letting us talk about the new direction- financial logistics, which allows not only to arrange and control financial flows, but also to study causal relationships at all movement stages for interconnected flows of material, financial and information resources and to flexibly rebuild them if needed. At the same time, the multitude of process metrics and functionally interconnected financial and economic indicators can be combined into a “mobile” financial model allowing to create various scenarios for company developing or for particular aspects of its activities. Such technique allows quicker navigating in “technological jungle and forests” and generating target value chains much faster and at lower cost.

At the actual enterprise level, the proposed approach is based on decision-making feasibility of financial and material resources management, accounting for any restrictions on the amount of capital allocated for of material assets acquisition, as the company’s capital amount for implementing logistics processes in the corresponding supply chain may be restricted by the actual company potential. Figure 1 shows the logistic scheme of financial flows for a group of companies, drawn up on the above concept basis.

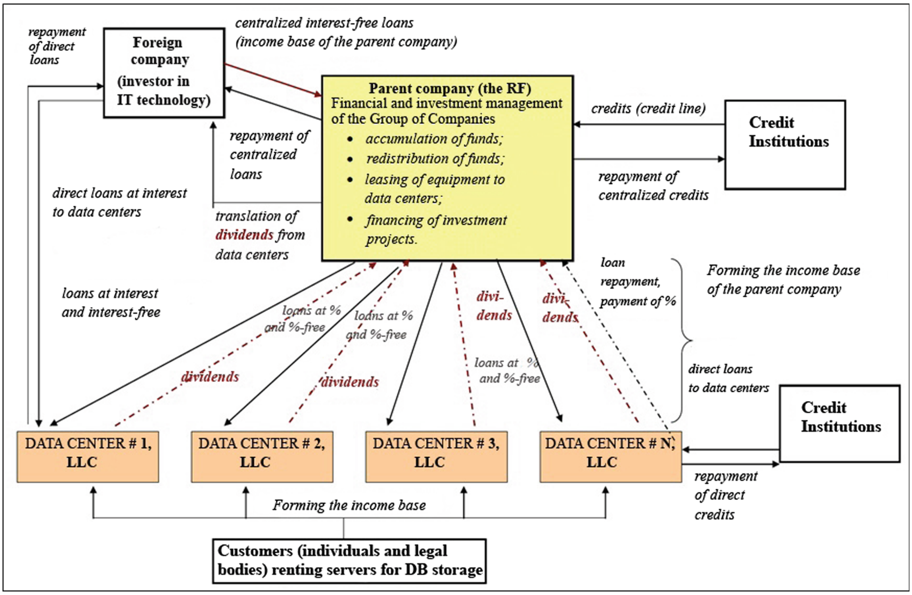

Fig. 1. Logistic scheme of financial flow for a group of companies

2.2 Virtualization and Container Logistics

Modern realities necessitate the possibility for forming adaptive dynamically configurable IT infrastructures. Since this article addresses the development of approaches to IT infrastructure building of modern organization, we consider it logical to start with approaches to building up a modern DPC. Due to computing servers constantly getting out of date, more and more productive solutions are required. Many organizations have already developed a heterogeneous hardware infrastructure. Generally, such equipment operates in different network segments and serves various corporate services in accordance with the available configuration. This approach allows to develop a DPC linearly by gradually decommissioning old equipment and replacing it with a new one, each time encountering the problem of data migration, software updating, etc.

All this results in the continuous increasing of the IT budget required for development of such data center continue, thus minimizing any competitive advantages of the organization taken as a whole. In such situation, we consider it is better to use the concept of “technology zoo” (Infrastructure as a Zoo, IaaZ) by employing a limited thin layer of “pets” on the user’s side. Given the capabilities of modern server and cluster platforms, IaaZ-type infrastructures are best used as a private cloud. However, this approach does not solve one very important problem. When combining heterogeneous (particularly in the context of computing capacity, bandwidth, disk speed, etc.) systems into a single computing cluster, it is very important to account for the performance of each specific computing unit. In our opinion, modern IaaZ platform should account for such computing optimality parameter during allocation of computing resources, according to the priority of the performed tasks.

3 Results

As mentioned above, there is a fairly wide range of server and cluster computing platforms existing today. Information systems may be built up from virtual machines, containers of various types. However, concerning the structure of most platforms, we speak about centralized distribution of hardware resources and load balancing, e.g., for such platforms as Hyper-V, System Center, Docker, Docker Swarm, kvm, Apache Mesos, Kubernetes, etc. Obviously, such approach won't be optimal for a number of situations. For example, in case of extreme, abnormal situations, overloads, etc. [4], it won't be possible to automatically reconfigure such systems without technical experts' assistance [5].

In this regard, we think that the currently existing and widely used terms, such as, e.g., "heterogeneous IT infrastructure", do not completely define many actual IT infrastructures of organizations, due to "heterogeneity" being present there in many aspects: hardware, network, software, logic, etc. [1].

At the stage of inevitable transition to digital economy, the situation with forming hybrid structures [6] involves the more frequent usage of the term "multi-agent virtualization" [3], with employing as active agents such virtualized entities as, e.g., applications deployed on virtual machines and containers (Fig. 2), are used as active agents.

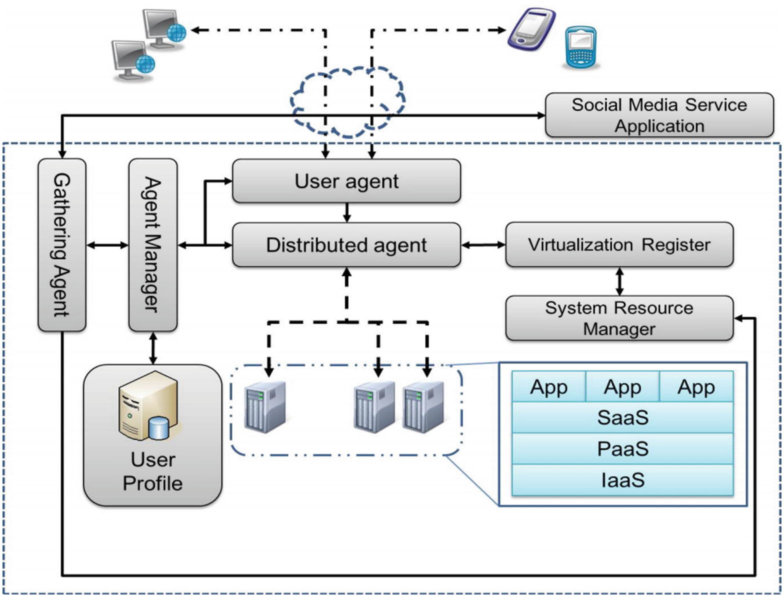

Fig. 2. Intelligent multi-agent model for resource virtualization [3]

Obviously, platforms like IaaZ require multi-agent approach, with virtual entities (containers or virtual machines) being able to independently select the leader and automatically reconfigure, to allocate resources according to the priority of encountered tasks, as well as to the overall data center workload.

In general, there is no reason to use only one virtualization type within the IaaZ system. In our opinion, it's necessary to provide for the possibility to dynamically switch the virtualization type (provided that the platform or cluster software is compatible). Our studies and researches demonstrate that both KVM virtual machines and Linux containers running under Docker may be the best choice for various tasks [6]. Figure 3 shows the test results for sequential, random and mixed data reading and writing performed by using the "FIO" Linux utility.

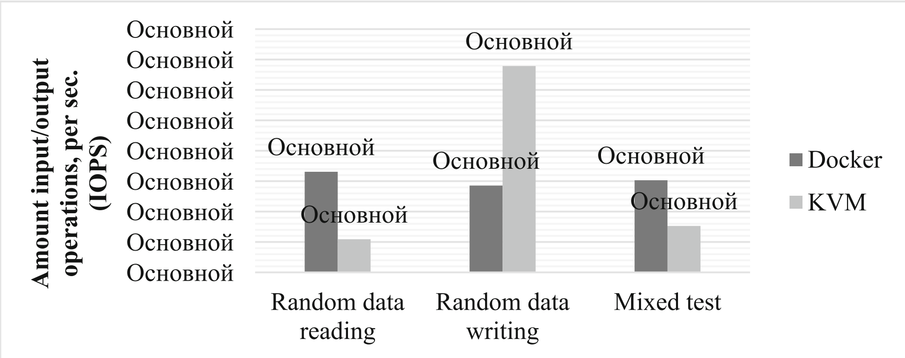

Fig. 3. Test results with the aid of FIO utility [6]

Whereas the setup time distribution for typical corporate IT service (Ubuntu Server 16, Apache, Maria DB, Drupal) looks like the following, Fig. 4.

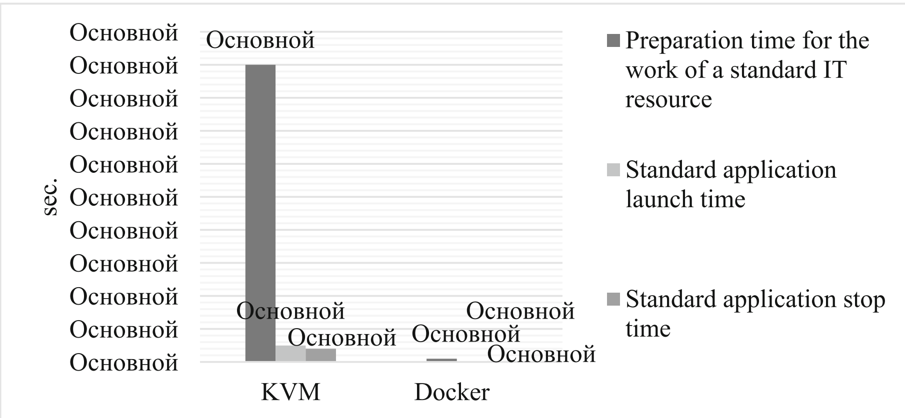

Fig. 4. Experimental results of typical resource launching [6]

The results of the experiments have clearly demonstrated that, with the equipment used (average-priced corporate level server equipment of 2016), it was better to launch the tasks requiring fast response in disk operations on KVM virtual machines. As for the tasks requiring rapid creation of many similar IT resources (e.g., research virtual laboratory for students for 1–2 classes), with quick shut-down potential, they were better to launch in Docker containers.

It's obvious that such performance measurements for typical tasks can be carried out on regular basis and also be taken into account for dynamic (automatic) selection of the virtualization type [8]. Additionally, machine learning methods should be used for such system's self-education. The prototype architecture of hybrid, dynamically configurable IaaZ system is shown in Fig. 5.

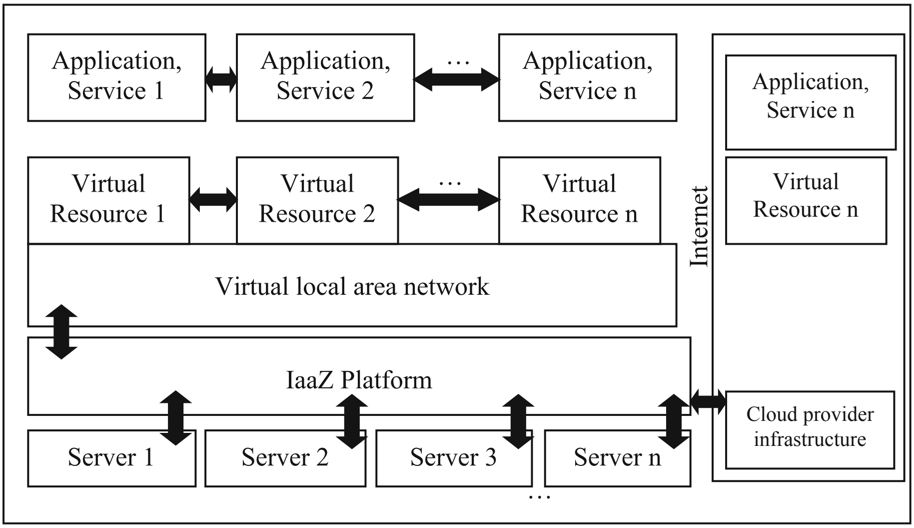

Fig. 5. General IaaZ hybrid system architecture

The above tendencies show that macro level (e.g., in case of transnational corporations) IaaZ-systems, with combined corporate information infrastructures, supersede more rigid heterogeneous structures. Application of the IaaZ approach using the extensive IaaJ zone (Infrastructure as a Jungles) with flexible vertical and horizontal connections provides great potential for generating reliable target systems. Such important parameters as communication channels' security, network connection delay factor, availability of VPN tunnels for aggregating geographically distributed sites, reducing the cost of ownership, etc. are implemented in these systems and at the macro level.

4 Discussion

The new terms presented in this article and allowing to expand the thesaurus established in the development of corporate information systems, are, in our opinion, caused by appearing, in the last decade, of such new computing paradigms as cloud computing, big data, as well as by the widespread use of virtualization and containerization technologies. All this made it possible to accelerate the clustering of data center organizations. The transition to even more modern paradigms, such as “fog computing” and “data lakes”, is characterized by the impossibility of applying classical approaches to data processing, storage and transmission by using only local DPC or only computing cloud. At the same time, the terms proposed in this article, as well as approaches to generating dynamically configurable information infrastructures for modern organization, can be applied within the framework of the modern computing paradigms specified above.

5 Conclusion

From the perspective of the logistics theory as a science, the following should be emphasized. In the framework of the common approach, the DPCs are developing linearly, old equipment is gradually decommissioned and replaced by new equipment, but there is a problem of data migration and software updating, etc., which increases the company’s budget.

The key feature of the approach presented in the article is the study object comprising not randomly functioning heterogeneous technologies, but scientific search for methods and techniques of arranging organized interaction of IT infrastructure elements resulting from expansion of IT capabilities. This expansion was achieved by adding various equipment based on a set of logistic approach methods (primarily, description of logistic financial flow), providing for introduction of new conceptual framework containing definitions and descriptions of the existing heterogeneous IT infrastructure resembling “zoo” in its diversity.

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Methodical Apparatus for Selecting the Best Motor Transport Vehicle by the Set of Its Characteristics

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Abstract. In today's world, motor transport is of great importance. The advantages of motor transport vehicles are the possibility of door-to-door delivery (it is possible to deliver the goods anywhere in the country and abroad right under the door of the customer), high speed of delivery (the car will drive up to almost any place), the ability to quickly change the route (whereas with air and railway transportation it is impossible to do), the continuity of transportation without overloading the goods (which is especially important for perishable goods), fast organization of new transportation, a variety of types of vehicles (motor transport vehicles are divided by purpose, capacity and passenger capacity, which allows to reduce the cost of transportation by the selecting the vehicle most appropriate to the type and volume of cargo). All this in general makes motor transport one of the most profitable and convenient. Nowadays there is a wide variety of different motor transport vehicles, even within the same class of vehicles there are differences in technical characteristics, design, financial condition, warranty. The article discusses an integrated approach to decision-making on the selection of the best vehicle by quantitative and qualitative characteristics. Evaluation of options and selection of the best option of the vehicle is proposed to be carried out on the basis of the methodology built using the methods of spectral analysis and analytic hierarchy process. The description of methods and algorithms of decision-making using these methods are given. The disadvantages and advantages of these methods are analyzed. The article presents the results of the selection of the most appropriate motor vehicle from four most widespread in Russia models belonging to the same class.

Keywords: Decision-making · Motor transport · Artificial intelligence · Analytic hierarchy process · Method of spectral analysis · Car

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1 Introduction

Motor transport is of the greatest importance in the overall transport system of the economy of any country. It is widely used in all sectors of the economy [1, 2]. Motor transport is used to deliver the most important goods from producers to consumers over relatively short distances, as well as for the delivery of goods to railway stations, seaports and river piers. Motor transport in cities serve industrial and commercial enterprises, and in rural areas - agricultural enterprises and farms. An important role is played by cars and passenger transport (buses, taxis and cars of official use).

The number of motor transport vehicles registered in different countries is growing every year [3, 4]. Back in 1986, the global number of cars was a figure of 500 million names (passenger cars, various models of cargo vehicles and buses are taken into account). At the end of 2018, about 1.3 billion cars are operating in the world. The global level of motorization is 182 cars per 1000 people.

Therefore, the problem of selecting the best motor vehicle on the set of qualitative and quantitative characteristics from a set of available options becomes particularly relevant [5–7].

If only quantitative characteristics of motor vehicle are known, it is more efficient to select the most appropriative option by the method of the spectral analysis. But the characteristics of motor vehicles are not only quantitative, but also qualitative. In this case, the problem of selecting one of the options can be solved on the basis of the analytic hierarchy process, which allows to make a choice based on both qualitative and quantitative characteristics [8, 9].

Both methods have their advantages and disadvantages. The method of spectral analysis has not subjective estimates in the selection of initial indicators and calculations. However, its application is possible only for uniquely given numerical characteristics. In addition, there is no consideration of the importance of characteristics.

The method of spectral analysis allows to take into account the importance of the characteristics of motor vehicles in the calculations, but it is predetermined with the involvement of experts, and thus becomes a subjective value.

Analytic hierarchy process is applicable in multivariate selection by the set of characteristics, both quantitative and qualitative, and the characteristics have a given importance. A significant disadvantage of the analytic hierarchy process is the subjectivity of assessing the importance of criteria and priority of specific option of the motor vehicle for each of the selected criteria [10, 11].

Thus, both methods have disadvantages and advantages and their use is determined by the conditions of the specific task of selecting the best option of the motor vehicle. To level the shortcomings and strengthen the advantages of the methods, an integrated approach is proposed, which allows to make a decision on the basis of two methods.

2 Experimental Section

The procedure of obtaining an integral assessment of the set of quantitative and qualitative characteristics for each option of motor vehicle and the order of ranking array of motor vehicles is as follows:

1. Determination of quantitative and qualitative characteristics of the proposed options of motor vehicles for which the choice will be made.
2. Ranking of options of motor vehicles and their quantitative characteristics on the basis of the spectral analysis method.
3. Normalization of the obtained ranked array of options of motor vehicles using the approach applied in the method of analytic hierarchy process.
4. Ranking of options of motor vehicles taking into account only qualitative characteristics based on the method of analytic hierarchy process.
5. Summation of the obtained priority vectors for quantitative and qualitative characteristics for each motor vehicle and ranking array of motor vehicles.
6. Analysis of the results.

2.1 Method of Spectral Analysis

If only quantitative characteristics of motor vehicles are known, the most simple and effective method of solving the problem of rational selecting is the method of spectral analysis. The essence of the method is as follows [12, 13].

There are n compare options of motor vehicles (MV) (MV_i, $i = \overline{1, n}$), which can be assigned to a number of technical characteristics X_j, $j = \overline{1, m}$, that determine the preference of a technical systems. The preference of the technical systems TS from the standpoint of one of the characteristics X_j can be defined by indicator x_{ij}, has a certain physical meaning.

It is considered that all characteristics initially are equivalent: $W_i^{(0)} = 1, V_j^{(0)} = 1$, where $W_i^{(0)}, V_j^{(0)}$ – weight values at zero iteration for the technical systems and their characteristics, respectively.

It is necessary to build the array technical systems from the available set of different models by preference, taking into account the set quality indicators x_{ij}, $i = \overline{1, n}$, $j = \overline{1, m}$. Then, make a choice of the most preferred technical system.

The problem is solved by implementation of spectral analysis iterative procedure:

$$W_i^{(k)} = \left(\sum_{j=1}^{m} V_j^{(k-1)} \tilde{x}_{ij} \right) \Big/ \left(\max_i \sum_{j=1}^{m} V_j^{(k-1)} \tilde{x}_{ij} \right) \quad (1)$$

$$V_j^{(k)} = \left(\sum_{i=1}^{n} W_i^{(k-1)} \tilde{x}_{ij} \right) \Big/ \left(\max_j \sum_{i=1}^{n} W_i^{(k-1)} \tilde{x}_{ij} \right) \quad (2)$$

where n is the number of technical systems;
m - the number of technical characteristics;
$k = \overline{1, K}$ – the iteration number in the iterative process (if $k \to \infty$, then W_i, $V_j \to const$); $W_i^{(k)}$, $V_j^{(k)}$ - weight values at k-iteration for technical systems and their characteristics, respectively;

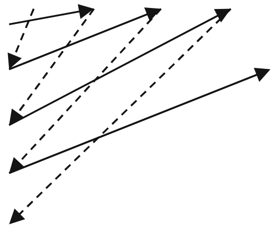
$$\tilde{x}_{ij} = \begin{cases} \frac{x_{ij}}{max\{x_{ij}\}}, \text{ if the increase } x_{ij} \text{ leads the enhancement of properties MV;} \\ \frac{min\{x_{ij}\}}{x_{ij}}, \text{ if the decrease } x_{ij} \text{ leads the enhancement of properties MV;} \end{cases}$$

It is suggested, the following algorithm for solving the problem of selecting the most appropriate technical system:

1. To build a calculated table in the form of Table 1 (the direction of the calculations is shown by arrows).

Table 1. Intermediate calculations form.

	V_1	…	V_j	…	V_m	$W_i^{(0)}$	$W_i^{(1)}$	$W_i^{(2)}$	$W_i^{(3)}$
W_1	$\tilde{x}_{11}$	…	$\tilde{x}_{1j}$	…	$\tilde{x}_{1m}$	1	$W_1^{(1)}$	…	$W_1^{(3)}$
…	…	…	…	…	…	…	…	…	…
W_i	$\tilde{x}_{i1}$	…	$\tilde{x}_{ij}$	…	$\tilde{x}_{im}$	1	$W_i^{(1)}$	…	$W_i^{(3)}$
…	…	…	…	…	…	…	…	…	…
W_n	$\tilde{x}_{n1}$	…	$\tilde{x}_{nj}$	…	$\tilde{x}_{nm}$	1	$W_n^{(1)}$	…	$W_n^{(3)}$
$V_j^{(0)}$	1	…	1	…	1				
$V_j^{(1)}$	…	…	…	…	…				
$V_j^{(2)}$	$V_1^{(2)}$	…	$V_j^{(2)}$	…	$V_m^{(2)}$				
$V_j^{(3)}$	…	…	…	…	…				
$V_j^{(4)}$	$V_1^{(4)}$	…	$V_j^{(4)}$	…	$V_m^{(4)}$				



2. To calculate the normalized matrix $\tilde{x}_{ij}, i = \overline{1,n}, j = \overline{1,m}$. Enter all the values $\tilde{x}_{ij}$ in Table 1.
3. For k = 1 to calculate by the Eq. (1) values $W_i^{(1)}$, assuming $V_j^{(0)}$ = 1 and taking values of $\tilde{x}_{ij}$, $i = \overline{1,n}$, $j = \overline{1,m}$ obtained in the previous step of the algorithm. Enter all the values $W_i^{(1)}$ in the Table 1.
4. For k = 2 to calculate $V_j^{(2)}$ by the Eq. (2) based on the data obtained in the previous step of the algorithm. Enter all the values $V_j^{(2)}$ in the Table 1.
5. To continue the calculation of the values of $W_i^{(k)}$ for odd iterations and $V_j^{(k)}$ for even iterations as indicated in steps 3 and 4 of the algorithm. The calculation was carried out as long as the value of $W_i^{(k)}$ and $V_j^{(k)}$ will not accept the weight values obtained at the previous iteration. A replay of the weight values usually starts at k $\geq$ 7.

6. Further filling of the Table 1 is carried out after settlement $W_i^{(k)}$ and $V_j^{(k)}$ by the Eqs. (1) and (2), but the calculation starts with finding the values $V_j^{(1)}$ assuming $W_i^{(0)} = 1$, and further by the algorithm.
7. Based on the obtained values of $W_i^{(k)}$ to build the array of technical systems MV_i, $i = \overline{1, n}$.
8. To determine the best technical system MV_i. The best option is the one, which have the highest value weight $W_i^{(k)}$.

2.2 Analytic Hierarchy Process

The analytic hierarchy process allows to solve the problem of choice on set of qualitative characteristics [14, 15].

The decision problem is decomposed into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently.

The method is based on constructing a hierarchy starting from the top (goal), through intermediate levels (a group of factors or criteria that relate the alternatives to the goal) to the very bottom level (the list of alternatives for reaching the goal).

Each element of the system, except for the top one, is subordinate to one or more other elements. The criteria can be further broken down into subcriteria, sub-subcriteria, and so on, in as many levels as the problem requires.

Then the hierarchy is analyzed through a series of pairwise comparisons: the criteria are pairwise compared against the goal for importance, the alternatives are pairwise compared against each of the criteria for preference. The comparisons are processed mathematically: at each level the set of matrix of pairwise comparisons is built (Table 2) [16, 17].

Table 2. Matrix of pairwise comparisons.

	A_1	A_2	A_3	...	A_n
A_1	w_1/w_1	w_1/w_2	w_1/w_3	...	w_1/w_n
A_2	w_2/w_1	w_2/w_2	w_2/w_3	...	w_2/w_n
A_3	w_3/w_1	w_3/w_2	w_3/w_3	...	w_3/w_n
...	...	...	...	...	...
A_n	w_n/w_1	w_n/w_2	w_n/w_3	...	w_n/w_n

$A_1, A_2, \ldots, A_n$ is the set of n elements and $w_1, w_2, \ldots, w_n$ respectively, their weight, or intensity. Weight, or intensity, of each element is compared with the weight or intensity of any other element of the set in relation to the common property or the goal (i.e. w_1/w_1 means comparison, not dividing the weights of these elements).

The comparison of weights can be represented as follows: the elements of any level are compared with each other regarding their effects on guided element on 9-point scale (from 1 – equal importance to 9 – very strong superiority).

If the element A_1 is dominant over the element A_2, the cell corresponding to the row A_1 and column A_2 is filled with an integer, and the cell corresponding to the row A_2 and column A_1 is filled with the integer reciprocal (fraction).

Then at each level the synthesis of priorities is made, i.e. for each row the geometric mean is calculated. The vector of priorities is obtained by dividing each geometric mean by the sum of all geometric means (Table 3) [18].

Table 3. Calculating of the vector of priorities.

	A_1	...	A_n	The rating of the eigenvector components by row	Vector of priorities
A_1	w_1/w_1	...	w_1/w_n	$\sqrt[n]{\frac{w_1}{w_1} \times \ldots \times \frac{w_1}{w_n}} = a_1$	$\frac{a_1}{\sum_{i=1}^{n} a_i} = x_1$
...	...	...	...	...	...
A_n	w_n/w_1	...	w_n/w_n	$\sqrt[n]{\frac{w_n}{w_1} \times \ldots \times \frac{w_n}{w_n}} = a_n$	$\frac{a_n}{\sum_{i=1}^{n} a_i} = x_n$

Multiplication of the matrix by the vector of priorities is as follows:

$$\begin{pmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{pmatrix} * \begin{pmatrix} x_1 \\ x_2 \\ \cdots \\ x_n \end{pmatrix} = \begin{matrix} \frac{w_1}{w_1}x_1 + \frac{w_1}{w_2}x_2 \ldots + \frac{w_1}{w_n}x_n = Y_1 \\ \frac{w_2}{w_1}x_1 + \frac{w_2}{w_2}x_2 \ldots + \frac{w_2}{w_n}x_n = Y_2 \\ \cdots \\ \frac{w_n}{w_1}x_1 + \frac{w_n}{w_2}x_2 + \ldots + \frac{w_n}{w_n}x_n = Y_n \end{matrix} \quad (3)$$

It is important to note that in the matrix of pairwise comparisons there is no ratio w_i/w_j, there are only integers or integer reciprocals from a scale. This matrix in the general case is inconsistent. Algebraically the problem of consistency is the solution of the equation $Aw = nw$, $A = (w_i/w_j)$, and the total task is the solution of the equation $A'w' = \lambda_{max} \cdot w'$, $A' = (a_{ij})$, where λ_{max} is the largest eigenvalue of the matrix of pairwise comparisons A.

To check the consistency of each matrix the eigenvalues of the matrix are calculated (as the sum of the vector components obtained by multiplying the matrix of pairwise comparisons by the vector of priorities):

$$\lambda_{max} = \sum_{i=1}^{n} Y_i \quad (4)$$

Next, the index of consistency (IC) and consistency ratio (CR) are calculated:

$$\text{IC} = (\lambda_{max} - n)/(n - 1), \quad (5)$$

where λ_{max} – eigenvalue of the matrix, n – the number of compared elements.

$$CR = IC/RI, \quad (6)$$

where RI – random index.

CR and IC should not exceed 10%. Otherwise, the quality of the judgments should be improved, perhaps by revising the way in which questions are asked when conducting pairwise comparisons.

When conducting assessments it is important to keep in mind all compare items to comparison was relevant. To conduct a reasonable numerical comparisons should not compare more than 7 ± 2 elements.

Then hierarchical synthesis is conducted, i.e. the sum of all the weighted components of the corresponding eigenvectors of the hierarchy level lying before is calculated.

3 Results Section

The buyer (auto enterprise) is studying the possibility of buying a car from a range of cars belonging to the same class. The proposed method was applied for solving the task of selecting the most appropriate car from four most widespread in Russia models: Ford Focus, Mazda 3, Nissan Sentra, Skoda Octavia.

Main quantitative technical specifications of cars are: curb weight, acceleration time up to 100 km/h, maximum speed, fuel consumption, engine power, torque, trunk volume.

3.1 Method of Spectral Analysis

Main quantitative characteristics of cars, selected for comparison, are presented in Table 4 [20].

For calculations has been used a program previously written in Delphi 7 [19]. The number of iterations was taken equal to ten (k = 10).

Table 4. Main quantitative characteristics of cars selected for comparison.

Car model	Quantitative characteristics						
	Curb weight, kg	Acceleration time up to 100, sec	Maximum speed, km/h	Fuel consumption, l	Engine power, kW	Torque, N*m	Trunk volume, l
Ford Focus	1284	11.8	195	8.7	92	159	388
Mazda3	1287	11.6	191	7.4	88	150	384
Nissan Sentra	1267	11.3	184	8.1	86	158	488
Skoda Octavia	1250	12.0	190	9.0	81	155	520

Initially, calculations are made for four cars and seven technical specifications. As a result of calculations was obtained the array of characteristics (the values of assessment are given in the brackets):

1. Curb weight, kg (1.000);
2. Acceleration time up to 100, sec (0.9854);
3. Maximum speed, km/h (0.9911);
4. Fuel consumption, l (0.9123);
5. Engine power, kW (0.9592);
6. Torque, N*m (0.9951);
7. Trunk volume, l (0.8713).

The array of options and the normalized array of options are presented in Table 5:

Table 5. The results of ranking of options of cars.

Car model	The values of assessment	Global priorities by quantitative characteristics
Ford Focus	0.9759	0.2478
Mazda3	0.9798	0.2488
Nissan Sentra	1.0000	0.2539
Skoda Octavia	0.9822	0.2494

3.2 Analytic Hierarchy Process

Experts in [20] identified five qualitative characteristics (criteria), which correspond to the car. Main qualitative characteristics of cars, selected for comparison, are: the driver's workplace, interior, driving performance, comfort, adaptability to Russia.

Driving performance includes dynamics, brakes, behavior on the road. None of the cars are quicker, especially Skoda. Mazda suffers from poor informative brake pedal, but has good handling. Ford has effective brakes compared to other models, but it has ambiguous settings electric power steering. Nissan-the worst handling, but has good brakes.

Adaptability to Russia includes accessibility, service, operation. All cars have a decent clearance. Skoda has a shorter warranty period than other cars, but it has no mileage restrictions. Ford has no filler neck tube. The other parameters of the machines are the same.

The driver's workplace includes the driver's seat, controls, overview. The worst driver's workplace compared to other has Nissan, the driver's seat with a modest range of adjustments in length is set too high and the steering wheel is too cheap, but it has excellent visibility, thin front struts are combined with a rear-view camera. Ford in the presence of the camera has a thick front struts. Skoda and Mazda have good visibility.

Interior includes comfortable cabin, ample trunk space and cargo. There are no serious claims to ergonomics. Skoda has a thoughtful and spacious interior, especially at shoulder level, the convenience of landing the driver. Mazda and Ford have a tight back row in all dimensions. Nissan is much more spacious. But Nissan fails (at head level) is located on the ceiling handles, Skoda is no Central headrest. In addition, Skoda has a huge functional trunk.

Comfort includes quiet cabin, smooth running, climate control. Mazda is the most noisy compared to other cars. Skoda engine noise during acceleration, but with uniform motion is the quietest. Nissan is the leader in smooth running. Mazda is outside rum for smoothness. In terms of climate control the best car is Ford, because it has a heated steering wheel and windshield. All cars except Skoda have dual-zone climate control. Skoda has a conventional air conditioning, but it has deflectors blowing the rear sofa.

The criteria pairwise comparisons, the vector of priorities and the result of their multiplication Y_i are presented in Table 6.

Table 6. Calculating of the criterion vector of priorities.

	C_1	C_2	C_3	C_4	C_5	The rating of the eigenvector components by row	Criterion vector of priorities	Y_i
C_1	1	2	3	5	7	2.914	0.423	2.173
C_2	1/2	1	3	5	7	2.208	0.320	1.641
C_3	1/3	1/3	1	2	3	0.922	0.134	0.674
C_4	1/5	1/5	1/2	1	2	0.525	0.076	0.385
C_5	1/7	1/7	1/3	1/2	1	0.321	0.047	0.235
						λ_{max} = 5.107	IC = 0.027	CR = 0.024

Criteria:

C_1 - driving performance;
C_2 - adaptability to Russia;
C_3 - the driver's workplace;
C_4 – interior;
C_5 – comfort.

The eigenvalue of the matrix, IC and CR were calculated by the Eqs. (4), (5) and (6), CR and IC are not exceed 10%.

The alternatives pairwise comparisons, the vectors of priorities, the results of their multiplication Y_i, λ_{max}, CR and IC for each alternative are presented in Table 7.

Alternatives:
A_1 - Ford Focus;
A_2 - Mazda3;
A_3 - Nissan Sentra;
A_4 - Skoda Octavia.

The eigenvalue of the each matrix, IC and CR were calculated by the Eqs. (4), (5) and (6), CR and IC are not exceed 10%.

Table 7. Calculating of the alternatives vectors of priorities

C_1	A_1	A_2	A_3	A_4	The rating of the eigenvector components by row	Alternative vector of priorities	Y_i
A_1	1	1	1	2	1.189	0.291	1.245
A_2	1	1	1/2	1/2	0.707	0.173	0.732
A_3	1	2	1	1	1.189	0.291	1.173
A_4	1/2	2	1	1	1.000	0.245	1.028
					λ_{max} = 4.177	IC = 0.059	CR = 0.066
C_2	A_1	A_2	A_3	A_4			
A_1	1	2	1	1	1.189	0.286	1.143
A_2	1/2	1	1/2	1/2	0.595	0.143	0.571
A_3	1	2	1	1	1.189	0.286	1.143
A_4	1	2	1	1	1.189	0.286	1.143
					λ_{max} = 4.000	IC = 0.000	CR = 0.000
C_3	A_1	A_2	A_3	A_4			
A_1	1	1	2	1	1.189	0.286	1.143
A_2	1	1	2	1	1.189	0.286	1.143
A_3	1/2	1/2	1	1/2	0.595	0.143	0.571
A_4	1	1	2	1	1.189	0.286	1.143
					λ_{max} = 4.000	IC = 0.000	CR = 0.000
C_4	A_1	A_2	A_3	A_4			
A_1	1	1	1/3	1/5	0.508	0.096	0.387
A_2	1	1	1/3	1/5	0.508	0.096	0.387
A_3	3	3	1	1/3	1.316	0.249	1.013
A_4	5	5	3	1	2.943	0.558	2.270
					λ_{max} = 4.058	IC = 0.019	CR = 0.021
C_5	A_1	A_2	A_3	A_4			
A_1	1	4	1	2	1.682	0.347	1.396
A_2	1/4	1	1/5	1/3	0.359	0.074	0.300
A_3	1	5	1	3	1.968	0.406	1.643
A_4	1/2	3	1/3	1	0.841	0.173	0.704
					λ_{max} = 4.043	IC = 0.014	CR = 0.016

The result of conducted hierarchical synthesis is presented in Table 8.

Table 8. The results of the selecting of the most appropriate car by analytic hierarchy process.

Car model	Global priorities
Ford Focus	0.276
Mazda3	0.168
Nissan Sentra	0.272
Skoda Octavia	0.284

The result of obtaining an integral assessment of the set of quantitative and qualitative characteristics for each car is presented in Table 9.

Table 9. The results of obtaining an integral assessment.

Car model	Global priorities
Ford Focus	0.524
Mazda3	0.417
Nissan Sentra	0.526
Skoda Octavia	0.533

4 Discussion Section and Conclusions

Thus, the best option by the set of quantitative characteristics may be to consider the Nissan Sentra. Skoda Octavia is significantly behind. Mazda3 and Ford Focus have approximately equal values of assessment. The most important characteristic is Curb weight. The best option by the set of qualitative characteristics may be to consider the Skoda Octavia, which combines the best driver's workplace, interior, driving performance, comfort and adaptability to Russia. The least successful is Mazda3.

Thus, in the array obtained on the basis of qualitative characteristics by analytic hierarchy process, considering the quantitative characteristics, the 2nd place takes Nissan Sentra, shifting Ford Focus to 3rd place, but the advantage of the Nissan Sentra before Ford Focus is slight. The best option by the set of quantitative and qualitative characteristics is Skoda Octavia.

It should be noted that the result of evaluation depends on the selected set of characteristics (quantitative and qualitative). It is important to choose from a large number of characteristics the main quantitative and the most important qualitative indicators.

The proposed method (combined use of spectral analysis and analytic hierarchy process for solving the problem of choice on set of qualitative and quantitative characteristics) allows reduce the subjectivity in decision-making, especially in conditions when a rapid assessment of alternative options is required. This method can be used not only to solve the problem of selecting the best car from available set, but also for any other technical systems.

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Control of Idle Losses in Power Transformers of Distribution Electric Networks

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Abstract. For lightly loaded electrical networks and for seasonally changing loads, it is proposed to reduce the idle losses in power transformers by changing the connection scheme of the primary and secondary winding coils provided that the transformation coefficient is constant. In this case, the transformer windings must have branches corresponding to the number of coils on the high and low voltage sides. The quantitative estimates of reducing the idle losses in power transformers by the proposed method are based on the methods of a full-scale experiment using the example of a single-phase transformer and simulation modeling of a three-phase power transformer. Circuit designs for sectioning the windings of power transformers are developed. For automatic control of losses in the transformer, an expression is obtained for reducing the total losses in the transformer by changing the connection scheme of the coils of the primary and secondary windings when the load changes. From a practical point of view, a transformer with a change in the connection schemes of its windings using the proposed method can find application as a power transformer of distribution networks with a voltage of 35, 10 (6)/0.4 kV with a load of less than 20% (summer and cottage villages, seasonal loads of industrial enterprises).

Keywords: Power transformer · Reduction of losses · Experiment · Simulation modeling · Sectioning of state windings

1 Introduction

Improving the efficient performance and energy efficiency of electric power transmission in traction and distribution electric networks is achieved primarily by reducing energy losses. A significant share in the structure of technical losses of distribution networks is occupied by the idle losses in transformers at a voltage level of 6–10 kV, reaching 70% of technical losses with a small load on the electric network.

In the distribution networks of railways, oil transformers with a capacity of 100 to 1000 kV A are mainly installed. Losses of idle electricity within the boundaries of the West Siberian Railway in power transformers with a voltage of 6–10 kV amounted to about 9.59 million kW h in 2018.

Nowadays, the problem of reducing idle losses in power transformers is solved mainly by turning off one of two parallel transformers working at light loads (if possible),

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replacing transformers with transformers with lower installed capacity, which corresponds to the load, or with an energy efficiency of a higher class [1]. Also, the idle losses in the transformers depend on the voltage level on its primary winding, but the installed control means do not allow for “loss control”.

For lightly loaded electrical networks and for seasonally changing loads, it is proposed to reduce the idle losses in power transformers by changing the connection scheme of the primary and secondary winding coils provided that the transformation coefficient is constant. In this case, the transformer windings must have branches corresponding to the number of coils on the high and low voltage sides.

2 Theoretical Part

According to the European standard [2], the following energy classes of transformers are distinguished: A, B, C, D, E. Class A transformers have the best energy efficiency.

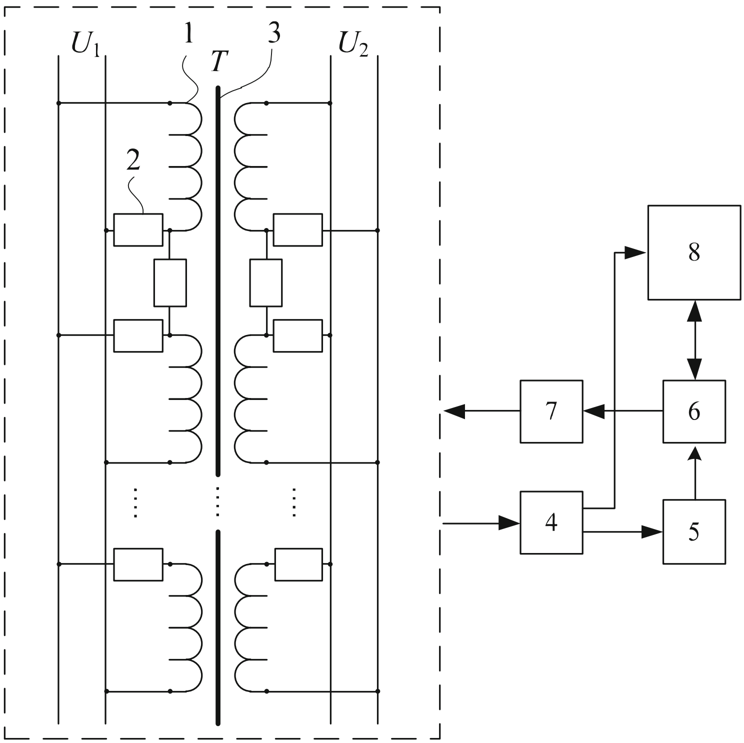
Modern domestic transformers mainly belong to class D and E in accordance with the European standard [2]. For example, a transformer with rated voltages of 10/0.4 kV of TMG type (three-phase transformer with oil and air cooling, totally enclosed) with a power of 400 kV•A (Sverdlovsk Works of Current Transformers JSC, Russia) has an idle loss power of 900 W, a short circuit power of 4900 W, and a Shingle transformer of AoAk type (ABS MINEL-TRAFO, Serbia) - idle power loss of 370 W, short circuit power of 3000 W.

A significant increase in the energy efficiency of transformers is ensured by the use of magnetic cores made of amorphous alloys and windings made of foil or high-temperature superconducting materials [3].

Obviously, the economic effect of the proposed measures to reduce losses in power transformers can be achieved on busy sections of the distribution network.

The problem of optimizing the mode parameters to minimize power losses in the electric network is usually solved in relation to load losses of electricity or power [4–6]. Conditionally constant losses are not controlled in electric networks. Under low load conditions, the issue of reducing idle losses in power transformers is particularly acute.

Figure 1 shows a diagram of a single-phase transformer with coils on the low and high voltage sides, and a control system. A three-phase transformer with a different number of winding coils (layers) having their own terminals (branches) is implemented in a similar manner. When the load of a transformer is close to nominal, the primary and secondary coils (layers) of the windings 1 are connected in parallel, providing the nominal parameters of the transformer, including the designed magnetic flux. With a decrease in the load power, it is possible to reduce the power of the transformer by simultaneously switching the connection circuit of the coils on the low and high voltage sides from parallel to serial (in-phase) or serial-parallel (with the number of coils more than four). In this case, the cross section of the windings is inversely proportional to the number of coils, i.e. the mass of active materials of the whole and sectioned winding (excluding terminals) is the same.



1 – coil (layer) of the transformer winding; 2 - switching devices; 3 - magnetic core; 4 - measuring module; 5 - state assessment module; 6 - coordination module; 7 - control actions generating module; 8 - top-level (network) control system

Fig. 1. Transformer scheme.

As is known [7], the induction in the magnetic core of a transformer is determined by the expression, T:

$$B = \frac{U_t}{4.44 \cdot f \cdot P_r}, \tag{1}$$

where f – frequency of supply voltage, Hz; Pr - active section of the rod, m2; Ut - turn voltage, V:

$$U_t = \frac{U_f}{w}, \tag{2}$$

Uf – winding voltage, V; w - the number of turns per winding voltage.

The idle power loss in a transformer mainly consists of magnetic losses (for hysteresis and eddy currents) and electric losses in the primary winding from the idle current [7]. In this case, the magnetic losses P_{mag} are proportional to the induction B and frequency f according to the relation:

$$P_{\text{mag}} = B^n f^{1.3}, \tag{3}$$

where n = 1.7 – 2.8, depending on the steel type of a magnetic core.

Thus, switching the coils of the primary and secondary windings from parallel to a serial circuit at low loads will reduce the voltage per turn of the primary winding, and, consequently, reduce the induction and magnetic flux by half, idle losses in the transformer by about four times. In this case, the nominal (for the new circuit) power will be reduced by half. This will increase electrical losses relative to the parameters of the original circuit at the time of switching by four times. Therefore, the circuit should be switched when the load factor of the transformer is less than 0.5, at the moment when the electrical loss will be equal to the idle loss.

It should be noted that to prevent the occurrence of equalizing currents, the voltage at the branches of the secondary windings should not differ from each other by more than 3% [8].

The expansion of the functionality of the transformer can be ensured by automatically controlling the change of winding sectioning schemes. For this, data from measuring transducers (currents, voltages, powers) and position sensors of switching devices are continuously transmitted to measuring module 4 of the device (Fig. 1). The received data array is continuously fed to the state assessment module 5, in which the analysis of the compliance of the received data with the established requirements of the rated mode of the adjustable transformer is performed. Based on the obtained data and the logic of the implementation of technological functions (for example, the minimum loss in the transformer) of the control, control actions are generated that are coordinated in module 6 with the control system of the upper level (network) 8. In the control actions implementation module 7, a coordinated signal is generated to control switching devices 2.

To solve the set problems, the methods of full-scale experiment and simulation modeling were used.

3 Practical Part

The experimental research program was carried out taking into account the provisions of Russian State Standard GOST 3484.1-88 [9] and included the measurement of idle losses, determination of the parameters of the T-shaped equivalent circuit, and other characteristics of the SOBS-2A single-phase transformer with different winding connections (Fig. 2) [7]. The measurements were carried out for idle mode, short circuit, mode with active-inductive load of the transformer.

The signal single-phase armored dry (SOBS) transformer is designed for powering traffic lights and has the following technical characteristics: power 135 V A, rated voltage of the primary winding 220 V, rated current of the primary winding 0.7 A, rated current of the secondary winding 3.86 A, rated voltage of the secondary windings 28 V.

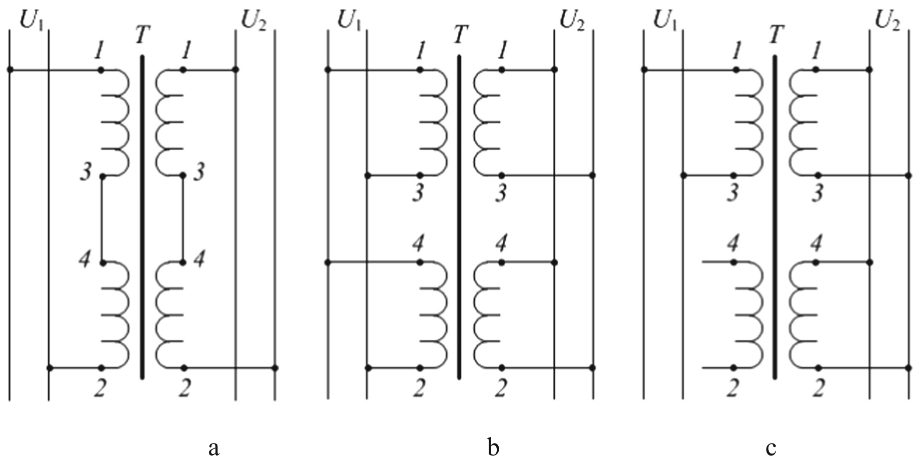


Fig. 2. Connection diagram of transformer windings.

The results of experimental studies of the transformer are presented in Tables 1 and 2.

Table 1. The results of measurements and calculations in an idling mode.

№	Diagram in Fig. 2	U_1, V	I_{10}, A	P_{10}, W	Q_{10}, var	U_{20}, V	r_0, O	x_0, O	z_0, O	cos φ_0
1	a	220	0.04	3.2	6.7	29.5	2000	5123	5500	0.36
2	b	220	0.28	12	53	29.5	153	771	786	0.19
3	c	220	0.28	13	54	29.5	166	768	786	0.21

Table 2. The results of measurements and calculations in a shirt circuit mode.

№	Diagram in Fig. 2	U_{1k}, V	I_{1k}, A	P_{1k}, W	I_{2k}, A	r_k, O	x_k, O	z_k, O	cos φ_k
1	a	7.3	0.19	1.3	0.95	36.01	13.39	38.42	0.95
2	b	13.8	0.71	5.1	3.82	10.12	16.60	19.44	0.52
3	c	14.0	0.73	5.8	3.87	10.88	15.79	19.18	0.57

Based on the obtained parameters of the equivalent circuit of the SOBS-2A single-phase transformer, its simulation modeling was performed in Matlab Simulink taking into account hysteresis losses, eddy currents and core saturation (Fig. 3). The main assumptions made during modeling are: stepwise setting the saturation curve of the transformer magnetic core, setting transformer parameters (r0, x0, rk, xk,) based on the T-shaped equivalent circuit [8]. The reliability of the results is confirmed by the experiment conducted in accordance with Russian State Standard GOST 3484.1-88 [9] and the coincidence of the obtained values with simulation modeling with an accuracy of about 5–10%.

Analysis of the results allows drawing the following conclusions:

– reduction of idle losses P10 in the diagram in Fig. 2a with respect to the diagram in Fig. 2b is about 4 times, which corresponds to relation (3);
– a slight increase in idle losses in the diagram in Fig. 2c with respect to the diagram in Fig. 2b is caused by an increase in electric losses in the primary winding from the open circuit current; therefore, the use of this diagram is impractical;
– reduction of short circuit losses P_{1k} in the diagram in Fig. 2a with respect to the diagram in Fig. 2b and c is caused by a decrease in the current (available power) of the windings and an increase in their resistance.

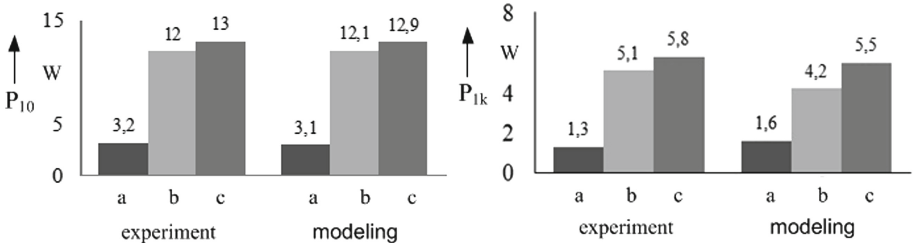


Fig. 3. The results of the experiment and simulation modeling of the SOBS-2A transformer.

Due to the proposed change in the connection scheme of the coils of the primary and secondary windings under the condition of a constant transformation coefficient (Fig. 2a, b), idle losses are reduced, but the equivalent resistance of the windings is increased by four times. Therefore, short circuit losses increase (in copper). Thus, the total losses in the transformer under consideration at a certain load can not only decrease due to idle losses, but also increase due to an increase in electric losses in the windings.

To assess the reduction in losses in a three-phase power transformer TM 400 with a voltage of 10/0.4 kV by changing the connection schemes of its windings in accordance with the proposed method (Fig. 2a, b), its simulation was performed in Matlab Simulink.

Figure 4 shows idle losses (no-load losses), short-circuit losses, and total power losses of TM 400 transformers with a voltage of 10/0.4 kV according to passport data at rated load (Fig. 4a) and with a load factor of 0.5 (Fig. 4b), as well as with the winding connection diagram according to Fig. 2a with a serial connection of windings split into two coils (TM 400, a = 2) with a load factor of 0.5 (Fig. 4c).

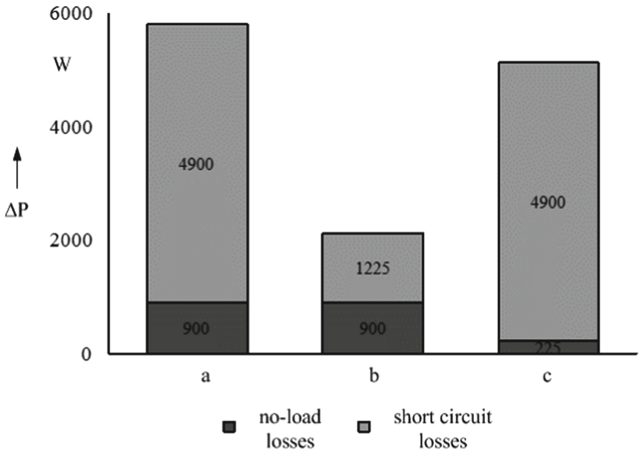


Fig. 4. Power losses in power transformers.

In order to assess a load at which the total losses of the transformer with the serial connection of two (a = 2), three (a = 3) and four (a = 4) split coil windings will be lower than with parallel connection (a = 1), a simulation modeling of the change in the total power losses in the TM 400 power transformer with the corresponding winding connection was performed (Fig. 5).

The load factor of the transformer, within which a reduction in losses due to a change in the winding connection diagram is achieved, is determined by the expression:

$$\kappa_{\mathrm{lmax}} = \frac{1}{a}\sqrt{\frac{P_0}{P_k}}, \tag{4}$$

where a − number of transformer winding coils connected in series.

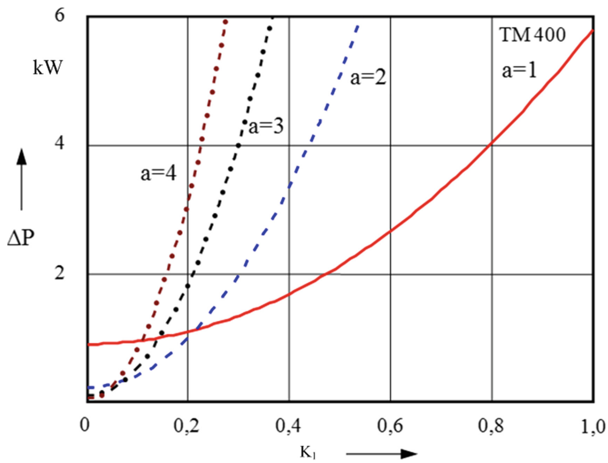


Fig. 5. Change in power loss in power transformers.

Expression (4) is obtained based on the equality of the total losses of the transformer with parallel and serial connection of the coils of its winding.

An analysis of the ratios of idle and short circuit losses (Figs. 4 and 5, formula (4)) indicates that the reduction of losses in the TM 400 transformer (a = 1), and, consequently, the regulation efficiency, is ensured with a load factor not exceeding:

0.214 with serial connection of windings split into two coils (a = 2);
0.143 with a serial connection of windings split into three coils (a = 3);
0.107 with a serial connection of windings split into four coils (a = 4).

Obviously, when a = 4, the number of combinations of connecting the coils of the transformer windings increases, for example, series-parallel connection is possible.

From the expression (4) it also follows that the maximum possible depth of regulation of power losses in the transformer corresponds to the equality of the idle and short-circuit losses at a load factor of 0.5, i.e. with an increase in idle losses of transformers, the depth of regulation of power losses increases.

For automatic control of losses in the transformer (Fig. 1), the expression for reducing the total losses in the transformer due to a change in the connection scheme of the coils of the primary and secondary windings with a change in load was obtained:

$$\Delta P(\kappa_1) = (\mathrm{a}^2 - 1)\left[\frac{P_0}{\mathrm{a}^2} - \kappa_1^2 P_k\right]. \tag{5}$$

It can be seen from formula (5) and Fig. 5 that the saving of power losses occurs only when the load factor is less than 0.2.

4 Conclusion

It is obvious that the transformer under consideration with a change in the winding connection schemes will have a higher cost due to changes in the design of the windings and their insulation, while the overall dimensions of the transformer will increase slightly, mainly due to the longitudinal insulation of the windings. The mass of active materials, i.e. windings and magnetic core, will remain the same. It is possible to change the ratio between the width and height of the transformer magnetic core due to an increase in the longitudinal insulation of the windings [7].

A more detailed assessment of the characteristics of the transformer under consideration can be performed according to the design results.

From a practical point of view, a transformer with a change in the connection schemes of its windings using the proposed method can find application as a power transformer of distribution networks with a voltage of 35, 10 (6)/0.4 kV, in which the load will be less than 20% for a significant part of the time (summer and cottage villages, seasonal loads of industrial enterprises). In addition, the above figure and formula show that the use of four windings will give an effect only when the transformer is loaded less than for 2.5%. Therefore, it is rational to use only two windings. The use of the proposed sectioning of the transformer windings will allow increasing its efficient performance by reducing losses at low loads. Also, the commissioning of the transformer, first with serial, and then with the parallel connection of the windings, will significantly limit the short circuit current (inrush magnetization current).

Automatic control of changes in winding sectioning schemes will expand the functionality of an automated process control system of substations in the task of reducing energy losses. The main components of such a system when changing load curves in real time are discussed in more detail in [4].

The obtained formulas (4) and (5) can be used in the design of the considered transformers with split windings and a feasibility study for controlling power losses in transformers according to real load curves.

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Financial Analysis in Budgetary Institutions

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Abstract. The article illustrates the relevance of developing new directions in the analysis and performance evaluation techniques aimed at results-based management optimizing the use of budgetary institutions' resources. It is noted that among the existing funds, a set of measures of public administration and improving the efficiency of the use of Finance has been developed. The paper considers and analyzes the problems that hinder the construction of an effective system of analysis. The aim of the study was to find innovative approaches to the formation of a system to improve the efficiency of the use of public financial and material resources. The assessment of a state institution's financial condition, its financial results, and risks is implemented by analysing the financial and economic activities of the budgetary institution. The article addresses the problem of determining the proper objectives of financial analysis in an institution, along with the sources of information. The authors also assess the priority methods. The article also analyzes the risks of the budget institution and assesses them in terms of inefficiency of budget execution on the basis of both accounting (financial) statements and non-accounting information. In General, the mechanism of financial analysis, which allows to increase the effectiveness of state control, is proposed.

Keywords: Analysis · Balance sheet · Report · Method · Depreciation · Coefficient

1 Introduction

In modern economic conditions, the process of deeper introduction of public finance in the economy takes place. This process requires the relevant techniques, extensive authority and versatile functions of state financial control. The possibility of succeeding in the specified directions is associated with achieving the best results while using the least resources.

The introduction of international financial reporting standards for the public sector in Russian accounting is aimed at achieving the primary goal – improving the efficient use of state financial and material resources and, accordingly, the effectiveness of state control.

In this regard, the comprehensive analysis of economic processes at the level of financial and economic activities of economic entities is of paramount importance. This creates favourable conditions for the development of financial analysis of state institutions activities [2, 5, 12].

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1.1 Theoretical Background

Figure 1 shows a set of public management activities and measures to enhance the effective use of financial resources.

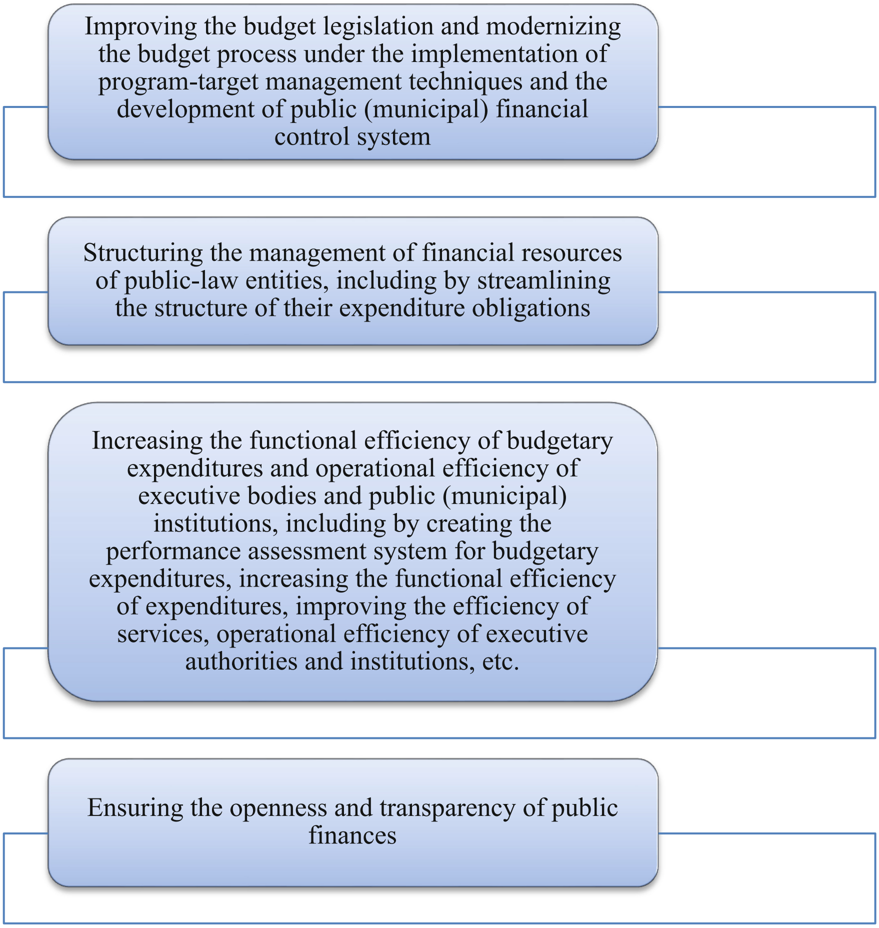

Fig. 1. A set of public management activities and measures to enhance the effective use of finance resources.

When addressing this issue, it is worth noticing that in the commercial sphere, it is medium-sized and large businesses that engage in financial analysis, since data received from standard forms of financial statements are not enough for managerial decision-making. The established finance analysis process to a certain extent characterizes the maturity of an enterprise. The reorientation from resource management to performance management in the public sector has set the budgetary institution with challenges similar to those facing a regular business. It is important for both the founder and the institution to achieve the goals by rational spending of resources within the permissible risk zone [1, 9, 10].

Financial analysis allows controlling this through a system of indicators of a budget institution, by comparing their actual values with the planned and similar in type of activity (Fig. 2).

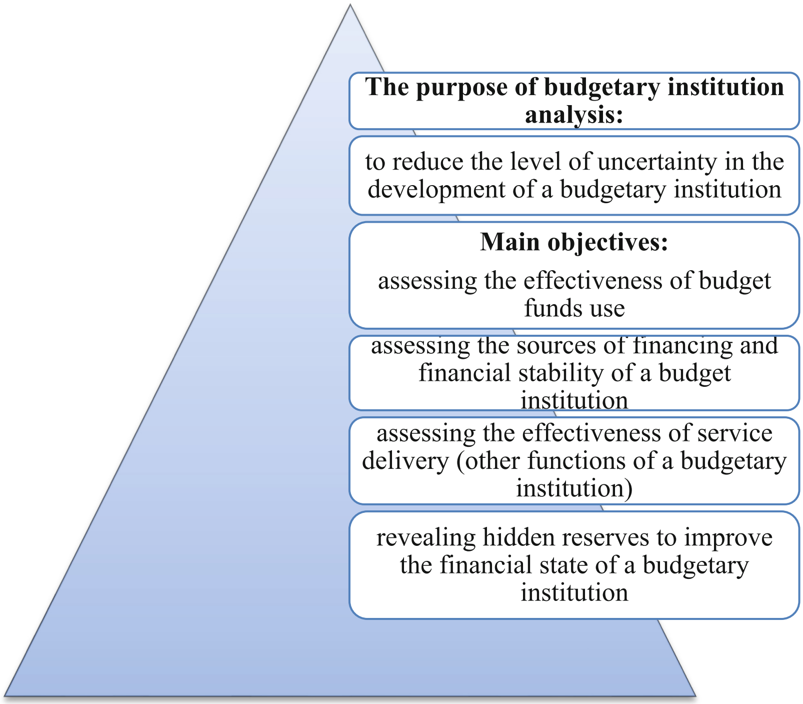

Fig. 2. Goals and objectives of financial analysis of budgetary institutions.

1.2 Methods

Accounting (financial) records are a source of financial analysis (Fig. 3).

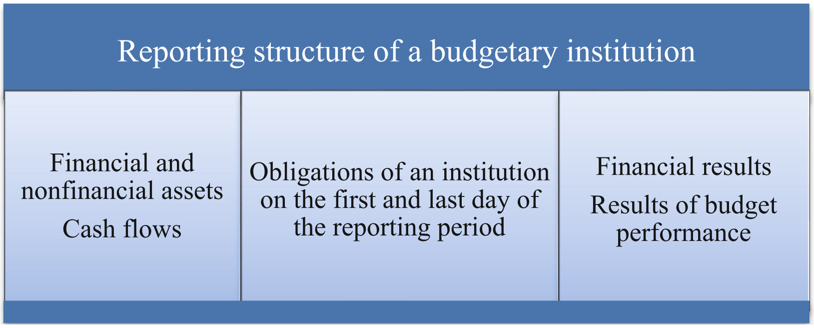

Fig. 3. Reporting structure of a budgetary institution.

The list of accounting (financial) statement indicators of a budget institution used for financial analysis includes [3, 6, 8]:

(1) balance sheet indicators (assets, liabilities, net assets). They provide information on the distribution of assets of a budget institution by articles, the need for investment, the ratio of fixed and current assets, along with the amounts of receivables. The analysis of the structure of liabilities, long-term and short-term debt provides important information. The balance sheet formula is presented in Fig. 4;

Fig. 4. Mathematical definition of the balance sheet.

(2) indicators of the report on the financial performance that characterize the economic features of revenues and expenses for the reporting period. The main goal of state institutions is not to receive profit, but to control budget funds. Revenues are important for government activities that are wholly or partly funded by consumer fees. However, for activities funded primarily from budgetary allocations, the primary interest is costs;
(3) cash flow statement indicators reflecting cash inflows and outflows. This information is of interest to analyse the inflow sources and expenditure during the reporting period;
(4) report indicators comparing the approved budget with the budget execution;
(5) explanatory note to the disclosed indicators;
(6) explanations [4, 7, 11].

1.3 Results

When conducting financial analysis, it is necessary to consider that the indicators presented in the financial statement are interconnected. For example, the depreciation presented in the statement of financial performance compared with the volume of assets from the balance sheet provides information on the write-off volumes and possible investments. The analysis of reporting indicators allows concluding about the proper or inappropriate activities of a budget institution, to decide whether it is possible to trust its leader in the future and to change the direction of its activities.

Let us further consider some analysis methods of financial and economic activities applicable to budgetary institutions.

2 Ratio Analysis Method

The coefficients are relative indicators, calculated based on accounting entries. They include the following groups:

2.1 Stability Ratios (Fig. 5, Table 1)

The financial stability ratio provides protection against the bankruptcy risk. It is a ratio of capital to borrowed funds (leverage). Limiting the leverage ratio through financial stability contributes to minimizing the risks associated with the generation of losses, early withdrawal of loans by lenders, and cash gaps.

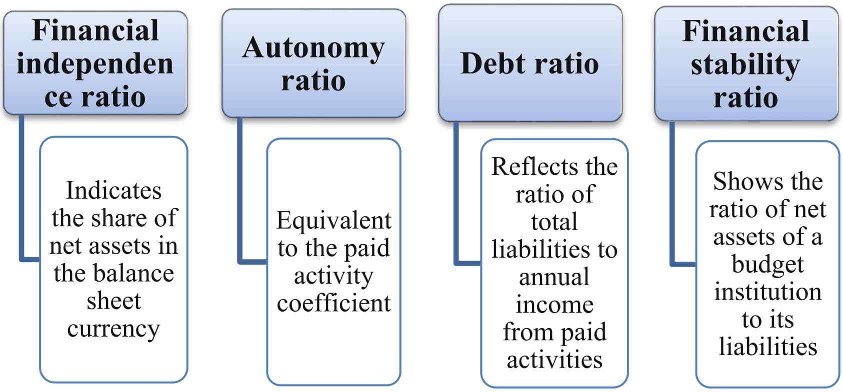

Fig. 5. Stability ratios.

Table 1. Characteristics of the financial stability ratio.

Indicator	Criterion	Characteristic
Financial stability ratio	Not lower than 0.5–0.7	At least 50–70 kop. of capital should be allocated per 1 ruble of borrowed funds

When setting the value of the financial stability standard, it is worth considering that in economic growth, the coefficient may be lower than in a crisis. Industry specifics also affect the standard value: regular cash flow from several independent clients forms the basis for lowering the indicator, and on the contrary, irregular receipts, high concentration of revenue on large customers are grounds for tighter conditions and higher indicator. Depending on the macroeconomic situation and the type of institution activity, the ratio may vary from 0.2 to 1.

Example 1. Let us calculate the financial stability ratio of an enterprise based on the balance sheet presented in Table 2.

Table 2. Notional balance sheet of an enterprise.

Balance sheet	Amount, thousand rubles
Cash	2,000
Current assets (excluding cash)	16,000
Fixed assets	12,000
Total assets	30,000
Capital (equity)	10,000
Short-term liabilities	14,000
Long-term liabilities	6,000
Total liabilities	30,000

Rfin. stab. = (10,000/(14,000 + 6,000) thousand rubles) × 100% = 50%.

Conclusion: The ratio is in the acceptable risk zone.

A budgetary institution interested in increasing its budget revenues may use the concept of cost of capital for the following purposes:

- to calculate the alternative use of the property (for example, which is more profitable – to operate real estate and spend money in extrabudgetary activities or to lease property and place funds on deposit);
- to access the effectiveness of bank loans.

2.2 Liquidity Ratio (Absolute Liquidity, Urgent Liquidity, Current Liquidity)

The liquidity of a budgetary institution is the ability to make timely payment of monetary obligations of the federal budget at a certain point in a financial year.

To calculate the liquidity of cash in the economic sphere, one can use such indicators as quick, current and long-term liquidity ratios. However, the traditional method of calculating the liquidity ratio is not suitable for public finance. It is worth noticing that in Russia the budget is implemented rather unevenly. This is mainly because most contracts payments are made at the end of the year. Moreover, there is a practice of developing significant budget funds at the end of the year.

Considering the specifics of budgetary institutions, one can use the working capital ratio (WCR) to calculate the liquidity ratio:

$$R_{liq} = CB_{kg}/(1/12\,E) + (1/12\,P),$$

where CB_{kg} refers to cash balance at the reporting date;

1/12 is the WCR rate;

E refers to the federal budget expenditures for the corresponding year;

P refers to the payments from sources of financing the federal budget deficit.

3 Net Asset Value Method

To calculate the efficiency of using net assets of a budget institution, one needs to decide on the funds attributed to this category of assets. The financial result listed in the balance sheet liabilities forms the assets working in extrabudgetary activities.

As for the founder's funds, they participate in both major financial and extrabudgetary activities. Budgetary institutions can fully take them into account when calculating the net assets or allocate some conditional part of the founder's funds involved in extrabudgetary activities. One can use income or another more suitable indicator (salary rate, floor space) as an indicator to distinguish the founder's funds between the major financial and extrabudgetary activities. It is also possible to use the procedure established for calculating the ratios of paid activity.

Example 2. Based on the balance sheet of a budgetary institution, let us determine the size of net assets, provided that the assets are not divided between the major financial and extrabudgetary activities (Table 3).

Table 3. Notional balance sheet of a budgetary institution.

	Balance sheet account	Total, thousand roubles
Assets		
1	Residual value of tangible assets	199,518
2	Residual value of intangible assets	184
3	Inventories	13,792
4	Investments in nonfinancial assets	2,362
5	Production costs	580
Total nonfinancial assets		216,436
6	Monetary resources	161,072
7	Income Calculations	−5,614
8	Calculations on advances paid	22,740
9	Calculations with accountable persons	108
10	Other accounts receivable	−179,920
10.1	Calculations for VAT tax deductions	1,374
10.2*	Settlements with the founder	−337,294
10.3*	Depreciation of assets of particular value	156,000
10.4	Residual value of assets of particular value	−181,294
Total financial assets		−1,614
Balance		214,822
Liabilities		
11	Settlement of commitments	1,266
12	Settlements for payments to the budget	1,220
13	Other settlements with creditors	44
Total liabilities		2,530
14	Financial results	212,292
Total financial results		212,292
Balance		214,822

* Data in lines 10.2 and 10.3 are not included in the balance sheet currency

Net assets are calculated as follows:

$$\mathrm{NA} = (212.292 + 181.294)\,\text{thousand roubles} = 393,586\,\text{thousand roubles}$$

When assessing the effectiveness of a budgetary institution, it is necessary to take into account all funds involved in income-generating activities: the founder's and the institution's own funds.

Particular attention should be paid to assessing the financial stability of a budgetary institution: compared to commercial organizations, the situation here looks different.

Example 3. Based on the balance sheet of a budgetary institution, let us calculate the financial stability ratio (data in Table 3):

$$\begin{aligned} \mathrm{R}_{\text{fin. stab.}} &= 212,292\,\text{thousand roubles}/(2,530 + 5,614)\text{thousand roubles} \times 100\% \\ &= 2,607\%. \end{aligned}$$

The capital exceeds the liabilities by 26 times. This fact indicates an extremely high security of obligations by the own funds of a budgetary institution due to their low value.

Let us examine the structure of the net assets of a budgetary institution. Net assets and net equity represent equity, respectively, for assets and liabilities. As a rule, net assets are not separated by items in the assets of the balance sheet – only their total value is calculated. At the same time, based on the conditions of economic feasibility, when the capital primarily includes low-liquid assets, and lastly the money, their conditional separation is possible. Indeed, the funds of creditors will first be charged from the institution accounts, and only then from less liquid assets.

Example 4. Based on the balance sheet (Table 3), let us disclose the structure of net assets including the owner's equity.

Net assets amount to 393,586 thousand rubles (Table 4).
Nonfinancial assets within the size of net assets are 216,436 thousand rubles.
Net asset balance = 393,586 – 216,436 = 177,150 thousand rubles.
Calculations within the size of net assets = 22,740 + 108 + 1,374 = 24,222 thousand rubles.
Net asset balance = 177,150–24,222 = 152,928 thousand rubles.
Financial resources in net assets = 152,928 thousand rubles.

Table 4. The structure of net assets of a budgetary institution including the owner's equity.

Net assets	Value, thousand rubles	Share, %
Nonfinancial assets	216,436	55
Calculations	24,222	6
Financial resources	152,928	39
Total net assets	393,586	100

This structure determines the potential for extrabudgetary activities of budgetary institutions. The net assets structure shows that the institution has everything necessary for the smooth operation (fixed and cash assets).

Example 5. Based on the balance sheet (Table 3), let us disclose the structure of net assets excluding the owner's equity.

Net assets amount to 212,292 thousand rubles (Table 5).
Nonfinancial assets within the size of net assets = 216,436 − 181,294 = 35,142 thousand rubles
Calculations = 24,222 thousand rubles,
Financial resources = 152,928 thousand rubles.

Table 5. The structure of net assets excluding the owner's equity.

Net assets	Value, thousand rubles	Share, %
Nonfinancial assets	35,142	17
Calculations	24,222	11
Financial resources	152,928	72
Total net assets	212,292	100

This structure determines the internal reserves of a budgetary institution in the field of loss coverage. A high proportion of financial resources creates a solid margin in case of unforeseen circumstances.

4 Degree of Operating Leverage

As an element of financial analysis in budgetary institutions, one can use the degree of operational leverage, the essence of which is that by changing the volume of services provided and the cost structure, it is possible to change the profit value.

This technique is based on the division of costs into conditionally constant and conditionally variable. The operating leverage shows by how many times the rate of change in profit from the provision of services exceeds the rate of change in revenue from the provision of services.

The degree of operational leverage manifests itself in both the major financial and extrabudgetary activities of a budget institution. The financing system through the state (municipal) assignment is a classic reimbursement scheme of fixed and variable costs. Property maintenance costs relate to fixed costs, the value of which is insensitive to changes in the volume of state assignments or additional paid services. In practice, the operating leverage leads to the following results:

(1) if the volume of the state assignment (paid activity) increases, in the conditions of constant property maintenance costs, a budgetary institution receives savings (profit);

(2) if the volume of the state assignment (paid activity) decreases, in the conditions of constant property maintenance costs, this leads to the over-expenditure (loss) in a budgetary institution.

Today, the use of this technique seems appropriate.

Previously, the degree of operational leverage did not pose a threat to the activities of budgetary institutions, as, firstly, in the conditions of good budget filling, the size of the state assignment was high, and secondly, the founder covered property maintenance costs even if it brought income from the paid activity.

Today the challenge is to prevent the negative side of the operating leverage, which can be achieved either by increasing the provision of paid services of a budgetary institution or by selling assets surplus. Moreover, budgetary institutions must solve this task under adverse macroeconomic conditions (under the reduced purchasing power of the population and business activity of the business sector).

5 Depreciation Analysis

The depreciation of valuable movable and immovable assets of an institution, in respect of which the institution does not have the right of independent disposal, is repeatedly reflected in the balance sheet of a budgetary institution. The depreciation:

– reduces the book value of assets;
– reduces debt to the founder;
– increases the positive financial result of a budgetary institution.

By reducing the book value of assets by the amount of depreciation, one can calculate the residual value of assets, objectively reflecting its real value, which corresponds to the generally accepted practice of financial reporting.

Although the budgetary institution's debt to the founder for the transferred assets is reflected in the balance sheet, it does not affect the balance sheet currency. When calculating the balance sheet currency, one should consider an indicator reflecting the difference between settlements with the founder and depreciation accrued on valuable assets.

Thus, financial reporting of a budgetary institution implies amortization of the debt to the founder. In this case, settlements with the founder are reflected in the asset balance with a negative sign. By contrast, it should be noted that for commercial institutions, the founders' (participants') contributions are recorded in the liability balance in own funds as equity capital and are not reduced as depreciation on assets is accrued to the authorized capital.

Another characteristic of a budgetary institution balance sheet is the reflection in its composition of a positive financial result of depreciation calculated on valuable assets. This is because budgetary institutions do not pay for the acquisition of these properties and do not have a debt affecting the balance sheet currency.

An example of a balance section of a budgetary institution is presented in Table 6.

Table 6. Example of a balance section of a budgetary institution.

Assets		Liabilities	
Balance sheet	Thousand roubles	Balance sheet	Thousand roubles
Nonfinancial assets		Financial results	
Book value of valuable assets*	200,000	Financial result of accrued depreciation of valuable assets	50,000
Depreciation of valuable assets**	50,000		
Residual value of valuable assets	150,000		
Financial assets			
Settlements with the founder***	−200,000		
Depreciation of valuable assets****	50,000		
Residual value of valuable assets	−150,000		

Note: data in lines marked with "*" are not included in the balance sheet currency.

Similar operations in a commercial organization are presented in Table 7.

Table 7. Notional balance sheet of a commercial organization.

Assets		Liabilities	
Balance sheet	Thousand roubles	Balance sheet	Thousand roubles
Book value of assets*	200,000	Authorised capital	200,000
Depreciation of assets	50,000		
Residual value of assets	150,000		

* Data on book value and depreciation value are not included in the balance sheet currency.

The share of accrued depreciation (reflected in the liability side of a balance sheet as a positive financial result) in the balance sheet currency of a budget institution is significant. Since settlements with the founder, reduced by the depreciation amount, are reflected in the assets with a negative sign, they cover the residual value of the valuable assets indicated in the noncurrent assets section.

Thus, there is a mutual absorption of balance sheet accounts, while the residual value of valuable assets has no effect on the balance currency of a budgetary institution. When assessing the balance of a budgetary institution in terms of the rules of commercial organizations, on the one hand, there is an overestimated profit, and on the other hand – an understated asset. When analysing financial activities of a budgetary institution, it is necessary to transform the balance to assess the efforts of a budgetary institution itself and the impact on the financial result of using the owner's equity. How does one assess a positive financial result in terms of accrued depreciation? Of course, it increases profit; however, it cannot be recognized as received at the expense of labour efforts of a budgetary institution. It is a sort of "gift". However, this profit is quite rightly taken into account when calculating the own funds of a budgetary institution when it is necessary to assess the financial stability (solvency) of an autonomous institution. It is advisable to calculate financial indicators in two sections: with and without accrued depreciation. As for the assets reflected in the asset of a balance sheet, when assessing the effectiveness of extrabudgetary activities, it is possible to divide the assets using the ratio of paid activity.

6 Conclusion

The above findings lead to the following conclusion:

When assessing the efficiency of using budgetary resources and developing techniques for measuring and creating performance criteria, one should consider not only the economic component linking the volume of works (services), the result with the cost of their provision, but also various other components of efficiency.

Financial analysis is intended to ensure an objective assessment of budgetary institution activities. Based on the analysis results, the founder and the director of a budgetary institution make management decisions to ensure the development of an institution. Financial analysis techniques allow comparing the actual values of indicators with those obtained in the context of rationing, previously planned or industry average. Comparative analysis of budgetary institutions does not only allow the founder to monitor subordinate agencies, the analysis results are also taken into account when allocating grants to perform government assignments.

Thus, financial indicators reflect the activities of a budgetary institution and its financial situation in a quantitative ratio.

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Freight and Logistics, Traffic Modelling

Modelling the Bottlenecks Interconnection on the City Street Network

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Abstract. The results of a questionnaire survey of Kyiv residents regarding their traffic to work places are considered and analyzed, taking into account the administrative-territorial division of the city territory. The traffic model of Kyiv city residents between its districts has been developed, on the basis of which the model of "bottlenecks" interconnection on the city street network is proposed, which allows to identify possible alternative routes of distribution of traffic flows on the network in case of failure of some of its elements.

Keywords: City · Traffic system · Traffic flow · Bottleneck · Traffic of inhabitants · Traffic route

1 Introduction

The vehicular traffic affecting significantly the living conditions of people and the further territorial and economic development of settlements has become a vital problem in many cities of Ukraine. Nowadays, the main aspects of such traffic problem are both the road network overload and inadequacy of road capacity at the certain road network sections to the traffic needs that cause the congestions and delays. Providing the required capacity for a certain road sections or junctions of a road network is a major indicator of creating the necessary conditions for the effective functioning of the entire city transport system [1–3].

2 Modelling the Bottlenecks Interconnection

The passenger traffic volume depends on the size of a settlement. As the population of the city grows, the territory and the volume of traffic increase. And as the size of settlement increases, the pedestrian traffic reduces and the number of trips by transport increases. The increase of passenger traffic depends mainly on the number of city inhabitants. Therefore, at this stage of the study, we are interested in the influence of the city's life structure on its transport network, in particular, on the distribution of transport and passenger flows, and what methods of traffic management are used to increase the traffic effectiveness. The peculiarity of major and largest cities is that the considerable proportion of inhabitants uses mainly the certain number of transport

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routes connecting chiefly the peripheral districts and city center zone of the city. Although in a modern cities with a developed division of social and production areas, such factor as a living place is less and less tied to the workplace. The volumes and directions of passenger traffic routes depend from both the volume of housing stock of residential districts and the number of jobs available in other districts. Therefore, the passenger traffic formation is quite spontaneous, but the process of this formation can be governed by analyzing the collected objective data on the volume and routes of work trips. It is the work trips of urban residents that are the most stable in real practice and are especially obvious in peak hours. It is also necessary to pay special attention to the traffic of the city inhabitants, taking into account the volumes and directions of their trips within the territory of a particular settlement. This allows identifying the directions of passenger traffic and main routes of transport vehicles to find out the most loaded traffic directions and the transport network sections [1].

In order to carry out the further surveys for obtaining the required information necessary for revealing the certain regularities in passenger traffic within city territory, the existing administrative-territorial division of Kyiv was used. The surveys were carried out for the entire city of Kyiv taking into account the existing administrative division. The city of Kyiv has ten administrative districts, among which there are adjacent links: Shevchenkivskyi district borders with five districts; Holosiivskyi, Dniprovskyi and Pecherskyi districts border with four districts; Obolonskiy, Podilskyi and Solomenskiy districts border with three districts; Darnytskyi, Desnyanskiy and Svyatoshinskiy districts border with two districts. The data on population and area of administrative districts of Kyiv are represented in Table 1 [2]. Considering that each administrative district of the city actually completely meets the necessary consumer services of its population, we analyze the passenger traffic caused by labor and education needs that is the most widespread in the morning time. It is this approach that will enable to find the location of employment gravity centers and reveal the passenger traffic regularities that will allow establishing the characteristic traffic routes for the population of each area and building the required transport infrastructure, which provides this traffic process, in particular, the correspondence of transport demand to its supply. According to the data [2] it is accepted that percentage of the employed population of Kyiv is 50.7%, and taking into account 8.3% of full-time students the total number is 59.0%.

The study mentioned above was performing in the city of Kyiv, by interviewing its inhabitants to identify the number of the district residents travelling to work only within the district territory, as well as between adjacent and remote districts. The questionnaire results are represented in Table 2. As a result of the surveys performed, the principles of district gravity centers distribution according to the administrative-territorial division were found, which characterize the peculiarities of mutual location of work and educational places in relation to the living places (Table 3). To find out the peculiarities of workplaces and determine main gravity centers of workplaces for residents of every district, the corresponding surveys were performed also. Such approach allows to identify the main stable traffic routes for the majority of residents of each district [4–7].

Table 1. The population and area of administrative districts of Kyiv.

The name of city district	The area of district, km^2	The population number, thousands of inhabitants	The working population number, thousand people	The proportion of the district population in the whole city, %	The Population density, inhabitants/km^2
Holosiivskyi	156	247.6	146.1	8.6	1584
Darnytskyi	134	314.7	185.7	10.9	2480
Desnyanskiy	148	358.3	211.4	12.5	2421
Dniprovskyi	67	354.7	209.3	12.3	5294
Obolonskiy	110	315.5	186.1	11.0	2868
Pecherskyi	27	152	89.7	5.3	5630
Podilskyi	34	198.1	116.9	6.9	5826
Svyatoshinskiy	110	340.7	201.0	11.8	3097
Solomenskiy	40	364.8	215.2	12.7	9120
Shevchenkivskyi	27	230.2	135.8	8.0	9208

Based on the volumes of passenger traffic for each administrative district obtained during peak periods of the whole transport system operation, the main traffic routes of population were found, which allowed revealing the regularities in traffic of Kyiv city residents to their workplaces and developing the methods of such traffic distribution depending on the traffic routes established.

Table 2. The trips of Kyiv city inhabitants from home to workplaces or educational institutions in accordance with its administrative-territorial division.

The name of city district	The area of district, km^2	The population number, thousands of inhabitants	The working population number, thousand people	The proportion of the district population in the whole city, %	The Population density, inhabitants/km^2
Holosiivskyi	156	247.6	146.1	8.6	1584
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Analyzing the possible traffic routes of the population within the city territory, the main traffic directions of the population are clearly traced, i.e., the routes of main inter-district passenger traffic flows within every administrative district.

The data obtained in the paper shows that transport connections between all districts of Kiev exist, but their volumes differ significantly, depending on their mutual territorial location, availability of jobs and location of city gravity center objects (Fig. 1). The obtained diagram of transport connections between the districts of Kiev forms a certain graph that has 10 vertices and 90 edges. However, the connections between the remote districts having no common boundaries pass through the territory of the adjacent districts and the districts through which the transport network is laid to provide the appropriate connection. The traffic between remote districts passing through the territory of other districts is characterized mainly by additional transit traffic on the street network (transit traffic flows). After analyzing the data obtained as a result of the experiment, you can determine the passenger traffic volume between districts (transport work) and, accordingly, define the volume of relationship between them as a percentage of any passenger traffic route volume of certain district with respect to the total volume of all city passenger traffic routes.

Table 3. The distribution of passenger traffic flows of Kyiv between its administrative districts.

The name of city district	The area of district, km^2	The population number, thousands of inhabitants	The working population number, thousand people	The proportion of the district population in the whole city, %	The Population density, inhabitants/km^2
Holosiivskyi	156	247.6	146.1	8.6	1584
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Using the diagram (Fig. 1), which demonstrates the fact that the traffic between remote districts pass through the other city districts, and the percentage of city residents traffic between its separate districts (Table 3), we can create the model (Fig. 2), which illustrates the relationship of traffic flows between administrative districts in the Kyiv city.

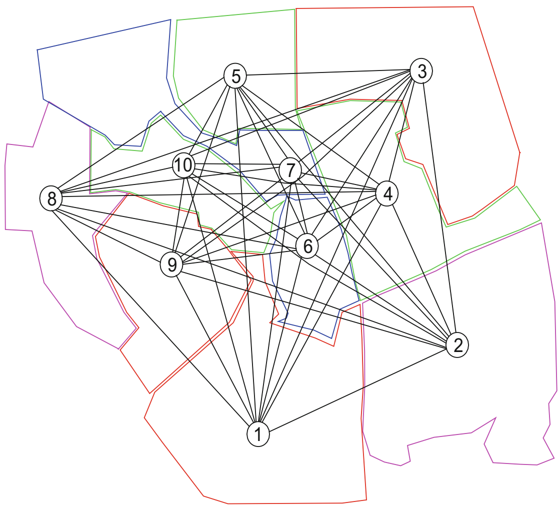


Fig. 1. The diagram of transport connections between all districts of Kyiv.

The obtained data concerning the city population traffic between administrative districts can be presented in the form of a weighted graph which can be used for further analysis and calculations (Fig. 2). The weighted graph is determined by the four variables:

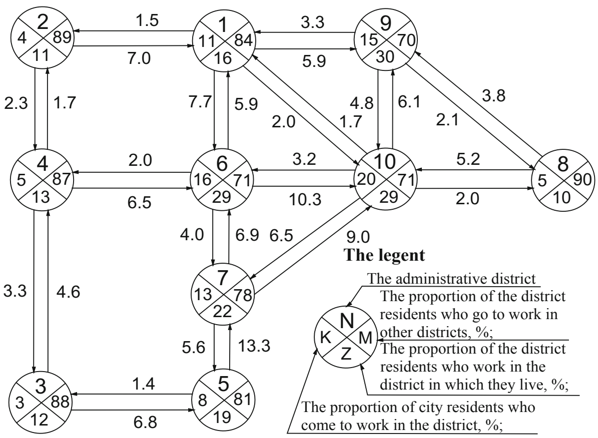
$$G = (V, E, X, C), \tag{1}$$

where

V = {vi}, i = 1,2,…,n	are the graph vertices;
E = {ei}, i = 1,2,…,n	are the edges;
X = {xi}, i = 1,2,…,n	are the characteristics of the graph vertices;
C = {ci}, i = 1,2,…,n	are the characteristics of the graph edges;

In this case, the city districts (vertices of the graph), the traffic directions (the graph edges), the number of residents moving from one area to another, as well as those who move within only one district (characteristics of the graph vertices), the number of residents moving in the directions between city areas (graph edges characteristics).

The weighted graph represents the inputs and outputs of residents' traffic for work trips and their percentage distribution by direction of movement between districts, which makes it possible to characterize the volume of inter-district traffic.



1- Holosiivskyi district;
2- Darnytskyi district;
3- Desnyanskiy district;
4- Dniprovskyi district;
5- Obolonskiy district;
6- Pecherskyi district;
7- Podilskyi district;
8- Svyatoshinskiy district;
9- Solomenskiy district;
10- Shevchenkivskyi district.

Fig. 2. Model of Kyiv residents' traffic between districts of Kyiv (for work trips).

The obtained model makes it possible to define and evaluate the transport and passenger demand, to determine the transport dependence of a district taking into account the directions of passenger flows and their volume. The corresponding model at this stage is a simple graph that shows only one connection between adjacent areas, which is in fact incorrect. But it does provide general information about city traffic, which allows you to determine the volumes and directions of traffic in the corresponding district.

In order to manage such traffic, it is necessary to determine the possible traffic routes between the certain city districts, and the maximum number of possible routes that can be formed between two gravity centers. This largely depends on the number and type of street network elements (bridges, overpasses, signalized intersections, etc.) that provide transport links between adjacent or remote districts and concentrate traffic flows around gravity centers within each district. Actually these elements determine the number of possible traffic routes between certain gravity centers.

By considering possible traffic routes between the administrative districts of a city, it is possible to select some number of street network centers through which you can travel from one district to another, that is, a certain number of possible traffic routes for inter-city and transit traffic.

Thus, each district has the k inputs and the n outputs. Each input has a link with any output. So that, you can create a graph of traffic routs for every district of any city. As an example, we selected locations of possible transport routs between the administrative districts of Kyiv. When analyzing the existing routs between administrative districts, all possible streets, roads and other elements of the street network were considered, regardless of their category and technical-planning characteristics. The number of traffic routs between the administrative districts of Kyiv is represented in Table 4.

A matter of particular importance in any city street network providing city traffic between administrative districts are so-called "bottlenecks" in each city district's territory, which affect, sometimes significantly, the formation of traffic routes for not only the inter-city and transit transport, but also for intra-district one. Such problem is solved by developing the model of the city's street network, based on the number of its nodal points ("bottlenecks"), through which traffic flows naturally pass, because any redistribution of traffic flows along the city street network require special attention to the traffic capacity of bottlenecks and their number. The number of bottlenecks and their traffic capacity affect the effectiveness of the decisions being made concerning the organization and management of city network traffic because bottlenecks are those critical elements through which traffic flows are to go.

According to our surveys there were identified 99 "bottlenecks" in the Kyiv city street network (Fig. 3):

– bridge crossings - 5 places;
– overpasses that cross over railway, subway or express trams - 36 places;
– traffic intersections on the arterial roads at different levels - 24 places;
– signalized intersections (located at or near the administrative district boundaries) – 23 places;
– entrances and exits from the city - 11 places.

Table 4. The number of traffic routs between the administrative districts of Kyiv.

The city district	The number of traffic routs between the administrative districts of Kyiv									
	Holosiivskyi	Darnytskyi	Desnyanskiy	Dniprovskyi	Obolonskiy	Pecherskyi	Podilskyi	Svyatoshinskiy	Solomenskiy	Shevchenkivskyi
Holosiivskyi	–	1	0	0	0	7	0	0	6	4
Darnytskyi	1	–	0	3	0	0	0	0	0	0
Desnyanskiy	0	0	–	7	1	0	0	0	0	0
Dniprovskyi	0	3	7	–	0	3	0	0	0	0
Obolonskiy	0	0	1	0	–	0	9	0	0	0
Pecherskyi	7	0	0	3	0	–	1	0	0	3
Podilskyi	0	0	0	0	9	1	–	1	0	9
Svyatoshinskiy	0	0	0	0	0	0	1	–	3	2
Solomenskiy	6	0	0	0	0	0	0	3	–	6
Shevchenkivskyi	4	0	0	0	0	3	9	2	6	–
Total	18	4	8	13	10	14	20	6	14	23

In this case, it is suggested to consider the city's traffic route system as the "bottlenecks" interconnections system.

Such approach allows to describe the city transport route system in the form of a graph [3, 4], on which each vertex characterizes a "bottleneck" through which vehicles are driving to a selected vertex. This model clearly exhibits a certain number of alternative routes and possible alternative streets that will allow redistribution of traffic flows when any difficult situation occurs in one of the traffic routes. This approach enables to remove some number of streets and intersections from traffic management system that do not have a significant impact on the traffic flows. Important in the study are only those nodes where traffic routes for a significant number of vehicles are changed or those road network elements where the main number of transport routes go along.

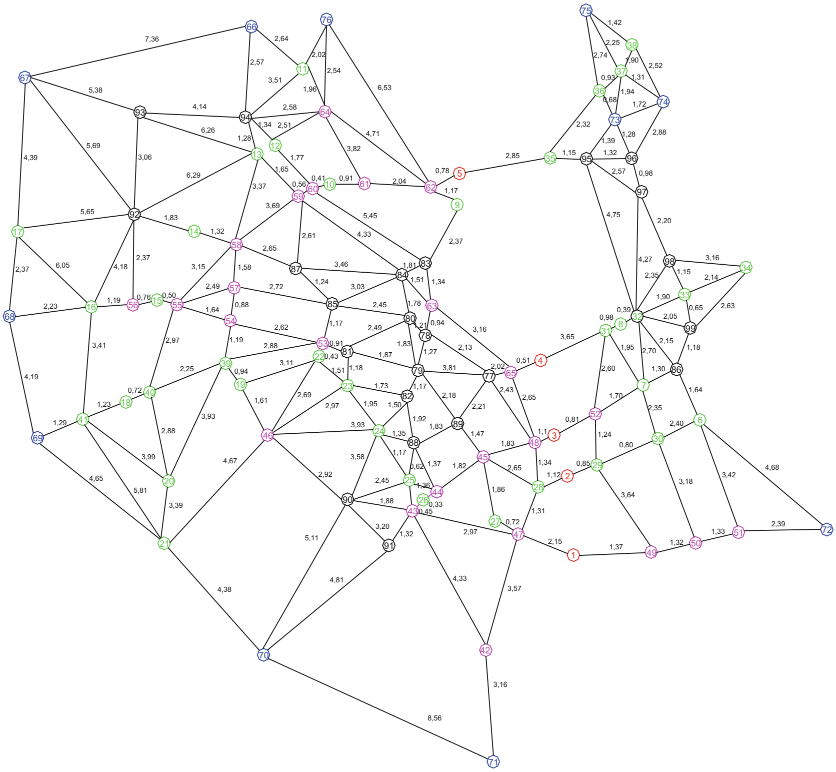


Fig. 3. Model of interconnections between “bottlenecks” of Kyiv city transport route system.

Such model of bottlenecks on the city’s street network is based on the selection of its optimal sections to ensure the most effective transit traffic to the required district under conditions of minimal time and expenditures. Each edge of the model’s graph can be characterized by the value t_{ij}, which corresponds to the total travel time on a given section of the street network.

The application area of the model is very broad: transport tasks, optimization tasks of street networks and transportation systems. One of the well-known optimization tasks is finding the shortest paths in a graph with weighted arcs. Also, assuming that the vertices of the graph are the source and purpose of population traffic, based on the data, you can solve the network problem of optimal flow, maximum flow and minimum cut, as well as build a model of interaction between different modes of transport.

Employing the Ford-Falkerson algorithm [5] to the model of bottleneck interconnections on the city's road network we can find the maximum flow in the network and determine the possible saturation flow of the entire network on the base of given traffic capacity of the vertex ("bottleneck") and not the arcs.

For this purpose, any oriented edge f: (a, b) is matched by the flow f (a, b) passing along the edge, provided that the flow value is less than or equal to the throughput of the edge z (a, b).

$$f : (a, b) \to f(a, b) \leq z(a, b) \tag{2}$$

At such condition, the conservation law is met for any vertex b, that does not belong to vertices S and T, that is, the magnitude of the flow coming along the edge f (a, b) must coincide with the magnitude of the flow originating from the vertex b on the edge f(b,c).

$$\sum\nolimits_{a;(a,b)\in E(G)} f(a,b) = \sum\nolimits_{c:(b,c)\in E(G)} f(b,c) \tag{3}$$

The traffic capacity of the cut

$$z(S,T) = \sum\nolimits_{z(S,T)\in R(S,T)} z(a,b) = G \tag{4}$$

Maximum flow in the network

$$Q \leq z(S,T) \forall R(S,T) \tag{5}$$

This method enables to reveal possible alternative routes of traffic flows distribution over the network at the time of failure of one or more of its elements, which provide transport connectivity and reliability of the city street network operation as a whole.

3 Conclusion

Having obtained data on the traffic capacity of the road network elements, it is possible to determine the correspondence of these elements to the city transport needs and define whether the construction of additional elements in the street network is needed, as well as identify possible unloaded alternative traffic routes, which is essential in creating an intelligent traffic management system that will allow effectively distribute traffic flows over the street network.

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Safe Train Route Options

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Abstract. Constantly increasing anthropogenic pressure on the environment inevitably leads to climate change, which in turn provokes an increase in the number of extreme weather events. Extreme weather conditions can leads to industrial accidents and disasters. This statement is confirmed by statistics on road accidents initiated by natural disasters on the roads of the Russian Federation, the USA and Europe. The transportation of dangerous goods in extreme weather conditions is a dangerous factor to shippers, rail carriers and society. This risk factor cannot be quantified and is not adequately presented in the cost of transportation.

Accident risk factors assessment that consider the impact of various types of natural weather disasters and quantitative assessment of the impact on railway infrastructure, can be a starting point for managing disaster risks and adapting human activities to an ever-changing climate. This article proposes a methodology for assessing the risk of a traffic accident considering the impact of various types of natural disasters. As a result of testing this method, the risk of a dangerous goods traffic accident at two North Caucasus Railway routes, after simulation was selected the safest route. For carriers of dangerous goods, the accident risk assessment method will allow you to choose the safest route for the transportation of goods and, as a result, reduce the chanse of an accident.

Keywords: Emergency risk · Emergency situations · Railway transport · Emergency situations of natural character · Freight railway transportation · Traffic safety

1 Introduction

Climate changes have a significant impact of land transport infrastructure conditions [1].

In some cases, the threatening factor in assessing of the climate impact may not be the dangerous events itself, but the natural or technogenic event that it creates. The dangerous climate events can initiate technogenic emergencies [2, 3].

The statistics of traffic accidents on the roads of the Russian Federation, the USA and Europe confirm the above:

January 3, 2018 in Switzerland wind storm with a wind speed more than 50 m per second blow away the train. As a result of this accident, the popular tourist transport route in Jungfraujoch was cancelled [4].

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August 13, 2016, in the Russian Federation at the Domikan−Argali route, seven empty containers was a fall from a freight train. Containers fell on an nearest track and blocked the movement of the oncoming freight train. Train traffic was blocked in both directions. Rapidly changing weather conditions (storm wind) was caused an incident. Empty containers in the tail of train was blown away by the storm wind [5].

March 13, 2019 in the U.S. in New Mexico state, near Logan town derailed 26 wagons of a freight train. Wagons fell from the bridge due to strong wind [6].

October 24–25, 2018 in the Russian Federation in Krasnodar region two road and one railway bridge was damaged by heavy rainfall (275–330 mm). Road sections "Tuapse – Maykop" and "Dzhubga – Sochi", the railway route "Tuapse – Krivenkovskaya" and "Tuapse – Adler" was damaged. 36 passenger trains were cancelled and 39 delayed [7].

Transportation of dangerous goods in heavy weather conditions, especially in conditions of their increase, poses a risk to shippers, rail carriers and the society. This risk factor cannot be quantified and is not adequately presented in the cost of transportation.

Some studies attempted to assess the possibilities of improving the safety of the transport of dangerous goods (HAZMAT) by diverting hazardous materials along an alternative route. For example, on the new York-Charlotte route, the alternative route resulted in a 91% reduction in risk, but at the cost of a 25% increase in route length. The results of the study indicate that the route redirection possible, but the choice of redirection is selected individually [8–13].

This article proposes a method for assessing the risk of a traffic accident, considering the impact of different types of natural weather disasters. The risk of a traffic accident during the transportation of dangerous goods along two routes of the North Caucasus railway was calculated and the safest of them was chosen as a result of testing this method.

2 Materials and Methods

The organized movement of trains in each direction on the i-th route of the j–th railway in accordance with the schedule is influenced by a number of random factors. The event $C_{j,i,m}$, which is an emergency of the m-th type of natural and technogenic nature, which occurred in the geographical area of Russia has a characteristic spatial scale $L_{j,i,m}$(km.) and a characteristic time of action $T_{j,i,m}$(h.), and also occurs with an average frequency $N_{j,i,m}$(1/year). The very natural emergency situation is characterized by some impact $D_{j,i,m}$ on the rolling stock and socio-technical system of railway transport in consequence of which there is a transport accident $B_{j,i,m}$—a derailment or collision of a train with certain consequences.

The movement of trains on the i-th route of the j–th railway is characterized by the capacity $N''_{i,j}$ in the even direction and in the odd direction $N''_{i,j}$ (the number of trains passing through the section per day). In General, $N''_{i,j} \neq N''_{j,i}$, for a pair train schedule $N''_{i,j} = N''_{i,j}$.

We make the assumption that the trains are moving in an even direction along the section of the road with the average time intervals between trains $\Delta\bar{T}''_{j,i}$ and the average spatial intervals between trains $\Delta\bar{X}''_{j,i}$ with the section speed $V''_{i,j}$.

Assessment of the probability of a traffic accident when a train is moving in an even direction on the i-th ection of the j–th railway, caused by a natural emergency of the m-th type, is made by the formula: accident when a train is moving in an even direction on the i-th ection of the j–th railway, caused by a natural emergency of the m-th type, is made by the formula:

$$R''\left(B_{j,i,m}\right) = R''\left(D_{j,i,m} \times C_{j,i,m}\right) = P''\left(C_{j,i,m}\right) \cdot P''\left(D_{j,i,m} | C_{j,i,m}\right) \tag{1}$$

$$\text{where } P(\mathrm{D_{j,i,m}}|\mathrm{C_{j,i,m}}) = \mathrm{P}(L_{j,i,m}|C_{j,i,m})\Delta P''(T_{j,i,m}|C_{j,i,m}). \tag{2}$$

$P''\left(C_{j,i,m}\right)$—the probability of occurrence in this geographical area of natural emergency of m-th type, characteristic spatial scale—$L_{j,i,m}$ for the average time of finding a train moving in an even direction on the i-th route, length $L_{j,i}$ [9];

where $t''_{j,i} = L_{j,i}/V''_{j,i}$, $V''_{j,i}$—local speed of trains on the i-th ection of the j–th railway in an even direction, km/h;

$P''(L_{j,i,m}|C_{j,i,m})$—conditional probability of impact on the sociotechnical system of railway transport events $C_{j,i,m}$ characteristic spatial scale $L_{j,i,m}$, which led to a traffic accident with a train moving in an even direction on the i-th route of the j–th railway [9]

$$P''\left(L_{j,i,m}|C_{j,i,m}\right) = 1 - \exp\left(-k_x\lambda''_x L_{j,i,m}\right)\sum_{k-0}^{k_z-1}\frac{(k_x\lambda''_x L_{j,i,m}}{k!};$$

$$\lambda''_x = 1/\Delta\bar{X}''_{j,i}, \tag{3}$$

when k_x	– the order of the normalized Erlang distribution;
$\Delta\bar{X}''_{j,i} = V''_{j,i} \times \Delta\bar{T}''_{j,i}$	– average spatial interval between trains moving in an even direction on the i-th ection of the j–th railway, km;
$\Delta\bar{T}''_{j,i}$	– average time interval between trains moving in an even direction on the i-th route of the j-th railway, h;
$P''(T_{j,i,m}\|C_{j,i,m})$	− the conditional probability of the impact on the sociotechnical system of railway transport of the event $C_{j,i,m}$ of the characteristic time scale $T_{j,i,m}$, which led to a traffic accident with a train moving in an even direction on the i-th route of the j–th railway [9]

$$P''\left(T_{j,i,m}|C_{j,i,m}\right) = 1 - \exp\left(-k_t\lambda''_t T_{j,i,m}\right)\sum\nolimits_{k-0}^{k_t-1}\frac{\left(k_t\lambda''_t T_{j,i,m}\right)^k}{k!};$$

$$\lambda''_t = 1/\Delta\bar{T}''_{j,i}, \tag{4}$$

when k_t – the order of the normalized Erlang distribution;

In the expression (1), recorded to assess the risk of a traffic accident when a train is moving in an odd direction on the i-th route of the j–th railway $R'\left(B_{j,i,m}\right)$, appropriate value $P'\left(C_{j,i,m}\right)$, $P'\left(L_{j,i,m}|C_{j,i,m}\right)$, $P'(T_{j,i,m}|C_{j,i,m})$ determined by formulas similar to the even direction of trains with the appropriate replacement of data.

Then the risk of accidents $\mathrm{R}\left(B_{j,i,m}\right)$ when driving trains in the odd and even areas for the i-th plot of the j–th railway caused by hazardous impact of natural disaster m-th species can be identified by a formula (taking into account the jointness of events):

$$\mathrm{R}\left(B_{j,i,m}\right) = R''\left(B_{j,i,m}\right) + R'\left(B_{j,i,m}\right) - R''\left(B_{j,i,m}\right) \times R'\left(B_{j,i,m}\right) \quad (5)$$

From formulas (1), (5) it is possible to receive the following estimates of probability of transport incident at movement of the train.

I. Assessment of the risk of a traffic accident during the movement of a train on the i-th route of the j–th railway, caused by all possible natural emergencies of M types (m = 1, 2, 3,…, M), we produce the following formulas:

when the train is moving in an even direction:

$$R''\left(B_{j,i}^{M}\right) = \sum\nolimits_{m=1}^{M} \varphi_m \cdot R''\left(B_{j,i,m}\right), \quad (6)$$

when the train is moving in an odd direction:

$$R'\left(B_{j,i}^{M}\right) = \sum\nolimits_{m=1}^{M} \varphi_m \cdot R''\left(B_{j,i,m}\right), \quad (7)$$

when the movement of trains in the even and odd directions:

$$R\left(B_{j,i}^{M}\right) = R''\left(B_{j,i}^{M}\right) + R'\left(B_{j,i}^{M}\right) - R''\left(B_{j,i}^{M}\right) \cdot R'\left(B_{j,i}^{M}\right), \quad (8)$$

where φ_m – frequency of occurrence of m-type emergencies among other types of emergencies, $\sum\nolimits_{m=1}^{M} \varphi_m = 1$;

$B_{j,i}^{M}$ – transport accident – an event that followed after the impact of all possible types of emergency M natural character on the socio-technical system of railway transport on the i-th section of the j–th railway

II. Assessment of the risk of a traffic accident when a train is moving along I (i = 1, 2, 3, …, I) sections of the j–th railway caused by a natural emergency of the m-th type, we produce the following formulas:

when the train is moving in an even direction:

$$R''\left(B_{j,m}^{I}\right) = 1 - \prod\nolimits_{i=1}^{I} \left[1 - R''\left(B_{j,i,m}\right)\right], \quad (9)$$

when the train is moving in an odd direction:

$$R'\left(B^{I}_{j,m}\right) = 1 - \prod\nolimits_{i=1}^{I}\left[1 - R'\left(B_{j,i,m}\right)\right], \tag{10}$$

when the movement of trains in the even and odd directions:

$$R\left(B^{I}_{j,m}\right) = 1 - \prod\nolimits_{i=1}^{I}\left[1 - \mathrm{R}\left(B_{j,i,m}\right)\right], \tag{11}$$

where $B^{I}_{j,i}$ – transport accident – an event that followed after the impact of emergency m-th type of natural character on the socio-technical system of railway transport on I (i = 1, 2, 3, …, I) sections of the j–th railway.

III. Assessment of the risk of a traffic accident when driving a train on I (i = 1, 2, 3, …, I) sections of the j–th railway, caused by all possible emergencies of a natural nature, we produce the following formulas:

when the train is moving in an even direction:

$$R''\left(B^{I,M}_{j}\right) = 1 - \prod\nolimits_{i=1}^{I}\left[1 - R''\left(B^{M}_{j,i}\right)\right], \tag{12}$$

when the train is moving in an odd direction:

$$R'\left(B^{I,M}_{j}\right) = 1 - \prod\nolimits_{i-1}^{I}\left[1 - R'\left(B^{M}_{ji}\right)\right], \tag{13}$$

when the movement of trains in the even and odd directions:

$$\mathrm{R}\left(B^{I,M}_{j}\right) = 1 - \prod\nolimits_{i-1}^{I}\left[1 - \mathrm{R}\left(B^{M}_{ji}\right)\right], \tag{14}$$

when $B^{I,M}_{j}$, – the event that followed after the impact of all possible m types of natural emergencies on the socio-technical system of railway transport on I (i = 1, 2, 3, …, I) sections of the j–th railway.

IV. Assessment of the risk of a traffic accident during the movement of a train on I sections (i = 1, 2, 3,…, I) J Railways (j = 1, 2, 3, …, J), caused by all possible emergencies of a natural nature, produce the following formulas:

when the train is moving in an even direction:

$$R''\left(B^{j,I,M}\right) = 1 - \prod\nolimits_{j-1}^{J}\left[1 - R''\left(B^{I,M}_{J}\right)\right], \tag{15}$$

when the train is moving in an odd direction:

$$R'\left(B^{j,I,M}\right) = 1 - \prod\nolimits_{j-1}^{J}\left[1 - R'\left(B^{I,M}_{J}\right)\right], \tag{16}$$

when the movement of trains in the even and odd directions:

$$R\left(B^{J,I,M}\right) = 1 - \prod_{j-1}^{J} \left[1 - R\left(B_j^{I,M}\right)\right], \quad (17)$$

where $B^{J,I,M}$ – transport accident – an event that followed after the impact of all possible types of emergency M natural character on the socio-technical system of railway transport on I (i = 1, 2, 3, …, I) sections J (j = 1, 2, 3, …, J) railways.

If in formulas (9)–(14) as I to take all sites of the j–th railway, it is possible to receive the corresponding estimates of emergency risks for the j–th railway as a whole (j = 1, 2, 3, …, J). If in formulas (15)–(17) take I sections (i = 1, 2, 3, …, I) J of railways (j = 1, 2, 3, …, J), it is possible to obtain corresponding estimates of accident risks for different routes and train directions.

3 Results

Let us assess the risks of a traffic accident $R\left(B_{j,i}^{M}\right)$ when trains move along two routes of the North Caucasus railway:

Route №1 "Nevinnomysskaya-Tuapse", consisting of 6 sections (i = 1, 2, 3, …, 6)

Route № 2 "Nevinnomysskaya-Tuapse through Krasnodar knot", consisting of 6 sites (i = 7, 8, 9, …, 12) and choose the most secure of them.

Figure 1 shows a map of the location of these routes.

On sociotechnical system of these directions there are three types of emergency of natural character:

Wind at a speed of more than 24 m/s (m = 1); frequency of occurrence among other types of emergencies $\varphi_1 = 0.11$; average annual number of natural emergencies $N_1 = 2$; characteristic spatial scale of natural emergencies $L_1 = 10$ km; characteristic time of action $T_1 = 3$ h;

flood (m = 2); frequency of occurrence among other types of emergencies $\varphi_2 = 0.06$; average annual number $N_2 = 1$; characteristic spatial scale $L_2 = 15$ km; characteristic time of action $T_2 = 1$ h;

heavy rain (m = 3); frequency of occurrence among other types of emergencies $\varphi_3 = 0.83$; average annual number of natural emergencies $N_3 = 15$; characteristic spatial scale of natural emergencies $L_3 = 1$ km; characteristic time of action $T_3 =$ hours 3.

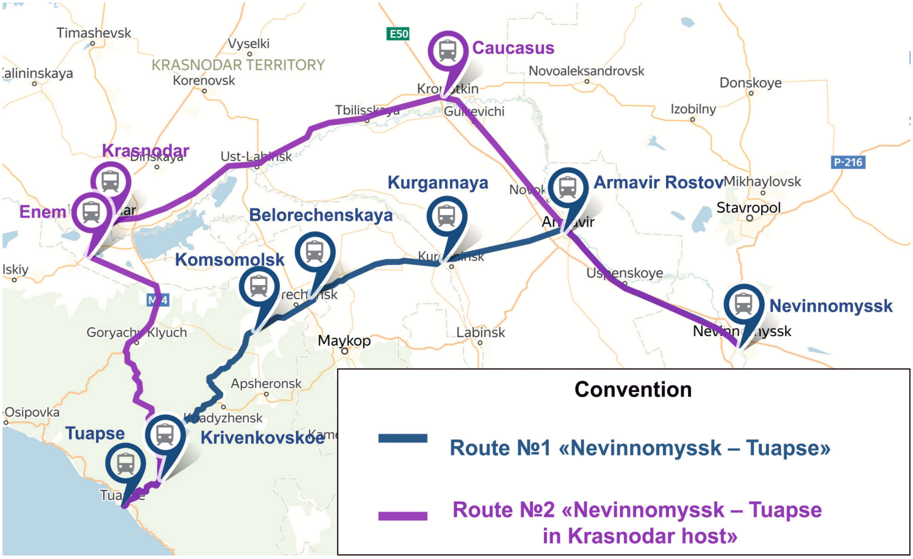

Fig. 1. Map of route 1 and route 2.

The results of the calculation of the risk of accident R(BMj,i) when moving trains on two routes of the North Caucasus railway are shown in Table 1.

Table 1. Results of calculation of accident risk.

i	Route name	Length, km	Trains/day	Wind speeds over 24 mps (m = 1; φ_2 = 0,11; N_1 = 2; L_1 = 10; T_1 = 3)	Flood (m = 2; φ_2 = 0,06; N_1 = 1; L_2 = 15; T_2 = 1)	Heavy rain (m = 3; φ_3 = 0,83; N_3 = 15; L_3 = 1; T_3 = 3)	Risk $R\left(B_{j,i}^{M}\right)$
				Risk $R(B_{j.,i,m})$	Risk $R(B_{j.,i,m})$	Risk $R(B_{j.,i,m})$	
Route 1 «Nevinnomysskaya-Tuapse»							
1	Nevinnomysskaya - Armavir Rostov	77	46	$4{,}85 \cdot 10^{-6}$	$1{,}08 \cdot 10^{-4}$	$2{,}69 \cdot 10^{-5}$	$5{,}30 \cdot 10^{-5}$
2	Armavir Rostov-Kurgan	40,5	40	$5{,}63 \cdot 10^{-6}$	$3{,}38 \cdot 10^{-5}$	$8{,}44 \cdot 10^{-6}$	$1{,}84 \cdot 10^{-5}$
3	Kurgan-Belorechenskaya	63,8	41	$1{,}00 \cdot 10^{-5}$	$5{,}85 \cdot 10^{-5}$	$1{,}46 \cdot 10^{-5}$	$3{,}21 \cdot 10^{-5}$
4	Belorechenskaya-Komsomolskaya	19,8	42	$3{,}48 \cdot 10^{-6}$	$1{,}99 \cdot 10^{-5}$	$4{,}98 \cdot 10^{-6}$	$1{,}09 \cdot 10^{-5}$
5	Komsomol Krivenkovskoe	87,6	42	$1{,}54 \cdot 10^{-5}$	$8{,}81 \cdot 10^{-5}$	$2{,}20 \cdot 10^{-5}$	$4{,}84 \cdot 10^{-5}$
6	Krivenkovskoe – Tuapse	18,2	77	$1{,}83 \cdot 10^{-4}$	$4{,}96 \cdot 10^{-4}$	$2{,}48 \cdot 10^{-5}$	$2{,}27 \cdot 10^{-4}$

(continued)

Table 1. (*continued*)

i	Route name	Length, km	Trains/day	Wind speeds over 24 mps (m = 1; φ_2 = 0,11; N_1 = 2; L_1 = 10; T_1 = 3)	Flood (m = 2; φ_2 = 0,06; N_1 = 1; L_2 = 15; T_2 = 1)	Heavy rain (m = 3; φ_3 = 0,83; N_3 = 15; L_3 = 1; T_3 = 3)	Risk $R\left(B_{j,i}^{M}\right)$
				Risk $R\left(B_{j.,i,m}\right)$	Risk $R\left(B_{j.,i,m}\right)$	Risk $R\left(B_{j.,i,m}\right)$	
Route 2 «Nevinnomysskaya-Tuapse» (Krasnodar transport hub)							
7	Nevinnomysskaya - Armavir Rostov	77	46	$4{,}85 \cdot 10^{-6}$	$1{,}08 \cdot 10^{-4}$	$2{,}69 \cdot 10^{-5}$	$5{,}30 \cdot 10^{-5}$
8	Armavir Rostov-Caucasian	65,5	73	$1{,}11 \cdot 10^{-4}$	$3{,}24 \cdot 10^{-4}$	8,10E-05	$2{,}02 \cdot 10^{-4}$
9	Caucasian-Krasnodar	135,7	29	$3{,}58 \cdot 10^{-6}$	$2{,}82 \cdot 10^{-5}$	$7{,}05 \cdot 10^{-6}$	$1{,}49 \cdot 10^{-5}$
10	Krasnodar-Enem	24,2	94	$8{,}56 \cdot 10^{-5}$	$1{,}74 \cdot 10^{-4}$	$4{,}35 \cdot 10^{-5}$	$1{,}20 \cdot 10^{-4}$
11	Enem-Krivenkovskoe	127	42	$2{,}23 \cdot 10^{-5}$	$1{,}28 \cdot 10^{-4}$	$3{,}19 \cdot 10^{-5}$	$7{,}02 \cdot 10^{-5}$
12	Krivenkovskoe – Tuapse	18,2	77	$1{,}83 \cdot 10^{-4}$	$4{,}96 \cdot 10^{-4}$	$2{,}48 \cdot 10^{-5}$	$2{,}27 \cdot 10^{-4}$

Using the formula (14), we assess the risk of a traffic accident during the movement of trains on two routes of the North Caucasus railway (j = 1) caused by three hazardous conditions (M = 3) of environmental objects (weather disasters):

Route 1 «Nevinnomysskaya-Tuapse» R(B6,31) = $3{,}90 \cdot 10^{-4}$;

Route 2 «Nevinnomysskaya-Tuapse» (Krasnodar transport hub) R(B12,31) = $6{,}88 \cdot 10^{-4}$.

From the diagram (Fig. 2) we can see that The route 1 “Nevinnomysskaya – Tuapse” shows a lower risk value than the Route 2 «Nevinnomysskaya-Tuapse» (Krasnodar transport hub). Route number 2 runs through a major transport hub and the densely populated city of Krasnodar. Transport accident with dangerous goods at route 2 can result in human casualties. Therefore, it is preferable for carriers of dangerous goods to choose Route 1.

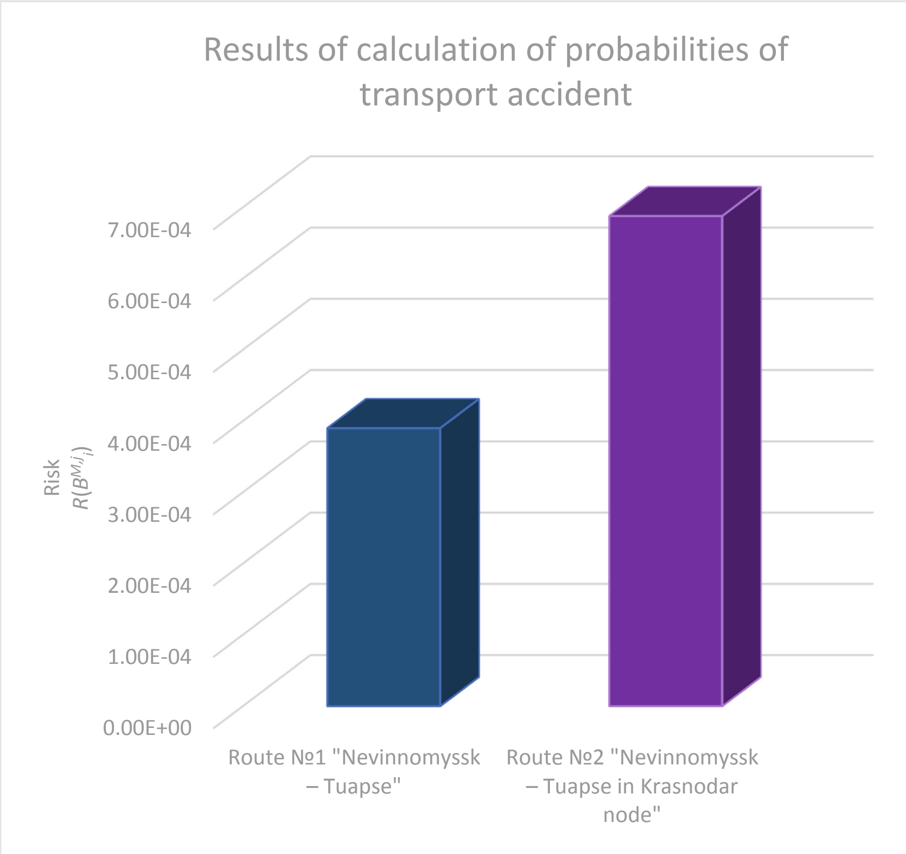

Fig. 2. Results of calculation of risk of transport accident $R(B^{M}_{j,i})$ two routes of the North Caucasian railway.

4 Conclusions

The ever-increasing anthropogenic pressure on the environment inevitably leads to climate change, which can provoke an increase in the number of extreme weather events. Extreme weather events can initiate technogenic accidents and catastrophes. Assessment of natural accident risk factors, considering the impact of various types of natural weather disasters, quantifying the impact on the railway infrastructure, serves as a starting point for disaster risk management and adaptation of human activities to the constantly changing climate. The issue of changing the route of trains by risk factors is given special attention [14]. The proposed method of assessing the risk of a traffic accident, taking into account the impact of different types of natural weather disasters is an actual. Carriers of dangerous goods, using method proposed in the article, can choose the safest route of transportation of goods and, as a result, to reduce the probability of an accident.

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Elaboration of Multichannel Data Fusion Algorithms at Marine Monitoring Systems

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Abstract. The work is motivated by problems of mathematical supply of distributed marine monitoring systems and is devoted to dimension reducing algorithms aimed at early stage discovering of wrecks. Technologies to detect vector process dissensions at early stage using singular value decomposition (SVD) of data matrix are proposed. These technologies are based on the C. Eckart and G. Young result that SVD solves the problem of low rank matrix approximation. A variant of that approach is also referred to as immunocomputing and is regarded at the neurobiological area of artificial intellect. By now similar techniques finds applications at different problems of revealing irregular situations, image recognition, data compression. The principal advantage here is that the approach under regard permits to solve problems of purposeful dimensionality reduction of multivariate data directly by data matrix without estimating of covariances. It's most valuable at data of high dynamics when current conclusions have to be based on sliding windows of comparatively moderate volume. In application to problems of multichannel data fusion it is essential that this approach doesn't use the idea of centering with respect to the mean value and makes it possible to expand the traditional model of the class (situation) as a realization of n Gaussian vectors with common mean regarded as an "ideal representative of the class of interest". The approach may also be regarded as an analog of factor analysis based on alternate description of dispersion characteristics.

Keywords: Multichannel monitoring · Process dissension · Singular value decomposition · Early stage control

1 Data Fusion Technologies

Natural means for automatic situation control at ship's compartments and technical environment are monitoring systems that are built according to block and modular principles [1–3]. When the system contains large number of detectors and data units it turns highly important to elaborate methods of automatic information fusion of different units at one or several modules to get reduced representations to supply effective support for human or IT-based decision making.

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Nowadays methods of fusion information from space- and time-distributed detection systems are subjects of new synthetic investigation area – Data Fusion [4–6].

Intellectual analysis of the data of any volume and dimension requires measures for dimensionality reduction, first of all – for purposeful selection of their most informative combinations (factors) [7, 8]. At distributed marine monitoring systems it is required to reduce the dimensionality of multivariate time series that represents the time dynamics of readings of detectors' set to elaborate some hierarchical system of compressed representations to be used as indicators of irregular and abnormal situations. Data readings are as a rule expressed at different scales, so they have to be reduced to some common scale. It may be achieved by their normalizing with regard to mean background level.

Usual means of purposeful data dimensionality reduction are different variants of principal components or multivariate scaling and their nonlinear generalizations [9, 10]. Nowadays growing interest is roused by a set of methods using singular value decomposition (SVD) of data matrix [11–13]. These technologies are based on the C. Eckart and G.Young result [14] that SVD solves the problem of low rank matrix approximation. The principal advantage here is that the approach under regard permits to solve problems of purposeful dimensionality reduction of multivariate data directly by data matrix without estimating of covariances. At problems of multisensory data fusion it is essential that this approach doesn't use the idea of centering with respect to the mean value and makes it possible to expand the traditional model of the class (situation) as a realization of n Gaussian vectors with common mean regarded as an "ideal representative of the class of interest". The approach may also be regarded as an analog of factor analysis based on alternate description of dispersion characteristics.

A variant of that approach is also referred to as immunocomputing and is regarded at the neurobiological area of artificial intellect [12, 13].

1.1 An Approach to Reduce Dimensionality of Readings Based on Singular Value Decomposition (SVD) of the Data Matrix

Regard the following extreme problem: for given matrix $X = [x_{ij}]$ of dimension $<n \times r>$ find matrix $\tilde{X}$ of equal dimension from the condition

$$\sum_{i,j} (x_{ij} - \tilde{x}_{ij})^2 \to min \tag{1}$$

under restriction $rank(\tilde{X}) = p < min(n,r)$.

For initial matrix $X <n \times r>$, $n > r$ regard Singular Value Decomposition (*SVD*),

$$X = L^* S^* RT, \tag{2}$$

where:

- $S = diag(s_1,\ldots,s_n)$ – diagonal matrix, whose elements $s_1 \geq s_2 \geq \ldots \geq s_n \geq 0$ are singular values of X – positive square roots of eigen values of XX^T or X^TX;

- L – <$n \times n$> - matrix; *it's* columns $L_1,\ldots,L_n$ are normalized orthogonal vectors that are eigen vectors of X^TX, they are named left singular vectors of X;
- R – <$m \times m$> - matrix; its columns $R_1,\ldots,R_m$ are normalized orthogonal vectors that are eigen – vectors of X^TX, they are referred to as right singular vectors of X.

The expansion (2) may be rewritten as a sum

$$X = \sum_{i=1}^{r} s_i L_i R_i^T = s_1 L_1 R_1^T + \ldots + s_r L_r R_r^T. \tag{3}$$

The principle result of Eckart - Young [14] is that the solution of the extreme problem (1) is given by the sum of first k summands at (4).

Such an approach may be regarded as some analog of principal components that is based not on covariances, but on minimization of mean square error (sum of dispersion and squared bias with respect to some arbitrary center). The refusal of centering X – matrix corresponds to an assumption that measurements being assigned to one class may have no common center. The important feature is that different singular components describe different properties of the data. At the basic variant of application the classification and recognition problems are solved using Euclid metrics at the space of several first singular components (projections).

The principle advantage here is that decomposition (3) may be found directly from data, without estimation of covariance matrix that is highly important at data of large dimension and not enough volume.

Now let X be the learning sample and expansion (3) for X is available. For arbitrary vector z of dimension r to be recognized we have to calculate its projections on basic axis that are columns R_j of the matrix R:

$$w_j(z) = \frac{1}{s_j} z' R_j,\ j = 1,\ldots,p \tag{4}$$

At j-th column L_j of the matrix L choose the element $l_i^{(j)}$ with minimal distance d_j to projection (4):

$$d_j = \min_i \left| w_j - l_i \right|,\ i = 1,\ldots,n \tag{5}$$

In such a way first p singular values are examined. The value

$$d = \min_i \sqrt{(w_i - l_i^{(1)})^2 + \ldots + (w_p - l_i^{(p)})^2} \tag{6}$$

defines the measure of proximity between the vector z and the learning sample X. If we have several classes defined with their learning samples, z has to be assigned to the class for that d is minimal.

At classification problems under traditional Gauss statements this method works similar to usual Fisher linear analysis thaw it provides at once p discriminant components that emphasizes different peculiarities of classes. First components that correspond to maximal singular values emphasize mostly trends while last of them are mostly connected with correlations (Fig. 1).

Serious shortage of such methods of fusion distributed data is the lack of simple proximity characteristic such as Mahalanobis metrics, so in partial situations it's necessary to analyze subsequently series of proximity measures (6).

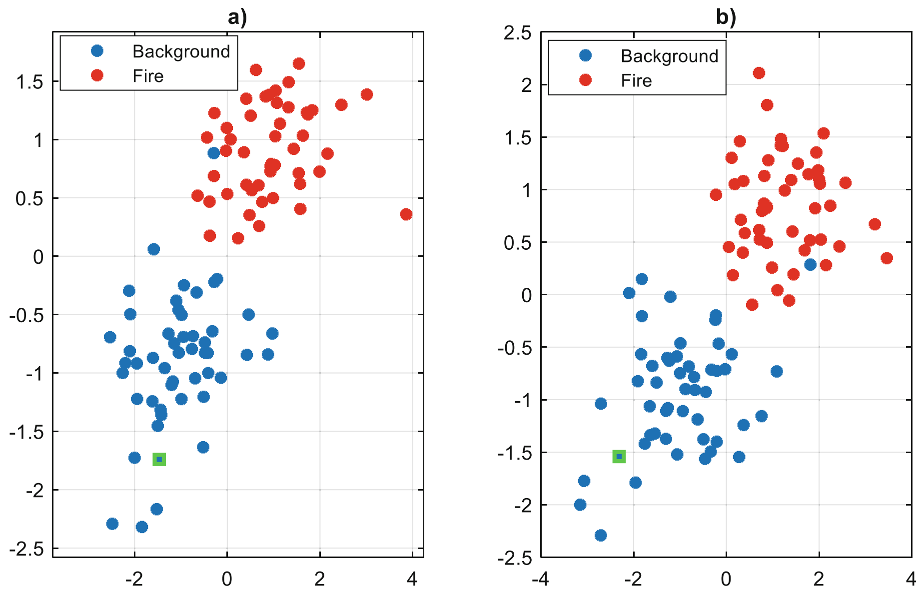

Fig. 1. Pairs of singular components for two Gaussian classes (p = 4): components 1 and 3 (a), components 2 and 3 (b).

1.2 Calculation of SVD

Basic mathematical instruments contain procedures to calculate the singular decomposition for X matrix of arbitrary dimensions $<n \times m>$ and rank p:

$$[L, S, R] = svd(X) \tag{7}$$

At such a handling the matrix L has dimensions $<n \times m>$, S - $<n \times n>$, R – dimensions $<m \times m>$, all superfluous elements of S are zeros. At handling

$$[L, S, R] = svd(X, 0) \tag{8}$$

(economic form of SVD) the matrix L has dimensions $<n \times p>$, S is the diagonal $<p \times p>$ matrix, R is of dimensions $<m \times p>$.

Otherwise the SVD may be calculated by recursive scheme known as Golub-Kahan algorithm [15–17]:

$$L_{(0)} = [1, \ldots, 1]^T \tag{9}$$

$$R = X^T \cdot L_{(k-1)} \tag{10}$$

$$R_{(k)} = \frac{R}{|R|} \tag{11}$$

$$|R| = \sqrt{r_1^2 + \ldots + r_m^2} \tag{12}$$

where:

- $R = [r_1, \ldots, r_m]^T, \quad L = [l_1, \ldots, ln]^T$;
- $L = X.R_{(k)}$;
  $L_{(k)} = \frac{L}{|L|}$;
- $|L| = \sqrt{l_1^2 + \ldots + l_n^2}$;
- $s_{(k)} = L_{(k)}^T \cdot X \cdot R_{(k)}, k = 1,\ 2, \ldots$

k increases till alteration of the singular value [18, 19] at subsequent iteration turns out to be worthless:

$$\left| s_{(k)} - s_{(k-1)} \right| < \varepsilon \tag{13}$$

By this the first singular value s and corresponding first columns of L and R matrices may be estimated [20–22]. At the following step the matrix X - sLR^T is used, the second singular value and second columns of L and R are estimated and so on [20, 23].

It's to be emphasized that even basic for SVD Golub-Kahan algorithm [24, 25] exceeds traditional approaches at multivariate analysis in simplicity and stability. Recently much more compact and stable algorithms are being elaborated [15, 20, 26].

2 Technologies of Treating Measurements at Emergency Warning Systems

Papers [1, 3, 27] introduce three stages of arising and developing the emergences:

Stage 1 – accumulation of disrepairs and abnormalities. This stage supplies necessary but not sufficient conditions for revealing the emergency.
Stage 2 – realization of some initial event. Such an event in combination with earlier accumulated disrepairs and abnormalities gives start to the emergency process.
Stage 3 – emergency itself. At this stage, as a rule, there remains no time to influence the course of events for localization and ceasing the emergency process.

The most important arising feature [28, 29] is that the stage of emergency itself is not possible without accumulation of disrepairs, abnormalities and exploitation regalement violations at the first stage [30–32]. As this first stage may elapse sufficiently long time the control is worth at those two first stages when the system is still capable for work [33–35].

Thus the early stage emergency control [36] is regarded as automatic controlling the state of technical means [37, 38], equipment and object's inner environment by some complex of parameters – emergency indicators [1, 2, 12, 39]. The purpose of introduction the emergency warning systems [40, 41] is preventing the out of control transition of the system to the state of emergency [35, 42]. Its goal [43, 44] consists in early stage [45, 46] revealing of emergency approach by observation the alterations at physical fields and inner environment parameters so as decision making to the breakdown preventing. The theoretic basis are objective laws of formation and displaying the physical field's parameters of object's equipment and inner environments.

At elaboration the methods of early stage emergency warning the system of manage thresholds – critic levels of registration, investigation and intervention is currently used [1, 23, 47]:

- At exceeding the registration level the fact is simply taken into account;
- At exceeding the investigation level the reasons have to be examined;
- At exceeding the intervention level the defense preventing measures have to be accomplished.

2.1 Technologies of Fusion the Distributed Data

The Figs. 2 and 3 display results of parallel observations [48, 49] on modelled fire seat by 7 gas analysers and 8 thermopairs normed with respect to background level [50–52]. For initial 15-dimensional time series pairs of its principal components [53, 54] in singular basis are revealed. Figure 2 shows patterns [37, 55] of normal functioning before firing [56, 57] and patterns corresponding to the beginning of firing till achieving the critic registration level [58–60]. Figure 3 shows patterns corresponding to the intervention level [61, 62] (third minute of fire developing).

2.2 Technologies of Detecting Changes in Multivariate Time Series

Suppose multivariate readings [63–65] are already normalized and reduced to one of their singular components [66, 67]. Regard these transformed readings [68, 69] as a time series {x(k)}, x(k) = x(kΔt), k = 1,…,n,… On-line [70, 71] current estimate of the signal level [72] is the sliding mean at a segment $[k_1\Delta t\ k_2\Delta t]$:

$$\tilde{x}(k) = \frac{1}{k_2 - k_1}\sum_{j=k_1}^{k_2} x(j). \quad (14)$$

According to [5, 11, 73], typical values are $\Delta t = 2$ (s), $T_1 = 120$ (s), $T_2 = 60$ (s). For current signal [73, 74] $x(k)$ the cumulative sum $S(k)$ for the segment of length $T_3 = k_3\Delta t$ is calculated:

$$S(k) = \sum_{j=k-k_3}^{k} [x(j) - \tilde{x}(j)]. \quad (15)$$

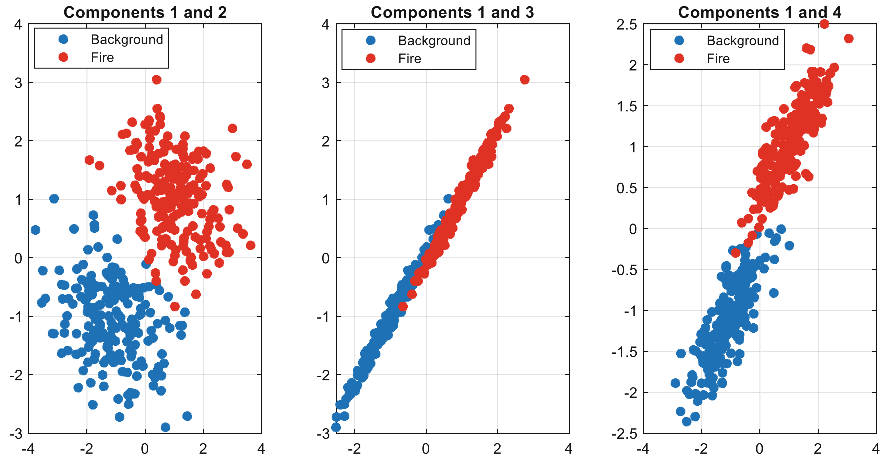

Fig. 2. Measurements projections on phase planes of first 4 singular components - beginning of firing.

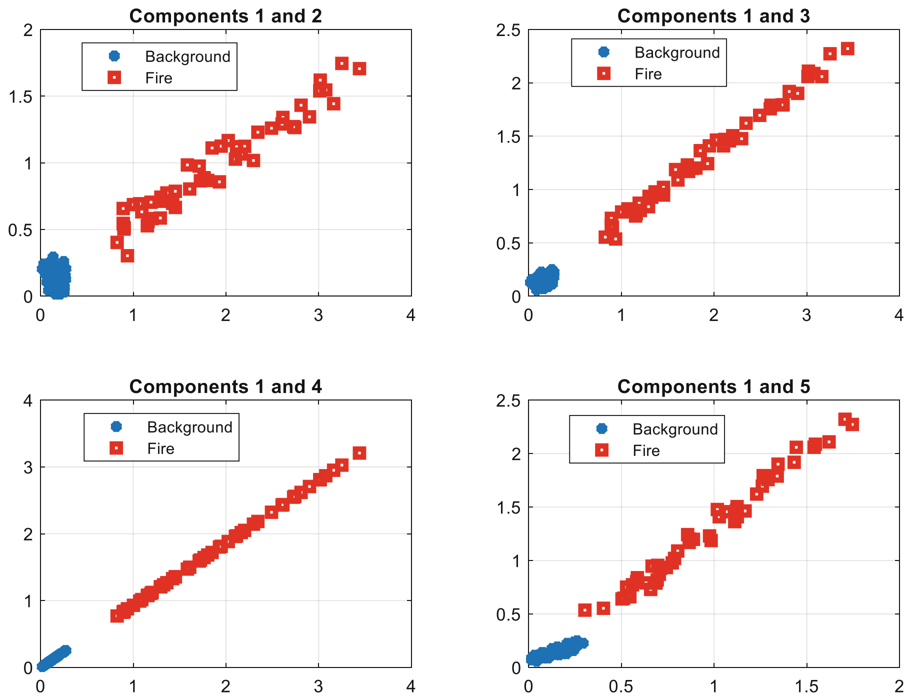

Fig. 3. Measurements projections on phase planes of first 4 singular components - level of intervention (3rd min of firing).

In conditions [75–77] of dissention cumulative sums increase shows to be 1–2 orders more rapid then the signal itself [78, 79]. It highly lightens the determining of thresholds and reduces level of faults [80, 81].

Figure 4 shows the behavior of normalized readings for combination [82, 83] of:

Temperature and pressure sensors;

Integral sensors of high-dispersed aerosols;

Spectral sensors of high-dispersed aerosols, already reduced to the first singular component.

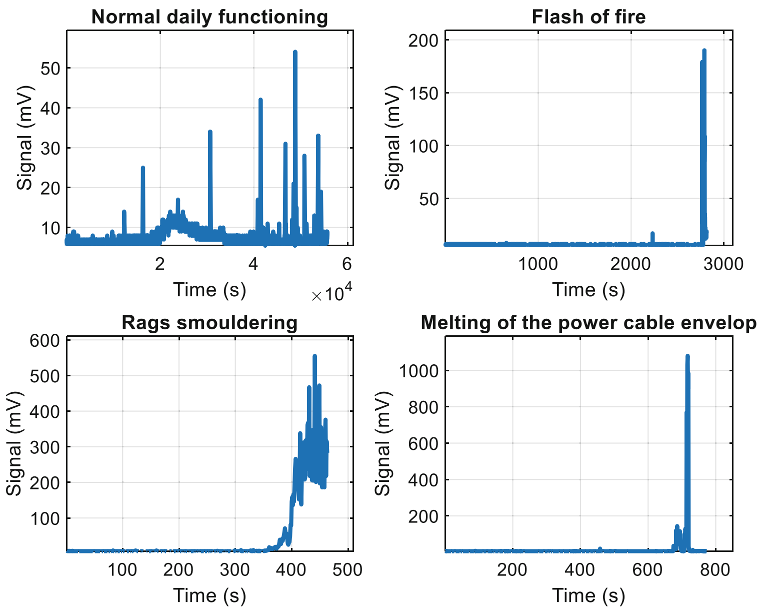

Fig. 4. Dynamics of the first singular component for several kinds of wrecks.

Figures 5, 6, 7 and 8 display same signals and the dynamics of their cumulative sums in common scale.

Calculations suppose the buffer with on-line renovation [84, 85] of the data segment [k-T_1-T_2, k]. Mean estimation may be replaced by exponential smoothing:

$$\tilde{x}(k) = \tilde{x}(k-1) + \alpha[x(k) - \tilde{x}(k-1) \tag{16}$$

($\alpha = 0.9 - 0.95$). In addition, the mean value at (1) may be replaced by the sample median [86–88]. This way (2) may be used in the form:

$$\tilde{x}(k) = \tilde{x}(k-1) + \alpha \cdot \psi[x(k) - \tilde{x}(k-1)], \tag{17}$$

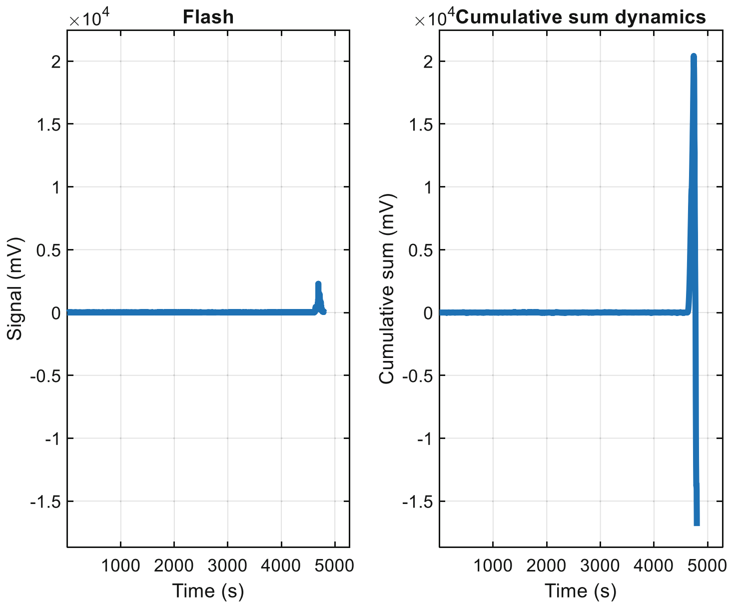

Fig. 5. Normal daily functioning.

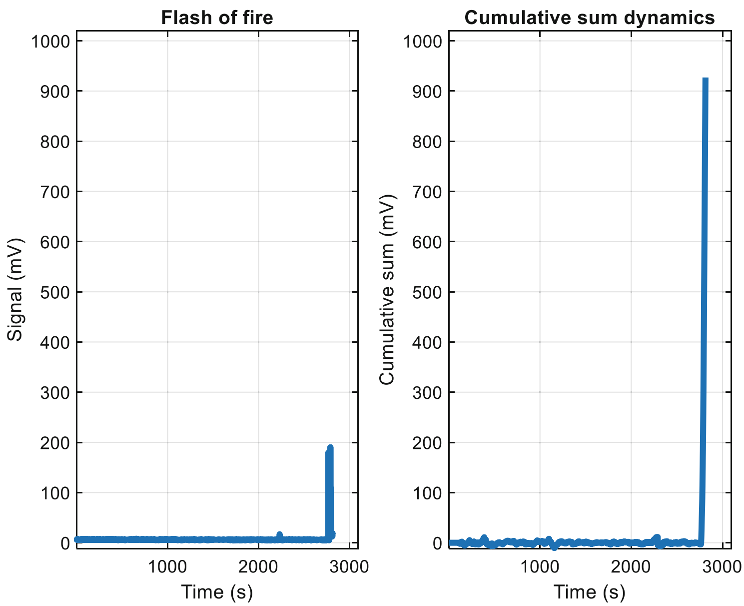

Fig. 6. Flash of fire.

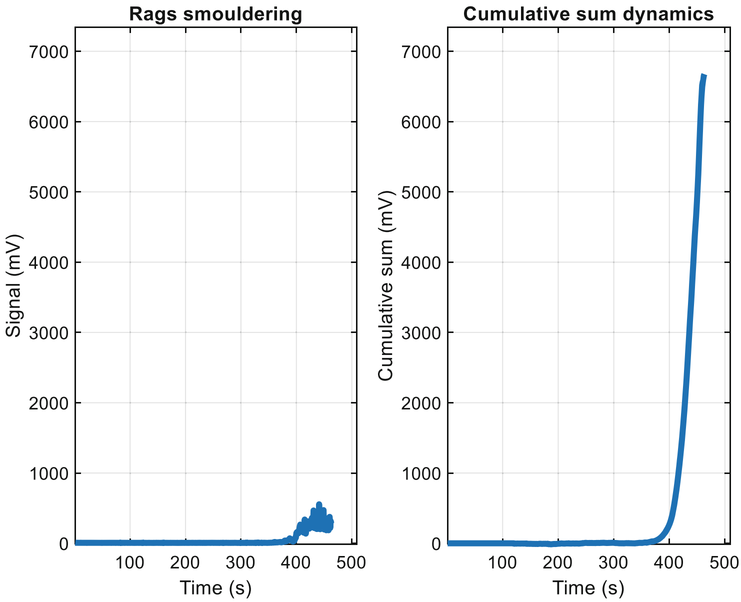

Fig. 7. Rags smouldering.

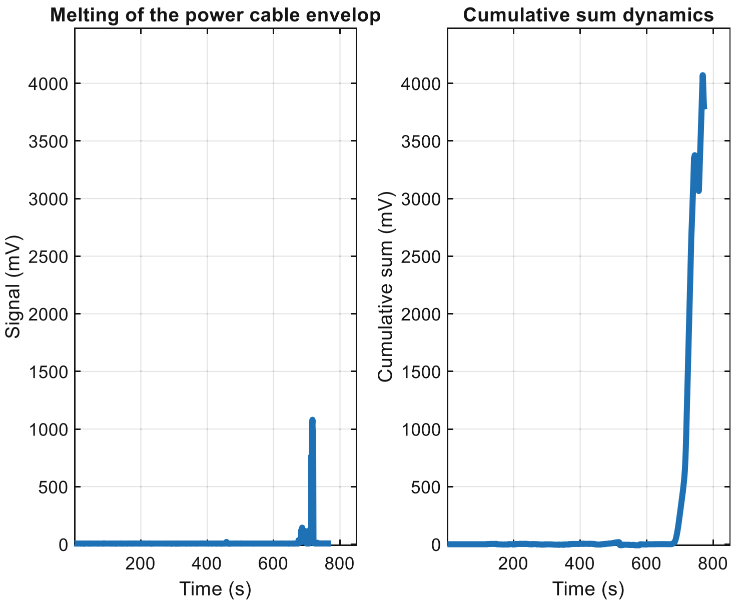

Fig. 8. Melting of the power cable envelope.

where $\psi(z)$ - one of standard functions of robust statistics [8], for example:

$$\psi(z) = \begin{cases} z, & |z| < 2\sigma \\ sign(z), & |z| \geq 2\sigma \end{cases} \tag{18}$$

or even

$$\psi(z) = (2 \cdot \lambda/\pi) \cdot arctg[z \cdot \pi/(2\lambda)], \quad \lambda \cong 2\sigma. \tag{19}$$

3 Conclusions

A new approach at fusing multichannel data in distributed monitoring complexes for marine technical means to be realized in perspective systems of emergence warning systems is proposed. It is based on mathematical technologies of revealing the vector process dissention using singular value decomposition (SVD) of the data matrix. The advantage consists in refusal of covariance techniques and of traditional Gaussian model assumptions, that makes it possible to analyze short patterns of large enough dimensionality. Data of on-polygon trials of firing sensors are used as examples.

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Monitoring and Predicting the State of the Road Network in Russia's Cryolitic Zone

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Abstract. The systematic increase in the surface air temperature observed in the permafrost areas creates significant risks of reducing the functionality of the road network and other objects of road transport infrastructure. To determine the projected state of the roads and identify the most rational types, volumes and timing of measures to preserve their functionality, it is proposed to use mathematical modeling carried out on the basis of constantly updated data on current climatic changes. A means of data collection in large areas of the road network in the cryolitic zone is an information system, the main functional elements of which are a geographically distributed module of instrumental observation and a prognostic module. The modeling sequence in determining the climatic risks caused by the increase in the temperature of soils in the foundations of road transport infrastructure objects is shown. The efficiency of the prognostic module algorithms is confirmed by numerical calculations of climate risks under climate change scenario providing for a warming of 2 °C. It is shown that in the case of sandy soils, risks can be characterized as low and not requiring the implementation of expensive measures to reduce them. The presence of clay soils at the base of roads leads to risks of an average level, when, according to the results of additional economic analysis, such measures may be appropriate.

Keywords: Road network · Cryolitic zone · Climate change · Climate risks

1 Introduction

Global warming, the main manifestation of which is a gradual increase in air temperature, is observed both on a global scale and in Russia for at least the last 30–40 years and is confidently predicted for the foreseeable future. The average coefficient of the linear trend for Russia as a whole is 0.44 °C/10 years, with variation over individual territories from 0.26 °C/10 years (Western Siberia) to 0.56 °C/10 years (European part of the country) [1]. In terms of infrastructure, including road transport infrastructure, located in the areas of permafrost or ever-frost (about 65% of the territory of Russia), warming primarily causes excessive thawing of soils at the base of buildings and structures [2], which leads to their increased subsidence and the loss of bearing capacity. Other manifestations of climate change, for example, rainfall of

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increased intensity, can also lead to accelerated destruction (erosion) of the roadbed under certain conditions [3].

Systematic monitoring of the current state of the road network in the cryolitic zone, aimed at the timely detection of subsidence of the roadbed and its prompt elimination, cannot fully solve the problem of ensuring the sustainable functioning of the road transport system. The reason for this is the very high inertia of permafrost degradation processes, which, especially at fast rates of warming, can be stopped only with the advance implementation of appropriate engineering measures to stabilize the soil temperature regime [4]. Determination of a rational list of such measures and the most appropriate time for their implementation is possible only on the basis of the results of predictive modeling of the soil temperature at the base of the road, taking into account the temperature dynamics of the air in the territory under consideration [5].

Since the time series of air temperature fields is a complex non-stationary stochastic process [1], its parameters can be determined with an accuracy sufficient for subsequent predictive modeling only with the help of direct systematic instrumental observations of the climate in a certain area. An effective means for organizing measurements of climatic parameters carried out in automatic mode can be an information system that includes two main functional elements: an environmental data collection module (similar to [6]) and a module for predicting (performed on the basis of constantly updated data) state of the road profile in the medium term (up to 1–2 years). When designing an information system, it is necessary to take into account the algorithmic aspects of building similar systems [7], as well as to fully envisage ways of collecting information using mobile objects when determining their location based on GPS and GLONASS [8, 9].

The main factor that decisively determines the predictive state of the road profile is the temperature dynamics of the surface air. Since this factor has a pronounced stochastic nature, it is not possible to obtain a strictly deterministic quantitative assessment on its basis that reflect the future state of the road segment. In such cases, the concept of “risk” is widely used, which is understood as the probability that the object under consideration leaves the region of admissible states [10]. In relation to the road segment, leaving the region of admissible states means its destruction and the related impossibility of its use for organizing traffic flows. In general, the risk does not necessarily represent the probability of a certain event (which, by definition, should belong to the range from 0 to 1), but it always has a probabilistic basis and its reliable empirical verification is possible only by statistical methods when considering a sufficiently large number of objects for which quantitative risk assessment was performed [11].

Thus, at the first stage of designing an information system that performs the prediction of the functional state of the road network in the cryolitic ozone, the following main tasks must be solved:

- develop a list of parameters recorded by the system and methods of their measurement implemented in the system;
- develop and confirm the operability of algorithms for predicting the state of road segments that form the basis of the prognostic module.

2 Object State Parameters and Methods of Their Measurement

The means and methods for recording state parameters differ depending on the characteristics of the object being monitored. To monitor the status of the roadbed, it is advisable to use the following methods:

- Inclinometric. It allows detecting the displacement (inclination) of initially vertical lines in the soil massif, resulting in the formation of cracks (in most cases, longitudinal to the direction of the road). The measurement accuracy is 0.01–0.1°, which makes it possible to reveal the process of crack formation even before its appearance.
- Automated surveying. Detects absolute displacement of sensors rigidly connected to the surface layer of the soil with an accuracy of no more than 10 mm. The use of the method is not advisable in the absence of open space (between sensors in the ground and a stationary laser level) or in case of frequent weather events that impair visibility (rain, snow, fog).
- Based on satellite navigation technology. In general, it is similar to the automated surveying method, but it is simple (only sensors are installed in the roadbed, and satellites play the role of monitoring device). However, in general, there is a measurement error of up to 1 m. To significantly improve the accuracy (up to 1 cm), it is necessary to install a source of the correction signal within 1 km from the sensors - a fixed ground station.
- Fiber optic geotechnical monitoring. It allows detecting horizontal displacements in a soil massif of 0.05 mm, is distinguished by increased reliability of fiber optic sensors, and is capable of continuous operation (around the clock and year-round).

For remote monitoring of bridge structures, the data collection module should use optical high-precision levels (for determining vertical subsidence), electronic total stations and satellite receivers (for determining displacements in horizontal and vertical directions). In critical areas, it is possible to install additional rangefinders, tilt sensors, accelerometers, strain gauges, slit-metering devices, and other means of data collection.

Monitoring the state of the road surface involves recording two groups of parameters:

- To monitor the geometrical parameters, laser scanners, which allow building three-dimensional models with an accuracy of up to 5 mm, optical theodolites (with a resolution of up to 0.001°) and electronic tachographs are used.
- The temperature parameters are recorded both by surface sensors (thermocouples, pyrometers, etc.) and temperature sensors in the soil, which allow controlling the accuracy of predictive models for determining the temperature dynamics of the road profile and its base.

The main indicators of the state of infrastructure objects of motor transport, obtained both by direct measurements and by the results of data processing from several measuring devices, are:

- depth of local subsidence of the road surface;
- width of crack opening in reinforced concrete structures of artificial structures (bridges, overpasses);
- deflections of structures and their displacement from the design position;
- areas of corroded sections on the structure surfaces.

To collect climate data, it is proposed to use roadside weather stations (located every 10–15 km), which automatically or semi-automatically determine the climatic parameters that have the most significant effect on the annual dynamics of heat transfer in the soil of the road profile and its basis: air humidity, fog intensity, snow cover thickness, type and intensity of precipitation, air temperature, wind speed.

3 Method of Functioning of the Prognostic Module

The procedure for predicting the functional state of the road profile and determining the appropriate climate risk consists of the following basic steps.

Step 1. Recording the parameters of numerical modeling, which ensure acceptable accuracy and performance of the algorithms used:

- spatial resolution of the model Δ_L, which determines the distance between the reference points of the soil, for which temperature modeling is carried out, is usually taken to be the same across all three axes and equal to 0.05–0.15 m;
- time resolution of the model Δ_T sets the interval during which all parameters of the state of the soil massif are considered constant, its values are in the range of 300–1800 s;
- start time of the modeling T_0, measured from the calendar start of the average year (time point corresponding to 00 h 00 min 00 s January 1);
- total duration of the modeling, T_{max}, which must be at least 2 years to achieve the steady-state temperature regime of the soil;
- initial temperature distribution in the soil (at the moment T_0), represented as an array of temperature values **TG0** over all points of the soil, for which the modeling will be performed in accordance with Δ_L.

Step 2. Modeling climate in two versions - basic and taking into account climate change, which has a probabilistic nature. The set of climatic parameters c1–cn is assigned in accordance with the model describing the interaction of the soil massif with the environment. In its simplest (and at the same time, most reliable and accurate) variety, this model includes air temperature and wind speed in the surface layer as two parameters that most determine the intensity of heat exchange over the contact surface of the soil and the surrounding air. If there are reliable quantitative data on additional factors contributing to the heat exchange between the soil and the environment, the thermal resistance of snow cover, the dynamics of liquid precipitation entering the territory, and the amount of solar energy delivered to the soil surface can be added to the list of climatic parameters. The formalized description of the average year C(T) is a set of n functions for determining the values of all climatic parameters at arbitrary points in time:

$$C(T) = \begin{bmatrix} c_1(T) \\ \ldots \\ c_n(T) \end{bmatrix}, \; T \in [T_0; T_{\max}] \tag{1}$$

Long-term statistics reflecting the state of the baseline climate are concentrated in geographically differentiated climate reference books. Since reference data are usually averaged for individual months of an average year, they are related to the midpoints of the corresponding months, and for intermediate times, the climatic parameters are determined by interpolation (linear or using cubic splines).

Step 3. Determination of soil conditions. The parameters on which the processes of heat transfer in the soil depend are divided into two groups:

- Physical characteristics determined by the results of engineering and geological survey of the road infrastructure object. These include the total moisture content of the frozen soil W_t, the moisture content of the frozen soil between the ice inclusions W_m, the total ice content i_t, dry soil density ρ_d, soil salinity D_{sal}, soil type (the index of plasticity I_p is used as the basis for separation of the soil by types).
- Physical and thermal characteristics determined by computational methods: concentration of pore solution C_{ps}, temperature of the beginning of soil freezing T_{bf}, soil moisture due to unfrozen water W_w, and also volumetric heat capacity C and thermal conductivity λ that depend on soil temperature.

Step 4. Numerical modeling of the temperature regime in the soil massif for the baseline and altered climate. The ultimate goal of the modeling is the determination of the temperatures at the reference points of the soil and the strength and deformation characteristics of the soil depending on these temperatures. The procedure for modeling the temperature regime is described in [4, 5].

Step 5. Recording the performance criteria of the object and establishing the boundaries of the region of admissible states. As a criterion, either the soil subsidence δ (this criterion is used for the road profile), or the carrying capacity φ (for the foundation of a building or structure) is used for objects that have foundations as independent structural elements. The range of admissible states when using subsidence is defined as:

$$\delta \leq \delta_0 + [\delta] \tag{2}$$

where δ_0 – the standard subsidence in conditions of the baseline climate, $[\delta]$ – the amount of deformation of the road profile surface (manifested in the form of mass chaotic subsidence and dips), at which operation of the road segment is considered impossible. In accordance with the road maintenance standards, as a rule, it is assumed $[\delta] = 0.1$ m. The range of admissible states of the object with the foundation:

$$\varphi \geq \varphi_0 / k_\varphi \tag{3}$$

where φ_0 – the bearing capacity of the foundation in conditions of the baseline climate, k_φ – the safety factor for the bearing capacity envisaged by the existing design standards (depending on the type of foundation, k_φ = 1.2–1.4).

Step 6. Calculation of criterion indicators δ or φ for the baseline and altered climate and determination of the risk of losing the object's functionality. To determine the level of the object's functionality u, normalized to the range [0; 1] and corresponding to the calculated value δ, the monotonically decreasing dependence $u(\delta)$ is set with $u(\delta_0) = 1$ and $u(\delta_0 + [\delta]) = 0$. When the bearing capacity of the foundation is used as a criterion, the dependence $u(\varphi)$ is monotonically increasing with the boundary points $u(\varphi_0/k_\varphi) = 0$ and $u(\varphi_0) = 1$. In both cases, a linear relationship is possible between two boundary points.

To take into account the probabilistic nature of climate change, several possible variants of the average year with a modified climate Ci(T) and with the probability of its realization corresponding to each variant pi are considered in the previous steps. The set of altered climate options forms a complete group, where the sum of probabilities for all options is 1. Accordingly, for each option, the predicted functionality level of the object ui is determined, and the climatic risk R is the weighted average of the functionality for all m considered climate change options:

$$R = \sum_{i=1}^{m} u_i p_i \tag{4}$$

4 Numerical Modeling Results

To confirm the efficiency of the prognostic module algorithms, a numerical modeling of the risks of reducing the functionality of the road profile was performed when the air temperature increased by +2 °C relative to the baseline climate, the parameters of which were taken into account when designing and building the road network. The air temperature for the baseline climate was determined by climatic reference books containing the average results of instrumental observations of the climate in a certain area over the period 1960–1990. Thirty four settlements were considered and united in 7 groups depending on the permafrost and climatic features of the territory of Russia's cryolitic zone.

Warming was assumed to be uniform throughout the entire average year. When building a model of the altered climate, all average monthly temperatures of the baseline climate were increased by +2 °C, and monthly average wind speeds were left unchanged. The duration of the modeling of heat transfer in the road profile was 3 years. At the end of this period, the transition from the previous state of the soil massif corresponding to the baseline climate to a new state in the altered climate was considered complete, and the annual temperature regime in the profile was considered finally established.

Two possible types of soil were considered - sandy, with a volume weight of $\rho = 1800$ kg/m^3, and clayey ($\rho = 2000$ kg/m^3). The total moisture content of the frozen soil Wt was taken at almost meeting upper and lower boundaries for each type of soil. The total ice content in all cases was taken as it = 0,1 Wt, soil salinity was absent (Dsal = 0) (Table 1).

Table 1. Predicted risks of reducing the functionality of roads when climate warms by 2 °C

№	Settlement	Coordinates		Average baseline climate indicators		Predicted risk R with the soil at the base of the road			
						Sandy		Clayey	
		B, °	L, °	T, °C	v, m/s	W_t = 0.2	W_t = 0.35	W_t = 0.3	W_t = 0.5
A. Low-temperature, predominantly continuous permafrost of Yakutia and the Far North-East of Russia									
A1. High-latitude (B > 65°) regions of Yakutia and Krasnoyarsk Krai									
A1.1	Deputatsky	69.311	139.981	−15.2	2.5	0.105	0.146	0.194	0.262
A1.2	Sakhanja	69.771	128.194	−14.2	1.0	0.120	0.152	0.172	0.216
A1.3	Saskylakh	71.963	144.092	−14.0	3.4	0.128	0.145	0.195	0.285
A1.4	Srednekolymsk	67.457	153.702	−12.5	2.1	0.098	0.143	0.187	0.279
A1.5	Essey	68.465	102.189	−12.5	2.9	0.109	0.148	0.201	0.205
A2. Magadan region and eastern (L > 145°) territories of Yakutia									
A2.1	Srednekan	62.440	152.333	−11.4	1.8	0.095	0.136	0.220	0.259
A2.2	Ust-Omchug	61.133	149.633	−11.0	2.5	0.126	0.139	0.214	0.273
A2.3	Yagodnyy	62.524	149.628	−11.0	1.7	0.123	0.139	0.220	0.273
A2.4	Susuman	62.781	148.154	−13.2	2.1	0.116	0.143	0.204	0.237
A2.5	Darpir	64.017	147.417	−13.1	1.8	0.139	0.148	0.183	0.273
A3. Central and Western Yakutia									
A3.1	Sogo-Khaya	64.200	126.405	−10.2	3.3	0.085	0.124	0.207	0.193
A3.2	Yakutsk	62.034	129.733	−10.2	2.1	0.099	0.129	0.201	0.251
A3.3	Yugorenok	59.756	137.695	−10.1	1.5	0.099	0.147	0.211	0.222
A3.4	Tommot	58.957	126.292	−8.6	1.0	0.101	0.132	0.211	0.263
B. Sporadic and massive island permafrost									
B1. Eastern regions									
B1.1	Nagornyy	55.948	124.919	−7.8	2.8	0.127	0.140	0.232	0.280
B1.2	Mogocha	53.734	119.765	−5.4	1.9	0.103	0.125	0.230	0.272
B1.3	Chara	55.816	118.299	−8.0	1.3	0.130	0.132	0.206	0.263
B1.4	Komaka	60.133	111.580	−7.2	1.2	0.101	0.136	0.229	0.263
B1.5	Nizhneangarsk	55.793	109.580	−3.1	1.9	0.106	0.136	0.223	0.266
B1.6	Kezhma	58.969	101.119	−4.3	2.6	0.117	0.125	0.189	0.271
B2. Northern regions									
B2.1	Nyda	66.626	72.926	−7.6	5.1	0.117	0.159	0.253	0.273
B2.2	Urengoy	65.965	78.369	−7.8	4.2	0.124	0.163	0.235	0.238
B2.3	Tazovskoye	67.472	78.716	−9.1	6.2	0.129	0.143	0.234	0.236
B2.4	Tura	64.278	100.218	−9.4	2.0	0.103	0.142	0.205	0.234
C. Permafrost of island and rare island character with temperatures of attenuation of seasonal fluctuations close to 0 °C									
C1. Regions of the eastern boundary of the cryolitic zone (L > 95°)									
C1.1	Severo-Yeniseysky	60.374	93.046	−4.3	3.3	0.099	0.131	0.217	0.263
C1.2	Nerchinsky zavod	51.308	119.616	−3.2	1.2	0.106	0.126	0.207	0.278
C1.3	Chemdalsk	59.631	103.324	−6.4	1.2	0.121	0.184	0.200	0.273
C1.4	Ulan-Ude	51.827	107.606	−1.7	2.6	0.098	0.124	0.199	0.243
C1.5	Goryachinsk	52.977	108.296	−1.5	2.9	0.119	0.164	0.275	0.308

(*continued*)

Table 1. (*continued*)

№	Settlement	Coordinates		Average baseline climate indicators		Predicted risk R with the soil at the base of the road			
						Sandy		Clayey	
		B, °	*L*, °	*T*, °C	*v*, m/s	$W_t = 0.2$	$W_t = 0.35$	$W_t = 0.3$	$W_t = 0.5$
C2. Regions of the northwestern boundary of the cryolitic zone ($B > 60°$)									
C2.1	Petrun	66.329	61.205	−4.4	4.5	0.125	0.136	0.254	0.315
C2.2	Kazym	63.700	67.244	−3.7	2.6	0.129	0.172	0.264	0.310
C2.3	Kellog	62.482	86.300	−5.4	2.5	0.108	0.131	0.196	0.263
C2.4	Saranpaul	64.257	60.907	−3.8	2.5	0.112	0.143	0.227	0.294
C2.5	Tolka	63.406	80.106	−6.1	2.6	0.106	0.136	0.204	0.279

The results of the quantitative risk assessment given in the table sufficiently and fully characterize the territory of Russia's cryolitic zone from the point of view of the expected decrease in the functionality of the road network in the case of the implementation of the climate change scenario considered in modeling.

5 Discussion of the Results

First of all, it should be noted that the method of predicting the functional state of the roads in the cryolitic zone makes it possible to obtain adequate risk assessments using the array of climatic, engineering and geological data, which is easily determined by empirical methods, as initial information. According to the results of numerical modeling, it is possible to record the following patterns that significantly affect the processes of maintaining the functionality of the road network in the cryolitic zone under conditions of expected climate change.

Motor roads located on sandy permafrost are markedly less vulnerable to a systematic increase in air temperature in the territory, as compared to roads, which are based on clay soils. At the same time, with increasing soil moisture, climate risks naturally increase, which is explained by increased deformations (subsidence) of moisture-saturated soil during its excessive thawing under the influence of climatic changes. A similar dependence of the predicted risks on the type of foundation soil is likely to be observed for other road infrastructure objects (bridges on pile foundations, buildings on strip foundations, etc.).

For roads on sandy soil, the risks expected from warming up to +2 °C do not exceed 0.184 (territory C1.3). Therefore, they are quite low. Their further reduction due to the planning and implementation of relevant engineering and technical measures seems inappropriate. Under climate change conditions, the most rational actions for road segments of this type are systematic risk prediction in accordance with the actual temperature dynamics in the territory in combination with the monitoring of the current state of the road surface. If there is clay soil at the base of the road, when the expected risk exceeds the value of 0.250 and is interpreted as average, additional technical and economic analysis is needed to identify the most rational option of the two possible actions: periodic repair work to maintain the functionality of the road segment (fixed costs at the average level), or ensuring the design temperature mode of the road profile due to the installation of thermal insulating layers, seasonal cooling devices, and others (one-time high costs).

The average annual values of air temperature and wind speed, considered in isolation from more detailed climate indicators in the territory, do not allow formulating reliable assumptions about the magnitude of risks arising from climate change. For example, for sandy soil with low moisture content, almost the same risk (in the range of 0.098–0.101) is predicted at significantly different average annual temperatures: −1.7 °C (territory C1.4), −4.3 °C (C1.1), −7.2 °C (B1.4), −10.2 °C (A3.2), and −12.5 °C (A1.4). At the same time, in some cases, at very close average annual temperatures, the risk is not the same: with moisture-saturated clay soil at a temperature of −7.8 °C, a risk of 0.238 is predicted for territory B2.2, and a risk of 0.280 for territory B1.1. Thus, taking into account the real dynamics of air temperature over a sufficiently long period (at least three years) is a necessary condition for obtaining adequate predictive assessments of the risk of reducing the functionality for individual road segments. This confirms the need for systematic observations of the climate throughout the entire road network using automatic climate measurement tools.

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Capacity and Traffic Management on a Heavy-Traffic Railway Line

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Abstract. In connection with the development of international trade relations with the countries of Western Europe and East Asia, carried out through the developing ports of the Azov-black sea basin, a significant increase in the volume of export cargo in the southern region of Russia. The purpose of the study is to master the growing volume of traffic and achieve efficiency in operational work. The tasks of research aimed at the development of ways to increase the capacity of a heavy-traffic line are defined. In this regard, the analysis of capacity is made using the example of the heavy-traffic railway line Kotelnikovo-Tikhoretskaya-9 km Passing Track of the North Caucasus railway, through which the supply of the largest volume of demanded export cargo to the ports of the basin is made. The bottlenecks in the operational work of the railway and ports of the Azov-Black sea basin are identified. Promising volumes of export traffic to its ports, the available and the required capacities of the sections under consideration are identified. Technical and technological measures aimed at improving the quality of operational activities that contribute to the development of export traffic growth are proposed. For solving the problems, the method of capacity calculation is used, as a result of which options for increasing it at the heavy-traffic section were offered, and the best option was chosen that ensures high reliability of transportation, timely delivery and unloading of cargo.

Keywords: Railway transport · Capacity · Traffic management · Railway line · Heavy-Traffic · Freight transportation · Freight market · Transport infrastructure

1 Introduction

The Russian railway transport system plays a key role in the provision of freight and passenger transportation. Over the past decades, the railway industry in many countries has undergone major changes, which include: a complete transition to market-based economic institutions in the system of transport organization, a change in the system of dispatching control, a continuous increase in the volume of cargo traffic in the directions to the ports, including the forecast values for the next decade, the long-term implementation of infrastructure projects for the development of throughput and

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carrying capacity of the port polygons of railway transport, a large load capacity of the main lines (to the ports) and others [1, 2].

To strengthen the position of rail transport in the freight market, it is necessary to develop transport infrastructure taking into account the growth of traffic volumes, to ensure a balance between the throughput and processing capacities of Railways and the ports they serve. The presence of infrastructure restrictions on cargo-loaded directions is observed in the South of Russia, especially in the summer with the growth of passenger traffic, as this problem is typical for other regions [3]. Under these conditions, the analysis of the accumulated theoretical and practical experience [4, 5], the development of ways to increase the capacity of the load-stressed areas, the development of measures aimed at improving the efficiency of operation of the railway infrastructure [6], ways of organizing the transportation process [7, 8], transportation logistics [9, 10], is a necessary tool to ensure the sustainable functioning of the transport system.

The lack of capacity reserves for railway lines leads to the abandonment of freight trains, which in turn complicate the management of train traffic. The existing methods of increasing the capacity are divided into organizational, technical and reconstructive.

The main organizational and technical measures include:

– increase the mass of trains based on the use of innovative cars, modern train locomotives, the installation of additional traction substations on electrified sections;
– reduction of station and inter-train intervals at stations and hauls, limiting the capacity of the site;
– increase the speed of freight trains;
– change of station service schedules by modular trains.

Ways to increase capacity and sequence of activities are formed for each direction depending on local conditions, given the size of the movement and technical and economic efficiency of various options [11–15].

2 Research Methods

This study examines options for enhancing the carrying capacity of the heavy-traffic line Kotelnikovo-Tikhoretskaya- 9 km-Passing-Track of the North Caucasus Railway (North-Caucasian Railway), which ensures the supply of export cargo to the port stations of the Azov-Black Sea basin (ABSB), the bottleneck for the capacity is the section Grechanaya- 9-km-Passing-Track (Fig. 1).

At the moment, the section under consideration, which is a single-track section with double-track inserts and a limited available capacity of 46 train pairs, is in the process of laying a continuous second track, at the end of which the available capacity will be N_{req} = 154 trains. Reconstruction of the section is carried out in connection with the expected growth of cargo traffic (V) to the ports of Southern Russia in the amount of 130 million tons and the need for its development. At the weight norm of the train of 4500 tons accepted on this direction for development of the specified cargo flow it is necessary to provide the admission of freight trains in the size (N_{fr}) calculated by the formula (1) according to the instruction on calculation of capacity of railway lines [9]

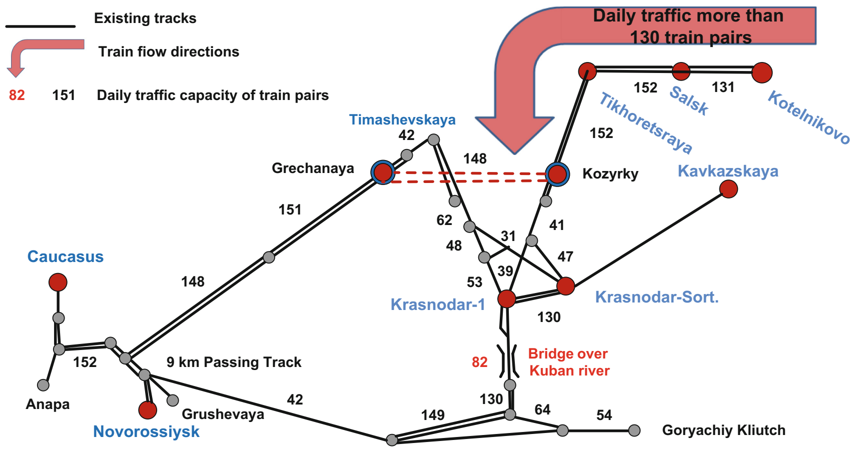

Fig. 1. Scheme of the heavy-traffic line Kotelnikovo-Tikhoretskaya- 9 km-Passing-Track

$$N_{fr} = \frac{V \cdot k}{365 \cdot Q \cdot \varphi} = \frac{130 \cdot 10^6 \cdot 1.1}{365 \cdot 4.5 \cdot 10^3 \cdot 2/3} \approx 131\, train\, pairs \quad (1)$$

where k – monthly peak factor $(k = 1, 1)$;
Q – standard gross weight of train $(Q = 4500$ т);
φ – net weight to gross weight of trains ratio $(\varphi = 2/3)$.

Passenger trains in the amount of 29 pairs of long-distance and local trains, three pairs of suburban trains and one pair of combined trains will be passed through the study section in addition to freight trains.

The average coefficient of removal of freight trains by passenger ones according to [1] is calculated by the formula (2)

$$\varepsilon_{pass} = \frac{t_{fr}(1 - \Delta) \cdot (0.8 - 0.005 \cdot n_{pass})}{I} + 1.3 \quad (2)$$

wherein t_{fr} – running time of a freight train on a limitative stage $(t_{fr} = 18\,\text{min})$;

Δ – ratio of net running time of passenger (accelerated) train in this category, which has a higher speed than the freight one, to running time of freight train on an estimated standard section $(\Delta = 0.77)$;
n_{pass} – total number of passenger trains on a section $(n_{pass} = 32)$;
I – estimated interval between consecutive trains on a Sect. (1 = 8 min).

Hence

$$\varepsilon_{pass}^{even/odd} = \frac{18 \cdot (1 - 0.77) \cdot (0.8 - 0.005 \cdot 32)}{8} + 1.3 = 1.63 \tag{3}$$

The coefficient of removal of the schedule threads by the combined train is determined by the number of serviced stations. The section under study has 9 separate points, of which 5 stations are served by a combined train team. When a combined train stops at each station, the removal rate of the threads of the schedule will be $\varepsilon_{as} = 5$.

Then the required capacity of the double-track section, which in accordance with [1] is determined by the formula (4), will be:

$$N_{req} = \left[N_{fr} + N_{pass} + N_{as}(\varepsilon_{as} - 1)\right] \cdot \beta_{res}(\text{Trains/day}) \tag{4}$$

wherein N_{as} – number of combined trains, $(N_{as} = 1)$;
β_{res} – capacity reserve for double track section, $(\beta_{res} = 1.1 - 1.15)$.

$$N_{req} = [131 + 32 \cdot 1.63 + 1 \cdot (5 - 1)] \cdot 1.1 = 205.92 \approx 205(\text{train pairs}) \tag{5}$$

According to the results obtained, the capacity will not be sufficient to handle the growing volume of traffic, and the problem must be addressed either by developing the infrastructure of the direction in question or by reducing the number of trains by increasing their weight standards.

Laying the third main track on the stages of the Grechanaya-9 km Passing Track section will ensure the greatest increase in available capacity. Only when the growth rate of export traffic is significant (5–7%), as in the current situation in the south of Russia, laying of the third tracks on the hauls can be rational. In this regard, the work assesses the increase in the capacity of the investigated area due to the laying of the 3rd path.

As a second option to increase the capacity of the studied area, it is proposed to also consider the use of innovative developments of automated control systems for the transportation process, due to interval control of train traffic. One of such ways to increase throughput is the automatic locomotive signaling system (ALSO) with movable block sections. The term "mobile" or "floating" block-section means one or a combination of several track circuits behind the tail of the train, encoded by the same ALS signal [10]. In accordance with [10], thanks to the ALS system with movable block sections, the inter-train interval can be reduced by 15–20%.

The third option to enhance the carrying capacity of the studied direction is the organization of the movement of heavy trains, formed from innovative cars with an axle load of 25 tons/axle and more.

Heavy traffic today is an effective tool with the help of which the increase in carrying capacity of sections and directions, the formation of a reserve of carrying capacity is achieved [11, 12]. It helps to reduce the number of trains passing at the established traffic flow rates due to the organization of train circulation of the increased mass of trains compared to the values established by the schedule and the formation plan. And if earlier the organization of heavy traffic was accompanied by an increase in the time spent at work stations with such trains, today the use of innovative cars eliminates this drawback and provides more opportunities for passing of heavy trains while maintaining the standard train length.

The formation of heavy trains provides: better use of the length of the tracks and the power of the locomotive. All this leads to the development of freight traffic fewer trains. That is why the paper assesses the reduction of the required capacity due to the organization of heavy traffic while maintaining the available capacity of the site.

Another important aspect in achieving the efficiency of freight traffic is the use of new train locomotives. They can provide driving of trains with a weight from 7100 to 8000 tons, increase the duration of overhaul runs, increase the structural speed up to 120 km/h, reduce energy costs up to 15% or more. The study proposes to assess the increase in capacity by accelerating the running speed through the use of new train locomotives and innovative cars.

3 Research Result

In order to estimate the increase in the capacity of the Grechanaya-9 km Passing Track section due to the construction of a third track on its stages, it is necessary to determine the option of its operation. It is proposed to use the third main track for two-way train passes. The available capacity of the section is determined for its limitative stage by the formula:

$$N_n^{even} = \frac{(1440 - t_{tech}) \cdot \alpha_{rel}}{T_{per}} = \frac{(1440 - 75) \cdot 0.96}{39} \approx 33 \left(\frac{\text{trains}}{\text{day}}\right) \quad (6)$$

wherein t_{tech} – duration of technological window in a section, $(t_{tech} = 75\,\text{min})$;
α_{rel} – coefficient given the impact of failures in the operation of technical equipment (paths, signaling and signaling devices and communications, contact network), $(\alpha_{rel} = 0.9 - 0.96)$
T_{per} – period of schedule, otherwise time of occupation of stage by a group of trains, typical for this type of schedule.

$$T_{per} = t'_m + t''_m + \sum \tau_{st} + \sum \tau_{dis.del.}, min \quad (7)$$

wherein t'_m, t''_m – running time of pairs of trains in odd-numbered and even-numbered directions for limitative stage, min.;
τ_{st} – station intervals, min;
$\tau_{dis.del.}$ – time for acceleration and deceleration of a freight train, min.

$$T_{per} = 16 + 16 + 2 + 4 = 39\,min \tag{8}$$

The total capacity is estimated for each direction as the sum of the capacity of the main track, specialized for the considered direction and the capacity of the third track in this direction. The estimated results are shown in Table 1.

Table 1. Estimation of capacity of the three-track line in section Grechanaya- 9 km Passing Track for 2025

Available capacity of double-track section	Third track capacity	Total capacity of section	Required capacity	Efficiency of capacity utilization
154	33	187	205	1.1

Total length of the Grechanaya-9 km Passing Track section is 97.7 km, the need for investment is 29.6 Billion Rubles, the technological effect of the third main track is to increase the capacity from 154 to 187 pairs of trains per day. Nevertheless, the implementation of this proposal does not allow the North Caucasus railway (SCR) to provide services for the transportation of goods and passengers in projected volumes by 2025.

When assessing the increase in capacity due to the use of the system of automatic locomotive signaling (ALSO) with movable block-sections, it is necessary to take into account that the interval between consecutive trains in 6 min today is only allowed between the passenger trains. Between freight trains, taking into account the requirements of traffic safety, the interval should be 8 min. In view of the differences between consecutive trains time interval between trains of different categories, in the calculation of available capacity, it is proposed to consider share of the size of the passenger and freight trains scheduled to pass through the section under study. In this case, the approximate value of the available capacity can be calculated using the following formula:

$$N_n = \alpha_{pass} \frac{(1440 - t_{tech}) \cdot \alpha_{rel}}{I_{pass}} + \beta_{fr} \frac{(1440 - t_{tech}) \cdot \alpha_{rel}}{I_{fr}} \tag{9}$$

wherein α_{pass}, β_{fr} – size shares respectively passenger and freight traffic in the section;
I_{pass}, I_{fr} – inter-train interval, respectively, between passenger and freight trains.

According to the above formula, in the event that the size of the passenger traffic prevails, it is possible to have a significantly larger amount of available capacity and only then can we speak about eliminating the need to build a third track on heavy-traffic sections. For example, on the section Presovka - Millerovo North-Caucasian Railways, 75 passenger trains and 37 freight trains are allowed to pass, which is α_{pass} = 0.67 and β_{fr} = 0.33 in shares.

The available capacity of the Northern section of the North-Caucasian Railway with $t_{tech} =$ 150 min and $\alpha_{rel} = 0.96$ in this case is:

$$N_n = 0.67\frac{(1440 - t_{tech}) \cdot \alpha_{rel}}{6} + 0.33\frac{(1440 - t_{tech}) \cdot \alpha_{rel}}{8} = 138.3 + 51.1 = 189.4 \approx 189\,Train\,pairs \tag{10}$$

The greater the share of passenger trains, the greater must be the actual capacity of the section, the maximum value which can be $N_{нал}$ = 206 train pairs, provided the passenger trains of the packets between consecutive trains every 6 min.

However, in the study Grechanaya- 9 km Passing Track section the freight traffic prevails, and in shares it is α_{fr} = 0.805 и β_{pass} = 0.195.

Then the available capacity of the Grechanaya- 9 km Passing Track section will be equal to:

$$N_n = 0.195\frac{(1440 - t_{tech}) \cdot \alpha_{rel}}{6} + 0.805\frac{(1440 - t_{tech}) \cdot \alpha_{rel}}{8} = 40.2 + 124.6 = 164.8 \approx 164\,\text{train pairs} \tag{11}$$

Based on the results, the following conclusions can be drawn:

1. The available capacity should not be considered as a constant parameter, but as a variable, depending on the ratio of the size and speed of passenger and cargo traffic.
2. The resulting reserve capacity without investment in track development will allow mastering the train traffic only to 2020. For the development of further growth of freight traffic, it is necessary to implement additional measures to increase the capacity, one of which is the organization of heavy train traffic.

When organizing the movement of heavy trains, it is necessary to determine the possible number of freight trains of standard weight that can be skipped along the section and the number of heavy trains formed to ensure the missing capacity reserve. The possible number of freight trains passing through the section in compliance with the 15% capacity reserve is set by the formula

$$N_{fr}^{pos} = \frac{N_n}{\beta_{res}} - (N_{pass} \cdot \varepsilon_{pass}^{пак} + N_{as}(\varepsilon_{as} - 1)) \tag{12}$$

$$N_{fr}^{pos} = \frac{154}{1.1} - (32 \cdot 1.63 + 1(5 - 1)) = 83.84 \approx 83\,train\,pairs \tag{13}$$

It is proposed to use the system of Eq. (14) to determine the required number of heavy trains.

$$\begin{cases} n_{st} + n_h = N_{fr}^{pos} \\ \varphi \cdot (B_{st} \cdot n_{st} + B_h \cdot n_h) = V_d \\ V_d/(\varphi \cdot B_h) < N_{fr}^{pos} \end{cases} \tag{14}$$

wherein n_{st} – number of standard weight trains;
nh – number of heavy-weighted trains;
Bst – weight standard of train, million tons;
Bh – accepted weight of a heavy train, million tons;
N_{fr}^{pos} – the number of freight trains that can be passed on the section with the existing technical equipment, $N_{fr}^{pos} = 83$ trains;
Vd – daily cargo flow to be processed, (Vd = 0.356164 million tons).

The results of solving the system of equations depend on the accepted standard weight of the train and the weight for a heavy train. In this case, the weight of the heavy train should be taken so that in the case of the formation of all heavy trains their number was less. N_{fr}^{pos}. Two options of weight standards of trains are considered: 7000 tons and 7800 tons, which are critical in the studied direction. The options considered in this paper and the results are summarized in Table 2. The number of cars in the heavy train was determined based on the condition that innovative cars with a load of 27 t/axle or 108 t/car are used.

Table 2. Results of calculation of the number of heavy trains per day depending on the accepted weight standards

Option	Weight standard of train B_{st}, million tons	Weight of heavy train B_h, million tons	Number of trains of standard weight, n_{st}	Number of trains of heavy weight, n_h	Number of cars in heavy-weight train, m_c
1	0.0045	0.007	19	64	65
2	0.0045	0.0078	34	49	73

Based on the results obtained, it is necessary to choose the best variant of the weight norm of trains. As is well known, in determining the optimal weight standards train proceed from the condition of full power utilization of the locomotive, however, restrained the growth speed of may decrease traffic safety, because the presence of more than 50 cars, leads to an increase in the number of stretches in the trains, damage to traction motors, sharp flanges. In this regard, for the feasibility study of the optimal weight norm of a heavy train for each option, it is proposed to determine the given costs according to the formula [1]:

$$\Sigma P = P_{dr} + P_p + P_n \tag{15}$$

wherein ΣP – comparable given cost of the meter, RUB;
Pdr – train traction costs, RUB.;
Pp – cost of passing trains on section, depending on the traffic scale, rubles.;
Pn – costs associated with accumulation of trains at the point of their formation, RUB.

According to [1] the costs associated with traction are determined by the formula (16):

$$P_{dr} = n \cdot l \cdot e_{nL} + M \cdot t \cdot e_{MH} + H \cdot t \cdot e_{Mh} \tag{16}$$

where n – average daily number of heavy freight trains (based on results of calculations from Table 2);
l – distance between stations of recurrent locomotive depot serving the considered section (for this section, the stations of the reverse depot are Salsk and 9 km Passing Track, $l_{уч}$ = 374 km);
M, H – required number of train locomotives and locomotive crews;
t – worktime of train locomotives and locomotive crews;
e_{nl} – expenditure rates by train-km;
e_{MH} – expenditure rates by train-hours;
e_{Mh} – expenditure rates by crew-hours.

Worktime of train locomotives and locomotive crews can be determined by formula (17):

$$t = \frac{l_{uch}}{V_{uch}} = \frac{374}{44} = 8.5\,\mathrm{h} \tag{17}$$

wherein V_{uch} – section speed in the considered section (planned for 2030 is to increase the speed to 44 km/h).

The costs of passing trains on the section depending on the scale of traffic in accordance with [1] can be estimated by the formula (18), and the cost of accumulation of trains at the point of their formation by the formula (19):

$$P_p = \frac{L_{\mathrm{H}} \cdot n}{v_{uch}} \left(e_{MN} + 4.5 \cdot e_{Mh}\right) \tag{18}$$

wherein l_{uch} – section length;
n_t – daily traffic scale of heavy trains.

$$P_n = N_t \cdot t_n \cdot e_{nh} \tag{19}$$

wherein N_t – average daily car traffic volume, covered a formation of heavy-weight trains;
t_n – time of trains accumulation depending on their lengths;
e_{nh} – hourly rate for occupying station tracks by one car.

The cost of trains accumulation for the considered section is estimated at the station named after M. Gorky, where it is envisaged in the future the formation of trains to the ports of the Azov-Black Sea basin.

The time of accumulation of cars is determined by the formula:

$$t_n = \frac{C \times m_c \times K_{naz}}{N_t} \tag{20}$$

wherein $C -$ accumulation parameter (for the station named after M. Gorky $C = 11.4$ h),
m_c – average number of cars in a train (see Table 2),
K_{naz} – number of appointments according to the plan of station formation, followed through the considered section, $K_{naz} = 17$;
Nt – average daily number of cars accumulated in heavy-weight trains (taken from Table 2).

The results of cost calculations for the organization of heavy traffic on the given elements and the total costs are presented in Table 3.

Figure 2 shows visualization of dynamics of cost of organizing of heavy-trains traffic, depending on the number of cars in their sets. According to the data obtained, it can be argued that the weight of the train with a modern system of expenditure rates is not limited to operating costs, and the greater the weight of the train, the lower the costs. Under these conditions, the limitation in increasing the weight of heavy trains is the track development of the stations used to handle heavy trains.

The station should have such a number of tracks to handle heavy and long-haul trains so that the time interval after which it becomes necessary to release at least one track to receive the next long-haul train is longer than the processing time at the station, i.e.:

$$t_{op}^{dl} < t_{free} \tag{21}$$

wherein t_{op}^{dl} – processing time of long-haul trains at the station (taken on the basis of the station's technological process);
t_{free} – time interval after which it becomes necessary to clear at least one track.

The time interval after which there is a need to clear at least one track to receive a long train is determined by the formula (22):

Table 3. Results of cost estimation for organization of heavy traffic

Option	Daily number of heavy-weight trains, n_t	Cost of traction, thousand rubles P_{dr}	Cost of passing trains on section, depending on traffic scale, thousand rubles P_p	Average number of cars in a set of train, cars m_c	Average daily number of cars accumulated in heavy-weight trains, cars N_t	Time of car set formation, t_n	Costs on cars accumulation, thousand rubles P_n	Total costs on organization of heavy-weight trains, thousand rubles ΣP
1	64	1180.43	3398.02	65	4160	3.03	3.91	4582.36
2	49	903.77	2601.61	73	3577	3.96	4.39	3509.77

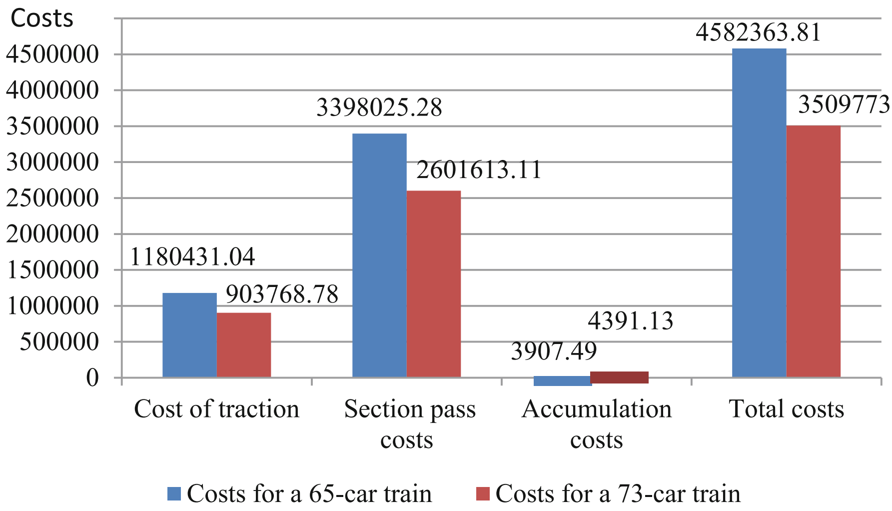

Fig. 2. Dynamics of cost of organizing heavy trains traffic, depending on a number of cars in their sets

$$t_{free} = k_r^{dl} \cdot t_{ar}^{dl} \quad (22)$$

where k_r^{dl} – number of tracks that can take trains of the required length;
t_{ar}^{dl} – estimated interval between arrival of long-haul trains at the station, which is calculated by formula (17)

$$t_{ar}^{dl} = \frac{(1440 - t_w) \cdot \alpha_n}{2 \cdot n_t} \quad (23)$$

where t_w – duration of technological window in adjacent section (for double-track traffic t_w = 75 min);
n_t – number of heavy trains longer than standard;
α_n – technical equipment safety factor ($\alpha_n = 0.90 \div 0.96$).

For the direction under study, the stations for processing heavy trains of increased length along the route are the stations Salsk and 9 km-Passing-Track. The results of evaluation of the capabilities of these stations to receive all trains of increased length are shown in Table 4. In this case, only the option of passing heavy trains with a length of 73 cars is evaluated, since 65-cars heavy trains are not increased trains for a given route.

Table 4. Estimation of station capacity to receive all trains of increased length

Station	The number of heavy trains longer than the standard, n_t	Arrival interval of long-haul trains to station, min. t_{ar}^{dl}	Number of tracks that can accommodate a train of required length, k_r^{dl}	Time interval after which there is a need to release at least one track, min t_{free}	Processing time of long-haul trains at the station, min t_{op}^{dl}
9 km-Passing-Track	42	16	14	224	185
Salsk	42	16	6	96	153

According to the data obtained, the 9 km-Passing-Track station copes with the entire train traffic of increased length, and the Salsk station, with the existing track development, is not able to master the considered size of long-haul trains. As a result, a decision is made on the formation of heavy trains with a lower weight of 7,000 tons and a length of 65 cars. However, in the future, taking into account the proposed reconstruction of the station, according to one of the options for which it is planned to build at least 4 additional large capacity receiving routes, the number of tracks capable of accommodating trains of the required length will be $k_r^{dl} = 10$. Then the required t_{free} interval will increase to 160 min. As a result, condition (15) will be fulfilled, in connection with which it will be possible to organize the movement of heavy trains weighing 7,800 tons, the omission of which will reduce operating costs using the new electric locomotive 2ES5 SKIF for this purpose. Its distinctive feature is the maximum unification with the electric engine EP20, which reduces the cost of production and maintenance of the electric locomotive. This locomotive has the following characteristics: long-time traction force of 536 kN; speed of the long regime is 50 km/h; maximum speed of 120 km/h.

As a result, the use of new locomotives, subject to the use of innovative cars that can run at high speeds, will increase the maximum speed of freight trains to V_{max} = 120 km/h, which in turn will increase the local speed, which is calculated by the formula (24):

$$V_{uch} = \frac{l_{uch}}{\frac{l_{uch}}{V_{max}} + t_{add}} \tag{24}$$

wherein t_{add} – train standing time at intermediate stations, acceleration and deceleration and delay of the train on hauls.

If at a maximum speed of V_{max} = 90 km/h the local speed is V_{uch} = 44 km/h, then t_{add} is calculated using the formula (25):

$$t_{add} = \frac{l_{uch}}{V_{uch}} - \frac{l_{uch}}{V_{max}} \tag{25}$$

$$t_{add} = \frac{374}{44} - \frac{374}{90} = 8.5 - 4.1 = 4.4\,\text{h} \tag{26}$$

Then the possible local speed at the maximum train speed Vmax = 120 km/h, will be:

$$V_{uch} = \frac{374}{\frac{374}{120} + 4.4} = \frac{374}{7.5} = 49.86 \approx 50\,\text{km/h} \tag{27}$$

Based on the obtained results, it can be argued that despite the organization of heavy traffic is a technological measure to increase the carrying capacity of the section its greatest efficiency can be achieved only in a joint application with reconstructive measures to increase throughput.

4 Discussion of Results

As a result of the goal to assess measures to increase the capacity of the study area in the work for the first time were considered all possible options for which the calculation was carried out using existing techniques, adjusted by the authors to take into account additional conditions. The resulting algorithm of actions is universal and can be used to assess the activities and select the optimal for all areas included in the heavy-traffic line. Thus, to select the best measure to increase the capacity of the study area Timashevsk-9 km Drive, the results of the calculation of the capacity for all proposed activities are summarized in Table 5.

Table 5. Estimation of capacity increase depending on organizational activity

Activity	Available section capacity	Available capacity after the event	Required capacity for 2025	Usage coefficient, *K*
Construction of the third track on the section Timashevskaya - 9 km Passing Track	154	187	205	1.1
Locomotive alarm system with movable block-sections	154	164	205	1.24
Organization of heavy traffic using new locomotives	154	154	144	0.93

Analysis of the table shows that none of the reconstructive measure does not allow increasing the actual capacity sufficiently to master the forecasted traffic. And only a technological measure to increase the capacity by organizing the movement of heavy trains gives the necessary effect, but with a minimum reserve capacity. This indicates that each of the ways to increase capacity cannot be used separately, and a set of measures must be implemented to ensure the required capacity.

The development and growth of the capacity of this direction will ensure reliable organization of train traffic and increase the speed of cargo delivery, to achieve in the ports of the South of Russia the required rate of daily unloading, equal to 5 thousand cars. Increasing the speed of trains will help to organize the work of locomotive crews on the elongated shoulders of service from the station named after M. Gorky to the Salsk station and you can reach the 9 km-Passing-Track station. The average length of the service shoulder will increase from 150 km to 430 km, which will exclude part of the technological stops for changing crews on the route and, as a result, reduce the time of delivery of goods. The emergence of reserves in the capacity will also improve the quality of planning the supply of demanded cargo to ports on the basis of the dispatching information and logistics system. In terms of reducing delays of trains en route on the basis of this system, the quality of traffic control of traffic flows through the entire logistics chain from their origin to maturity, the reliability of automatically developing a plan for the rhythmic supply of demand cargo at the destination station will increase. This will be an incentive to improve the interaction between railways and seaports, their automated control systems to achieve, which will lead to positive dynamics and efficiency of export cargo transportation.

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Methods of Rating Assessment for Terminal and Logistics Complexes

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Abstract. The transport and logistics market make high demands on the speed of decision making and their economic feasibility. In the conditions of a dynamically developing market of transport and logistics services, decision-making must be carried out quickly, on the one hand, and reasonably on the other. The adoption of such decisions in complex terminal systems for the delivery of goods requires the use of methods that allow such a comprehensive assessment. Obviously, the methodology should be objective and consider many factors of the work of the terminal and logistics complexes. This circumstance determines the relevance and purpose of this work - the development of methods for integrated assessment of the parameters of the terminal and logistics complexes based on the total rating. To achieve the goal and approbation of the methodology, we used programming tools in the Scilab environment, as well as methods of systems theory, terminalistics, logistics, economics, organization and planning of railway transport operation, expert assessments, SWOT analysis, calculation of parameters of freight fronts, score ratings, linear and dynamic programming. The practical significance of the results obtained in the study is to develop applied assessment tools for conducting an express analysis of the activities of terminal and logistics complexes on several key parameters. The subject of future research may be to solve the problem of reducing the subjectivity of evaluation by this method.

Keywords: Logistics infrastructure · Samara region · Terminal and logistics complex · Rating assessment

1 Introduction

Transport and logistics complexes are a key part of any logistics chain. They perform the functions of converting the parameters of freight and transport flows. Modern transportation systems without them practically do not exist, since such complexes prepare cargoes for transportation, balance carrying and processing capacities of transportation participants.

At the same time, the "connection" to the delivery system of the terminal and logistic complexes (hereinafter referred to as TLC) significantly complicates the organization and management of the transportation process. This is because TLC also runs a wide

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range of integrated value-added services. It should be noted that the specifics of changing the parameters of incoming and outgoing flows are determined by the type and format of the TLC. This fact complicates decision-making in complex cargo delivery chains, as well as the choice by the client of a suitable TLC.

Today, the transport and logistics market make high demands on the speed of decision making and their economic feasibility. Therefore, a comprehensive assessment of the TLC from the perspective of the client becomes particularly relevant. The adoption of such decisions in complex terminal systems for the delivery of goods requires the use of methods that allow such a comprehensive assessment. Obviously, the methodology should be sufficiently objective and consider different factors of TLC operation. In the conditions of a dynamically developing market of transport and logistics services, decision-making must be carried out quickly, on the one hand, and reasonably on the other. Accounting and analysis of numerous factors influencing the choice of alternative TLC for inclusion in the logistics chain and applications for specific business problems, complicates management decisions when organizing a cargo delivery system. This circumstance determines the relevance and purpose of this work - the development of methods for integrated assessment of the parameters of the TLC based on the rating.

In this article, the term “Terminal and Logistics Complex” we define as a logistics facility, which is a geographically concentrated collection of transport communications, storage facilities of various specializations, as well as a single information field for providing a wide range of terminal-warehouse, transportation and logistics services [1].

In particular, it is proposed to call railroad TLCs related to the terminal-warehouse infrastructure of railways, performing the functions of the nodal elements of the terminal-logistic system for the technical support and practical implementation of loading, unloading, storage and distribution services, including bringing the goods to the final consumer, in the interaction with the participants of the delivery system and other types of transport.

In the general case, the logistic object is a key element of the transport and warehouse infrastructure system that performs a set of logistic functions in the system of cargo delivery from the initial supplier to the final consumer [2].

Depending on the pace and characteristics of the functional development, the TLC can be transformed, under the influence of external and internal factors, into an object of larger scale - a logistic area or region [3].

According to the theory of terminalistics (logistics of terminals and terminal networks), a logistic area is a set of logistic facilities of a certain degree of economic and technological interaction, combined on several attributes in spatial-geographical concentration. Logistics area - a set of interrelated logistics areas, providing integration into transport corridors and building a terminal network, which is stable in terms of composition and complexity of transport and logistics services.

Analysis of the literature showed the following.

In the Russian science TLC was studied from the standpoint of technical and technological design, as well as regional economy and logistics - V. Dybskaya [4], P. Popov [5]. Well-known classifications are directly related to the technical and technological components of the work of the TLC. However, most approaches reflect only certain groups of parameters and are not focused on a comprehensive assessment of the choice of TLC from the perspective of the client as a decision maker.

Comprehensive studies of TLC are devoted to the work of such foreign scientists as: Lukinykh V. et al. [6], Notteboom T. and Rodrigue J.-P. [7–9], Rushton A. [21], Higgins C.D. and Ferguson M.R. [10] and many others. The problems of interaction between individual subjects of logistics services were considered in the work of R. Fedorenko [11].

Monios, J. investigated the problems of integration of retailers, third-party logistics providers (3PLs) and rail operators [12]. Záhumenskáa Z. and Gašparík J. described the issue of supporting the connection of logistics centers to rail transport [13].

Analysis of literary sources has shown that in transport science TLC has traditionally been considered as a key element of the infrastructure for the transformation (transfer) of cargo traffic from one direction to another, as well as for servicing large residential and industrial sites. Most scientific papers focus on the track development of the TLC as an element of the railway junction (including promising general planning and integration into a residential and/or industrial center), as well as economic and geographical features and technical equipment. However, an integrated approach to the study of operating modes and comprehensive evaluation of TLC as a logistics facility has not yet received sufficient attention.

The author's approach of terminalistics implies a score-rating assessment of all types of TLC in all the variety of external and internal interdependencies, i.e. comprehensively, without disproving any of the above approaches, but integrating them into a single system of knowledge about logistics facilities.

The scientific novelty of the study is the method of score-rating assessment of the main logistics activity of TLC, which is further used in the classification of TLC by type, considering the total rating. The practical significance of the results obtained in the study is to develop applied assessment tools for carrying out an express analysis of TLC activities on a number of key parameters, for identifying the type of TLC and selecting the best TLC for a specific logistics chain and/or business.

2 Research Methods

To develop a general approach to the parametric description of the work of the TLC, a SWOT analysis of the condition of the terminal and warehouse infrastructure was carried out (using the example of the Samara region, Russia), which showed:

1. Strengths:

   - high density of road and rail transport networks;
   - favorable geographical position at the intersection of important transport corridors on the border with the rapidly developing region of the Republic of Kazakhstan, transport opportunities for trade with Central Asia and China;
   - location on the Volga River and access to the Unified Waterways System of the European part of the Russian Federation and access to the Caspian, Black, Baltic Sea;
   - stable investment rating of enterprises in the region.

2. Weaknesses:
   - high level of deterioration of the transport network and logistics infrastructure;
   - remoteness of the only airport from the largest cities of the Samara-Tolyatti agglomeration, low (insufficient) level of its transport accessibility;
   - insufficient capacity of highways;
   - lack of road bridges across the Volga;
3. Opportunities:
   - implementation of projects included in state programs and programs of state-owned companies, including the construction of a bridge over the Volga and the organization of an accelerated railway connection between Samara, Kurumoch International Airport and Tolyatti;
   - development of the transport and logistics sector as a result of increased international trade;
   - conjugation with the directions of key transport corridors, including the "New Silk Road" route;
   - attraction of foreign trade flows to the TLC network;
4. Threats:
   - increase in the degree of deterioration of the transport infrastructure due to insufficient investment in the transport sector;
   - the growing shortage of transport infrastructure due to non-implementation of planned projects;
   - decrease in the volume of cargo and passenger transportation due to unfavorable economic situation.

The paper proposes a new method of integrated assessment of TLC activity based on the rating calculation for each significant parameter. When developing the methodology, the results obtained in the previously published works of the authors were considered.

The authors used methods of the theory of systems, terminology, logistics, economics, organization and planning of operational work of railway transport, calculation of parameters of freight fronts, expert estimates, SWOT-analysis, point-rating methods, as well as methods of linear and dynamic programming.

3 Research Results

It can be stated that in most cases decision-makers in complex delivery chains are:

- customers who pay attention to such indicators as the cost of services, their range, complexity and quality of service;
- TLC owners (warehouse and logistics operators) for whom the size and dynamics of financial indicators are important. Main indicators are income from TLC activities, profits, business profitability in general and individual service packages in particular;

- carriers (transport and logistics companies) that decide on the choice of an alternative scheme for the delivery of goods through the TLC, considering the functional specifics of the TLC, to participate in the projected delivery chain;
- investors for whom the main indicators of efficiency are the indicators of discounted income, operating costs, profitability and solvency of the TLC;
- competitors evaluating the degree of honesty of competition, price policy, efficiency of TLC innovations;
- suppliers of material resources and other participants in the transportation process who consider TLC activity effective in cases where there are no failures in interaction: there is reliability of supplies, fulfillment of contractual obligations, implementation of logistics.

The choice of the client TLC in the general case is carried out in three key groups relating directly to transportation, additional services and goodwill. The main parameters are:

- Transportation: compliance with the characteristics of transportation (temperature, oversized, fragile, etc.), "geography" of transportation, the use of different types of transport (rail, water, air and road).
- Additional services: information support (tracking, notification of arrival); cargo insurance (possibility to choose a company or a list of insurance claims), additional operations with cargo (packaging in shipping containers, lathing, sealing, etc.), cargo storage (at the point of departure, at the destination, by type of warehouse, by temperature conditions), forwarding.
- Reputation and advertising of the transport and logistics complex: the site and its features, terms and regularity, feedback on the work, etc.

Various combinations and relationships of these elements in the process of organizing a TLC predetermine the diversity of its architectural, planning and spatial parameters.

From the standpoint of the evolutionary-functional approach [13], the development of a TLC as a logistics object takes place in 4 stages, taking into account the transformation of internal processes:

1. disconnected existence of individual elements (objects);
2. concentration (consolidation, integration of elements (objects) in a node (nodal infrastructure element);
3. building up infrastructure (connecting support elements, building up extended infrastructure support);
4. regionalization with a subsequent exit to a new level ("connecting" to local and global logistic systems).

A comprehensive assessment of the activity of the TLC allows to obtain an analytical conclusion about the current state of the TLC and its affiliation to a particular type on the basis of points and the calculation of the total TLC rating.

Let's consider the TLC rating procedure in general terms:

1. Definition of the list of indicators affecting the operation of TLC;
2. Refinement, identification of key indicators using comparative tables, Ishikawa diagrams, SWOT, ABC, XYZ analyzes;
3. Identification of functional dependencies between the main characteristics of the TLC;
4. Formation of a rating formula;
5. Identification of the main problems (bottlenecks) of the TLC;
6. Programming the solution of the task of automated evaluation of TLC according to the proposed methods based on comparative tables for a sample of TLC that consider the most important criteria.

The author's 5-point system for estimating the parameters of the TLC involves the use of a correction priority factor to consider the importance of the criterion for the client. The main evaluation criteria are:

- line of modes of transport;
- reputation, fame;
- cargo tracking;
- availability of special modes of transportation;
- insurance;
- document processing;
- development of the optimal route;
- online application;
- flexible tariff policy;
- packing and securing cargo;
- door-to-door delivery;
- forwarding;
- international transport, customs clearance;
- content and usability of the website;
- low cost of transportation;
- warehousing.

As the analysis shows, TLC are characterized by many indicators having a different nature. At the same time, it is impossible to limit the choice to one global indicator. The work of the TLC is often described by several multidirectional criteria, and since the client often makes decisions with a lack of reliable information, it is not possible to reduce several local criteria into one generalized ("supercriterion", for example) for client decision making tasks.

The task of optimal design and determining the optimal conditions for the functioning of a TLC is essentially multi-criteria: the more criteria are introduced into consideration, the more complete an idea can be obtained about the system under study.

However, several interdependencies between the influencing factors determine the complexity of solving the problem of optimizing the operation of a TLC. For example, reducing the number of loading and unloading machines will lead to an increase in the value of the criterion characterizing the use of machines over time during the day, but reduces the processing capacity of the cargo front, etc.

We will consider the following functions as the target functions:

- number of loading and unloading machines, LM;
- freight front operation time, t(o);
- downtime of vehicles and cargo-handling machines, t(d);
- storage time, t(s);
- storage area capacity, SC;
- time of submission/removal of vehicles, t(s/r);
- work on the direct option, W (do)
- resource costs, C;
- labor and loading machines productivity, P;
- time waiting for work, t(w).

The listed parameters form the basis for expert assessments and the calculation of the total point-rating assessment of the work of TLC.

Indicators striving for a minimum or maximum are considered in the following way: if the indicator is equal to the minimum (according to norms and technical and operational calculations), to which it should strive, then we take its rating value as 1. In real practice this is almost impossible, therefore the indicator will equal to the minimum with a certain coefficient K.

For indicators striving to a minimum, we take the rating value as $|1 - K|$. For the indicators that are striving for the maximum, we take the rating value $|K - 1|$. The indicators are calculated using an adjustment factor to increase the objectivity of the calculation. The adjustment factor is derived using the method of expert estimates.

The authors formed a rating system on a 5-point scale by the criteria:

- the range of transportation services provided by types of transport, RT;
- cargo tracking, T;
- development of optimal delivery route, DR;
- online application and consulting, OC;
- flexible tariff policy, T;
- international transportation and customs services, CS;
- the provision of specialized rolling stock and special mode of transportation, Srs;
- insurance, I;
- paperless paperwork, PP;
- packing and securing cargo, P;
- “door to door” delivery, D;
- forwarding, F;
- website user-friendliness, W;
- low cost of transportation, TC;
- range of storage services, RS.

All parameters are presented in the formula:

$$R1 = \frac{LM1}{LM2} + \frac{t(o)1}{t(o)2} + \frac{t(s)1}{t(s)2} + \frac{SC1}{SC2} + t(s/r) + t(d)t(w) + C + P + W(do) \qquad (1)$$

$$R2 = RT + T + Srs + I + PP + P + D + F + DR + OC + T + CS + W + TC + RS \tag{2}$$

Formula (1) gives an estimate of the parameters associated with the work of freight fronts in particular, and people, mechanisms for the transport and logistics complex as a whole, the maximum score of 10 points. Formula (2) gives a comprehensive rating assessment of the transport and logistics complex, the maximum score is 65.5 points.

4 Results

The authors developed a general view of the methodology for conducting a total TLC rating using the theory of terminology, the evolutionary-functional approach and the general theory of systems.

Table 1 presents a parametric description of the TLC selection problem by significant target criteria with an indication of the direction of the decisions (maximization or minimization of values).

Table 1. Parametric description of the TLC selection task

Parameter	Benefit by compliance	
	1 – TLC customer position	2 – TLC owner position
Number of loading and unloading machines, LM	max	min
Freight front operation time, t(o)	min	min
Downtime of vehicles and cargo-handling machines, t(d)	min	
Storage time, t(s)	max	min
Storage area capacity, SC	max	min
Time of submission/removal of vehicles, t(s/r)	min	
Work on the direct option, W (do)	max	
Resource costs, C	min	
Labor and loading machines productivity, P	max	
Time waiting for work, t(w)	min	

For practical testing of the proposed methodology, the authors analyzed expert assessments and compiled comparative tables for 250 objects of the terminal network at the testing ground that are Russian Railways. As a result, the authors developed a classification of TLC types and identified the boundaries of TLC rating. The low rating correspond to R2 values up to 16 points, the average - up to 32 points, above the average - from 48 to 50 points, the high rating - from 51 points.

We will consider the proposed classification considering the obtained boundaries of TLC ratings in Table 2.

Table 2. Classification of TLC typology by integrated rating assessment

Rating	Total points	Evaluation limit, %
Low	16	до 25
Average	32	26–50
Above average	48	51–75
High	66	76–99

In the Scilab programming environment, a software product was developed that automates the proposed methodology. The program was registered in Rospatent. The program has both a calculation module for this methodology, and an analytical module for unloading interdependencies and making decisions on the choice of TLC based on significant criteria.

Development of the terminal and logistic ranges is an important task. Researchers around the world are addressing this issue. Gogas M. et al. developed new integrated evaluation framework which allowed to compare two terminals [14]. Wang T. and Cullinane K. investigated the efficiency of container terminals within the context of global supply chain management. They have derived container terminals, distributed across 29 European countries using Data Envelopment Analysis. Leriche D. et al. described the process of modeling the operation of a large multimodal terminal. The simulation model allowed authors to test different management modes of future logistic pattern with the multimodal terminal.

Thus, we can conclude that the work presented was performed on a relevant and important topic for researchers. Authors have studied the main factors influencing the choice of TLC. The target functions of the TLC parameters were determined, and a rating system and TLC classification system implemented in the Scilab environment was developed. The program can be used by decision makers in organizing cargo delivery systems (logistics managers, customer representatives) in building and choosing a rational logistics chain, including the issues of building terminal networks and managing cargo delivery chains within such networks. The method of integrated assessment of TLC and related software can be used in the practice of the transport and logistics business, as well as in the educational process.

The subject of future research may be to solve the problem of reducing the subjectivity of evaluation by this method.

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Application of Conditional Spectra for Modeling Noise Propagation Ways

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Abstract. A model has been developed to identify sources and ways of noise and vibration propagation in engineering structures. Using the example of a front-wheel vehicle, the model's visibility is illustrated, and its application areas are discussed.

Keywords: Noise · Vibration in engineering structures · Front-wheel vehicle · Vehicle · Vibration and noise reducing arises · Noise protection

1 Problem Statement

Under the conditions of severe restrictions on the weight and dimensions of vehicles, the problem of the optimal placement of means for vibration and noise reducing arises. In the scientific and technical literature estimates of the effectiveness of these means $E_T(f)$ for different frequencies f are widely presented. However, the use of the selected tool does not guarantee the attainability of its passport effectiveness, since noise or vibration in the normalized compartment can be determined by several sources. The importance of the separation of noise and vibration contributions is due to the fact that to reduce noise in adjacent acoustic volumes, various structural measures are necessary depending on the prevalence of either structural or penetrating component of the air noise. Moreover, the realizable efficiency of a specific noise protection measure may be zero, for example, engine vibration insulation to reduce the noise in a vehicle, if the latter is determined solely by the source air noise.

2 Solution Method

In practice, the realizable efficiency of the applied means of vibration protection $\acute{Y}_\Sigma(f)$ lies within $0 \leq \acute{Y}_\Sigma(f) \leq \acute{Y}_T(f)$. It is proposed to determine such realizable efficiency based on the apparatus of conditional spectra [1], which works well for the model with correlated inputs shown in Fig. 1. In this case, the function of ordinary coherence between the two inputs is non-zero ($\gamma_{12}^2 \neq 0$). Normal coherence functions between each input process Xi(f) and the output process Y(f) are defined as follows:

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$$\gamma_{1Y}^2 = \frac{|G_{1Y}|^2}{G_{11} \cdot G_{YY}} = \frac{|H_1 \cdot G_{11} + H_2 \cdot G_{12}|^2}{G_{11} \cdot G_{YY}} \quad (1)$$

$$\gamma_{2Y}^2 = \frac{|G_{2Y}|^2}{G_{22} \cdot G_{YY}} = \frac{|H_1 \cdot G_{21} + H_2 \cdot G_{22}|^2}{G_{22} \cdot G_{YY}} \quad (2)$$

Product of numbers $\gamma_{1Y}^2 \cdot G_{YY}$ sets the coherent spectrum of the output process, equal to the contribution of X1 to the output process Y. But X1 affects output not only through frequency response system H1. Part of X1 also affects the output through the frequency response system H2. Analogically, X2 gets to the exit in two ways - through H1 and H2. Normal coherent output spectrum $\gamma_{2Y}^2 \cdot G_{YY}$ considers all the ways, which takes into account all the ways, in which X2 affects the output process Y. With weak interference, it is possible that $\gamma_{1Y}^2 + \gamma_{2Y}^2 > 1$.

The multiple coherence function generalizes the function of ordinary coherence. By definition [1] it is equal to the ratio of the ideal spectrum of the output process, due to the observed input processes in the absence of interference, to the summary spectrum of the output process, including the contribution of the interference:

$$\gamma_{Y:x}^2(f) = \frac{G_{VV}(f)}{G_{YY}(f)} = 1 - [\frac{G_{nn}(f)}{G_{YY}(f)}] \quad (3)$$

It follows from the formula (3) that for any frequencies $0 \leq \gamma_{Y:x}^2 \leq 1$, and if Gnn = 0, then $\gamma_{Y:x}^2 = 1$ and $\gamma_{Y:x}^2 = 0$ if G_{YY} = *Gnn*, that is, the output process has nothing to do with the observed input processes.

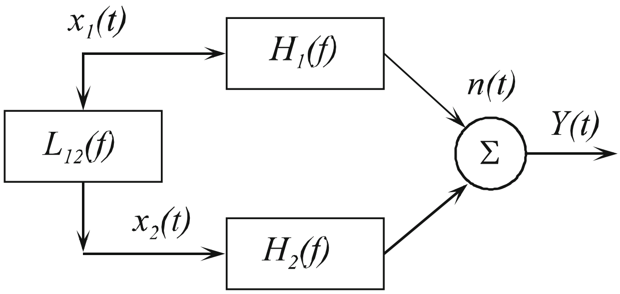

Fig. 1. Model with two correlated inputs and one output

If a pair of input processes is correlated (for example, vibration and engine noise), then to describe the car's noise, one should determine the degree of influence of one process on another [3]. This approach was implemented to identify the sources of noise and how it spreads in a front-wheel-drive car. In this case, the exclusion of the first process will lead to the deduction from the second contribution of the first due to the correlation, so that only that part of the second process that is not related to the first one remains. In other words, it is necessary to determine the optimal linear contribution of

$x_1(t)$ to $x_2(t)$, designated as $x_{2:1}(t)$. By the deduction of it from the $x_2(t)$, you can get a conditional (remaining) process $x_{2.1}(t)$, representing part $x_2(t)$, not related to $x_1(t)$. Formally $x_2(t)$ decomposed into a sum of two uncorrelated processes:

$$x_2(t) = x_{2:1}(t) + x_{2.1}(t) \quad (4)$$

By moving to the Fourier transformation, one can obtain

$$X_{2.1}(f) = X_2(f) - L_{12}(f)X_1(f) \quad (5)$$

where $L_{12}(f) = G_{12}(f)/G_{11}(f)$ - linear frequency response, predicting $x_2(t)$ by $x_1(t)$. For the spectral density is obtained:

$$G_{2.2}(f) = G_{22:1}(f) + G_{22.1}(f) \quad (6)$$

where $G_{22:1}(f)$ - coherent spectrum of the output process:

$$G_{22:1}(f) = |L_{12}|^2 \cdot G_{11}(f) = \gamma_{12}^2(f) \cdot G_{2.2}(f) \quad (7)$$

And $G_{22.1}(f) = [1 - \gamma_{12}^2(f)] \cdot G_{2.2}(f)$ - output interference spectrum. It should be noted that the index (22:1) means signal input of $x_1(t)$ to $x_2(t)$, and the index (22.1) – shows that part of the signal $x_2(t)$, which does not depend on $x_1(t)$.

In this case, there are no problems in determining the transfer functions of individual propagation ways $H_i(f)$ in order to suppress their resonant features. There is also no need for separate detection of discrete components of the source of vibroactivity, as from the point of view of noise reduction in a normalized room, both the resonant features of the propagation path and the discrete components of the source are invariant. In cases where the causal relationships between input processes are not clear, the mutual covariance function of these two processes should be calculated to determine the relative delay, which will show which of the two processes is ahead of the other. It should be noted that between two processes, for example, between noise and engine vibration, there can be a strong cross-correlation and strong coherence, although neither process is the cause of the other.

If there is no natural reasons for the ordering of the input processes, then it is possible to calculate the functions of ordinary coherence between each input process and the output $\gamma_{x_iY}^2$. Processes should be arranged in accordance with the values of the function of ordinary coherence at particularly important frequencies, for example, corresponding to the maxima of the spectrum of the output process, where most of the vibroacoustic energy is transmitted. At the same time, different ordering can be performed at individual frequencies. This means that the analysis uses different models.

If, for definiteness, the process $x_1(t)$ precedes $x_2(t)$, then the model shown in Fig. 1 is converted to the model shown in Fig. 2, which shows that the input processes $x_1(t)$ and $x_{2.1}(t)$ in the transformed model already uncorrelated. Also uncorrelated output processes $v_1(t)$ and $v_2(t)$. For conditional input processes, the equivalent model can be minimized to the original one if the frequency characteristics are taken as $L_{1Y}(f)$ and $L_{2Y}(f)$ and it looks like as follows:

$$L_{1Y}(f) = H_{1Y}(f) + L_{12}(f) \cdot H_{2Y}(f)$$
$$L_{2Y}(f) = H_{2Y}(f) \tag{8}$$

Then the main relation describing the system shown in Fig. 2 in the frequency domain will be written as:

$$Y(f) = L_{1Y}(f) \cdot X_1(f) + L_{2Y}(f) \cdot X_{2.1'}(f) + N(f) \tag{9}$$

where $L_{1Y}(f) = G_{1Y}(f)/G_{11}(f) \cdot \cdot ; \cdot \cdot \cdot L_{2Y}(f) = G_{2Y.1'}(f)/G_{22.1}(f)$.

Value $G_{2Y.1'}(f)$ is the conditional mutual spectral density, and $G_{22.1}(f)$ - conditional spectral density.

These conditional spectral densities can be calculated from the predetermined spectral densities of the original observed processes using simple algebraic operations. No averaging of Fourier conditional transforms is required:

- mutual spectrum of the output process with the second input with the influence of the first process excluded;

$$G_{2Y.1} = G_{2Y} - \frac{G_{21}}{G_{11}} G_{1Y} \tag{10}$$

- output noise spectrum for system with input $x_1(t)$ and exit $x_2(t)$;

$$G_{22.1} = G_{22} - \frac{G_{21}}{G_{11}} G_{12} = [1 - \gamma_{12}^2] \cdot G_{22} \tag{11}$$

- noise spectrum at the system output with the influence of the first process excluded

$$G_{YY.1} = [1 - \gamma_{1Y}^2] \cdot G_{YY} \tag{12}$$

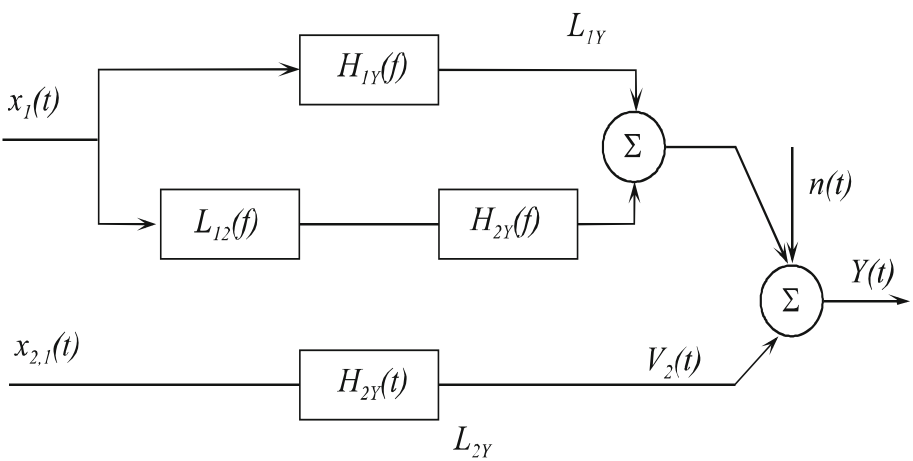

Fig. 2. Equivalent model with two uncorrelated inputs

3 Results

The developed model for identifying the propagation ways of vibration and noise can be further simplified and algorithmized. The formalization of this approach is that, based on the multiple coherence function, a set of frequencies fc is determined, at which its values exceed the value of 0.8. Usually these frequencies determine the noise energy in a particular premise of the vehicle. Therefore, the relative contribution of sources and diagnostics of the propagation paths of their vibroacoustic energy should be carried out only at these frequencies. Further analysis is performed in tabular form up to the last frequency fn determined by the condition $\gamma^2_{Y:3}(f_n) > 0{,}8$. At the same time, automatically, starting from a certain frequency, the multiple coherence function values will be below the accepted threshold, since there is always a limit on the number of input measurement points that sufficiently fully characterize the emission and propagation of sound only up to a certain frequency.

At selected frequencies fk, the values of the autospectrum levels of the directly measured noise $20\lg G_{YY}$ and levels of conditional spectra $20\lg G_{YY.1}, 20\lg G_{YY.2!}$, $20\lg G_{YY.3!}$ are calculated. At each frequency f_k, it is necessary to determine the successive differences of these levels:

$$D1(f_k) = 20\lg G_{YY}(f_k) - 20\lg G_{YY.1}(f_k) \tag{13}$$

$$D2(f_k) = 20\lg G_{YY.1}(f_k) - 20\lg G_{YY.2!}(f_k) \tag{14}$$

$$D3(f_k) = 20\lg G_{YY.2!}(f_k) - 20\lg G_{YY.3!}(f_k) \tag{15}$$

The subsequent analysis is carried out according to the following algorithm.

Whole range of values Di(fk), where i = 1, 2, 3 can be divided into three areas. In case if D1(fk) < 1 dB, then the first source X1 practically does not affect the internal noise in the normalized room at the frequency fk.

And if 1 dB < D_1(fk) < 5 dB, then the source X_1 making commensurate with all other sources taken together contribute to the internal noise.

In case if D_1(fk) > 5 dB The internal noise in a room at a given frequency is mainly determined by the first source.

Next on each frequency f_k the contribution of the second source X_2 should be determined. At that:

D_2(fk) < 1 dB – the contribution of X_2 is missing;

1 dB < D_2(fk) < 5 dB – the contribution of X_2 is comparable to the contribution of X_3;

5 dB < D_3(fk) – the contribution of x_2 prevails over the contribution of x_3.

Then this procedure is being repeated for the third input X_3.

D_3(fk) < 1 dB – the third input can be neglected and during repeated tests do not take measurements at the indicated points;

1 dB < D_3(fk) < 5 dB – the contribution of X3 is comparable to the contributions of unaccounted sources;

5 dB < D_3(fk) – the contribution of the third source prevails over interference and contributions of unaccounted sources.

According to the results of calculations $D_i(f_k)$, where i = 1, 2, 3 a formalized source contribution table is compiled, where "−" means the absence of the contribution of the i-th source at the frequency f_k; "0" – commensurability of its contribution with the remaining (in order of ranking) sources; "+" – the predominance of its influence in comparison with the remaining sources.

For example, we consider the front-wheel-drive car. As the first input X_1, the vibration of one of the engine support nodes was selected. As the second input X_2 - the engine noise in the engine compartment. The third entrance X_3 was the vibration of the right plate of the front floor of the cabin (hereinafter referred to as body vibration). In Fig. 3 given directly measured spectrum of noise in the car and conditional - with the exception of the influence of engine vibration.

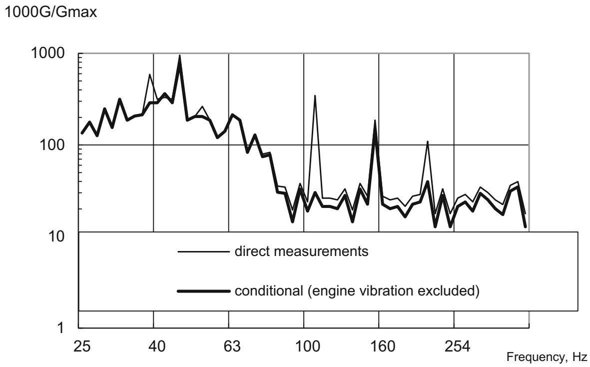

Fig. 3. The noise inside the vehicle

The results are presented in relative form, because the main interest is the comparison of two spectra with each other. The spectrogram shows the values of current frequencies f_2 = 105 Hz, f_3 = 155 Hz, f_4 = 211 Hz. Comparison of two autospectra shows their divergence only at two frequencies f_2 and f_4. In this case, the solid parts of the spectra approximately about the same.

Further analysis in accordance with the considered method will be carried out only at frequencies of discrete components, on which $\gamma^2_{Y:3}(f_n) > 0{,}8$ for measurement data (see Fig. 4). These frequencies are marked in the first row of Table 1. The following lines of the table show the consecutive differences of conditional autospectra D_1, D_2, D_3.

These lines of Table 1 can be rewritten in a more visual form in order to identify the contributions of vibroacoustic sources to the internal noise of the car (Table 2), where the predominance of the contribution of the above source over the following marked as "+"; "0" – the comparability of these contributions.

The results indicate the predominant role of engine vibration at the second harmonic of the reverse frequency f2 = 105 Hz, while engine noise dominates at frequency f3 = 155 Hz. At the same time, the engine vibration affects both the low frequencies 37 Hz, 43 Hz, where it is comparable to the body vibration, and at the frequency f4 = 211 Hz, where it makes an equal contribution to the engine noise.

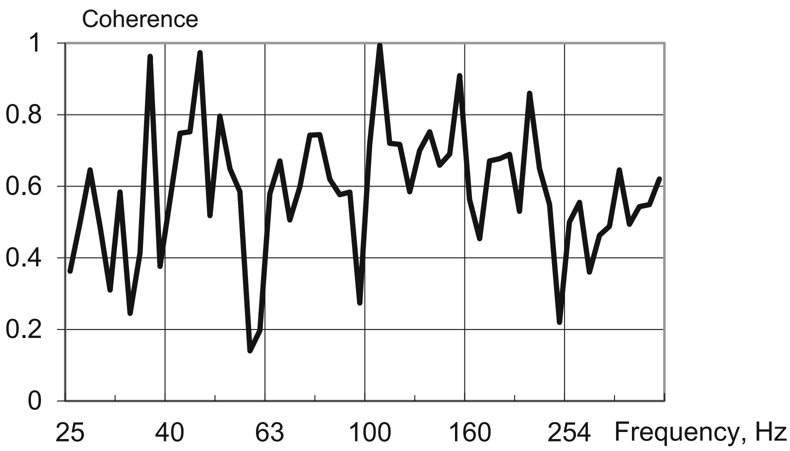

Fig. 4. Multiple noise coherence in the cabin with vibration and engine noise, as well as with body vibration

Table 1. Discrete values of the conventional noise spectra in the car

Frequency, Hz	37	43	105	155	211
D1, dB	5.5	3.2	24.5	1.1	4.7
D2, dB	0.7	0.4	2.8	11	6.2
D3, dB	11	12	0.2	0.9	0.4

Table 2. The contribution of vibroacoustic sources to the internal noise of the car

Source number	Source name	37 Hz	43 Hz	105 Hz	155 Hz	211 Hz
1	Engine vibration	0	0	+	−	0
2	Engine noise	−	−	0	+	+
3	Body vibration	+	+	−	−	−

4 Conclusions

Using the presented example, we can illustrate both the limitation of the applicability of the approach under consideration and its merits [2]. As the frequency increases, an increasing number of measuring points—system inputs—should be attracted to the design analysis, because vibrations of individual elements and nodes become uncorrelated. For example, such are the vibrations of individual plates of the floor of the car, and at even higher frequencies - individual zones of the same plate. Infinite build-up of measuring points and, accordingly, measuring ways, as is customary when using antenna arrays [4, 5], is inexpedient from a practical point of view, firstly because of the high cost of such a system, and secondly, due to the lack of a targeted strategy to search for significant sources of noise.

An alternative to increasing the number of channels is a kind of iterative procedure, when the main (large-sized) elements and components of the vehicle that determine the noise in the cabin are detected in the first step [3]. In the second step, all measurement capability focus on the selected element, for example such as the floor of the body, naturally divided into four quadrants. In the next step, for the most radiating quadrant, the maximum radiating area of this plate, which is advisable to damp, is determined by placing vibration sensors on it and calculating the corresponding conventional noise spectra. Here there is some analogy with the intensity of symmetry in the search for radiating spots of the structure with the advantage that the approach presented above is aimed at the final result - the diagnosis of the contribution of a particular element to the total noise of the premise.

Thus, the sequence of actions to identify sources and paths of propagation of vibrations and noise may be as follows.

Firstly, it is necessary to determine elements and components of the structure, which presumably cause noise in the premise as a whole or in separate frequency bands. This choice can be based on:

– on preliminary measurements of the radiation intensity of individual elements of the vehicle body at idle or artificial excitation;
– on solving a model problem describing the contribution of acoustic and vibration sources and taking into account the contribution of each element of the body to the resulting noise of the premise. Such a model can be created on the basis of energy-statistical analysis, according to the results of tests of a prototype or the given vehicle with another anti-noise complex.

In the case of the complete absence of a priori information about the contribution of individual elements to the resulting noise, these elements can be chosen arbitrarily, with subsequent adjustment based on the results of the first stage of testing.

The considered model of identifying sources and paths of common noise and vibration can be used for a wide class of engineering structures, for example, such as a highway overpass.

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Method of Two-Factor Analysis of Cars Operation in the Road Transport System of Cargo Transportation

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Abstract. Currently, the issues of providing the high-quality transport services with minimal costs are becoming particularly relevant. The purpose of this work is to increase the efficiency of freight road transport in cities through the development of a two-factor analysis method for the operation of automobiles in the road transportation system of goods. The developed method will allow (by calculation before the test) answering the question of what will happen to the results of cars while simultaneously changing two technical and operational indicators (factors). It is proved that the transportation of goods by vehicles on routes in the cities are carried out in road transport systems of different complexity of the composition and functioning. When solving the problem of establishing the dependence of the simultaneous influence of two significant factors on the resulting indicator, the method of univariate analysis was used - the method of "chain substitutions", which became most common in the practice and theory of cargo transportation by road. However, a significant drawback of using the "chain substitutions" technique is some identification of the practice of cargo transportation and the method of analysis used. Preliminary studies have shown that the reception of "chain substitutions", under the conditions of the simultaneous influence of two factors, does not allow obtaining the desired result. The application of the developed heuristic method of two-factor analysis of the vehicles operation in the considered road transport system for the transportation of construction goods will allow both setting such a problem and finding its solution.

Keywords: Cargo transportation · Vehicle · Construction goods · Method · Factors · Distance · Load capacity

1 Introduction

In modern market conditions, many scientists note that large cities in the Russian Federation face certain problems and difficulties in transportation, abroad is the same [1–5], [6]. Today in Russia, most private enterprises independently organize the transportation of their own construction materials by their own or hired vehicles in cities [1]. In these conditions, the organizer of the goods transportation also needs to know till the experience what will happen with the results of the car when changing

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individual factors. Known significant factors that have a significant impact on the results of the operation of vehicles in operational mode: the distance of cargo transportation, rolling stock carrying capacity and its utilization rate, average technical speed, idle time when performing loading and unloading operations, time spent on a duty and others [2, 3]. It is also known that, in practice, goods are transported daily to different distances by vehicles of different loads. This was the rationale for the need to study the influence of two simultaneously objectively changing factors - the distance of transportation and carrying capacity (cargo capacity) of cars.

One of the tasks of the organizers is to reduce the cost of transportation [5]. In our case, when the shipper has his own motor transport within the company's division, which is auxiliary to the main production, one of the characteristics of his work is the production cost (costs directly related to the transportation process).

The essence of the methods of factor analysis is to assess the influence of factors on the effective feature. According to theoretical ideas, the following methods of factor analysis are known: the method of "chain substitutions", the method of calculating differences, the logarithmic method, the ring method, the extremal method, the integral method, the methods of multivariate statistical analysis (correlation-regression, dispersion, cluster, component) and others. Each of these methods has its own characteristics, advantages and disadvantages.

Many scientists note the methods of univariate and multivariate correlation analysis. These methods allow us to obtain a conditional approximate relationship between the factors under consideration, as well as a regression equation. These methods need to collect and process a large amount of statistical material, its constant updating, moreover, they do not allow explaining cause-effect connections.

To solve the problems of analyzing the operation of automobiles in the practice and theory of freight road transport, the method of "chain substitutions" is common [3]. This is a method of single-factor analysis, in which the observed factor is a variable value, and the remaining factors are assumed to be conditionally constant values. This method has positive properties: sufficient ease of use and versatility, availability of results, a clear understanding of causes and effects.

In the existing theory of road freight transport, the dependence of the cost of transporting 1 ton or $t \cdot km$ on the carrying capacity of a car and its utilization factor, increasing the distance is expressed by an equilateral hyperbole or a continuous. The established dependences are obtained by the formulas:

$$S = \frac{\sum S_c}{\sum P} \cdot 100 \tag{1}$$

where S – the cost of transportation of goods, RUB/t or RUB/$t \cdot km$; $\sum S_c$ – the amount of the costs associated with the implementation of transportation for a certain period of time, kop.; $\sum P$ – transport work performed during the same period of time, t or $t \cdot km$ [4].

$$Q = \frac{q \cdot \gamma \cdot \beta \cdot V_a \cdot T_d}{l_{\text{lr}} + \beta \cdot V_a \cdot t_{\text{lt}}} \tag{2}$$

where Q – vehicle productivity per shift, t; q – vehicle load capacity, t; γ – static load capacity usage ratio; β – mileage ratio; V_a – average technical speed, km/h; T_d – time on a duty, h; l_{lr} – average length of laden rides, km; t_{lt} – loading and unloading time, h.

$$P = Q \cdot l_{\mathrm{lr}} \tag{3}$$

where P – transport work per shift, t · km.

The method of "chain substitutions" allows obtaining a discrete connection between the function and the factors under consideration, which is the point values of the function change from one or several parameters, taking into account the discrete nature of the transport process, which is characterized by discontinuity and intermittent changes in time. When constructing discrete dependencies, it is necessary to use models describing the functioning of each road transportation system of cargo transportation [3], where:

$$Q = q\gamma \cdot Z_r \tag{4}$$

where Z_r – number of rides, units.

$$P = q\gamma \cdot Z_r \cdot l_l \tag{5}$$

However, preliminary studies have shown that the method of "chain substitutions" is suitable for univariate analysis. In the present study, it is required to answer the question of what will happen to the results of the operation of automobiles in the road transport system, given the simultaneous change of two factors. Thus, to solve the problem, a heuristic two-factor analysis method was developed. The heuristic method is a method obtained in an experimental, practical way that allows you to achieve the goal of a study if the initial data is incomplete.

2 Research Methods

Task setting: it is required to establish a discrete dependence of the influence of simultaneous use of more lifting vehicles and increasing the distance of cargo transportation to the production cost (costs of cargo transportation) when transporting its own construction goods by its own vehicles by a private enterprise (organizer of transportation for itself) in cities.

Terms and conditions:

1. it is required to establish such an equal number of steps for changing the carrying capacity (tonnage) of cars and transportation distances in the ranges under consideration so that the number of payload values (in pallets) of more lifting cars and the number of transportation distance values are the same (equal);
2. it is known [2] that the use of more lifting cars at the same time causes a change in the average technical speed and downtime for loading and unloading, which should be taken into account in the calculations:

– in urban conditions, depending on the carrying capacity of the rolling stock: for vehicles with a load capacity of less than 7 tons, an average technical speed of 25 km/h is used for operational planning; for vehicles with a load capacity more than or equal to 7 tons, 24 km/h is used;
– norms of time for loading and unloading are taken, according to the reference book [2], taking into account the transport characteristics of construction materials, load capacity (tonnage) of cars, pallet mass, loading and unloading mechanisms, etc.

The formulation of the heuristic method (way) of two-factor analysis:

1. To solve the problem of establishing the dependence of the influence of the simultaneous use of more lifting cars and increasing the distance to production costs (freight transportation costs) when transporting their own construction goods with their own cars in cities, production cost values should be presented in tabular form, in which the number of rows and columns should be the same (equal).
2. The calculation of technical and operational indicators in the considered road transportation system is carried out, separately for the case of the use of a vehicle of each capacity (tonnage), starting with the minimum. Variable parameter - distance of goods transportation. For the calculation, the method of "chain substitutions" and the model for describing the functioning of the corresponding road transportation system developed in SibADI are used.

The planned results of each vehicle of each capacity operation, separately, are recorded in the software "Calculation of the cost of goods transportation as part of models of micro and extra small road transportation systems", where the calculation of production cost (cost of goods transportation) is carried out according to the sectoral methodology online for a job change for one car. Production cost for a group of vehicles per shift at each distance is determined by adding its values for each vehicle of the group. The results of the calculation of production costs for each value of the distance transportation of goods for each carrying capacity (tonnage) of the vehicle (group) are entered in the vertical raw cell of the table, of the corresponding distance.

3. In the diagonal cells of the table, the necessary (desired) values of the production cost (freight transportation costs) will be established while simultaneously using more lifting cars and increasing the distance of freight transportation along which it is possible to build the required discrete dependence.

3 Research Results

An example of establishing, using the developed heuristic method of two-factor analysis, a discrete dependence of the influence of simultaneous use of more lifting cars and increasing the distance on production costs (the cost of transporting goods) is presented. Transportations of own building materials are carried out by own vehicles of enterprises in cities in the aggregate of micro road transport systems.

Depending on the planned volume, the number of loading posts of the cargo center, cargo transport uniformity, cargo transportation by the shipper can be organized as an aggregate of micro road transport systems (technological scheme of transportation is several pendulum routes with a return not loaded mileage (cargo from a separate loading post is transported to a separate unloading post of the consignee). Since one car works separately on each route, the waiting time for cargo works is zero.

An example of solving the problem is presented by increasing the distance of cargo transportation from 6 km to 60 km in increments of a multiple range of 6 km. Since it is recommended to use vehicles of medium, large and extra-large carrying capacity for the transport of construction goods, the carrying capacity values are taken in the considered range, with a pitch multiple of the number of pallets (Table 1).

Table 1. Some initial data

Brand of the vehicle	Number of pallets, units	Shipping amount (gross), tons	Nominal loading capacity, tons	Static capacity usage ratio	Normal downtime for loading and unloading, min. per 1 ton	Average technical speed, km/h
KamAZ 43502-6024-45	5.00	4.00	4.00	1.00	5.00	25.00
KamAZ 5350-6015-42	7.00	5.60	7.32	0.77	4.25	24.00
KamAZ 5350-6015-42	9.00	7.20	7.32	0.98	4.25	24.00
KamAZ 53215	11.00	8.80	11.00	0.80	3.50	24.00
KamAZ 53215	13.00	10.40	11.00	0.95	3.50	24.00
KamAZ 63501-6996-40	15.00	12.00	14.00	0.86	3.15	24.00
KamAZ 63501-6996-40	17.00	13.60	14.00	0.97	3.15	24.00
KamAZ 6360-73	19.00	15.20	15.325	0.99	2.95	24.00
KamAZ 65225-6015-43 + 9406-211 (automaster)	21.00	16.80	20.00	0.84	2.50	24.00
KamAZ 65225-6015-43 + 9406-211 (automaster)	23.00	18.40	20.00	0.92	2.50	24.00

Requirements to prohibit the operation of vehicles during reloading are complied obligatory; the rates of downtime for on-board vehicles for loading and unloading goods in packages on pallets are taken when they are carried out in a mechanized way (gantry, bridge and other cranes except for mobile cranes).

The results of the calculation of production costs with the simultaneous use of a group of more lifting cars and increasing the distance of cargo transportation in the aggregate of micro road transport systems are presented in Table 2.

Table 2. The results of the calculation of production costs with the simultaneous use of a group of more lifting cars and increasing the distance of cargo transportation in the aggregate of micro road transport systems (where: **23382.1** (bold font) – the value of production costs with the simultaneous use of a group of more lifting vehicles and increasing the distance of cargo transportation in rubles)

Distance, km	Load capacity (cargo capacity in the number of pallets), units									
	5	7	9	11	13	15	17	19	21	23
6	**23382.1**	24607.2	23884.2	21768.7	20969.8	30187.2	28934.8	26390.3	31833.4	32241.9
12	25169.0	**27981.3**	26029.9	23481.5	23964.9	34086.4	31537.5	28840.1	37375.9	34760.9
18	25833.3	28712.6	**29099.2**	26218.7	26629.7	37456.9	33717.6	30899.6	36612.4	36875.1
24	26847.9	29839.5	30161.6	**27090.5**	27421.6	38540.8	38814.3	35778.7	41702.3	41971.4
30	30921.8	34362.9	34706.1	31249.0	**26368.4**	37368.4	37580.7	34536.1	40481.8	40651.8
36	29222.6	32485.6	32730.3	29358.0	29636.9	**41361.2**	41571.8	38394.3	44405.2	44621.0
42	32382.9	35987.7	36275.6	32618.8	32863.3	45306.0	**45555.9**	42247.3	48363.5	48583.4
48	35552.5	39523.4	39787.1	35828.7	36115.3	49280.1	49482.5	**46095.2**	52314.0	52539.0
54	38738.0	43088.8	43353.7	39117.0	39406.1	42434.3	42578.5	39420.9	**45448.6**	45612.6
60	41878.5	36122.8	36286.4	32562.9	32728.7	45258.3	45401.0	42034.6	48256.1	**48425.0**

According to data in Table 2, located in the diagonal cells of the table, there was built a discrete dependence of production cost (Sp) on the simultaneous use of a group of more lifting cars and increasing the distance of cargo transportation (ll), where the dotted line indicates the decrease in the number of rides, presented in Fig. 1.

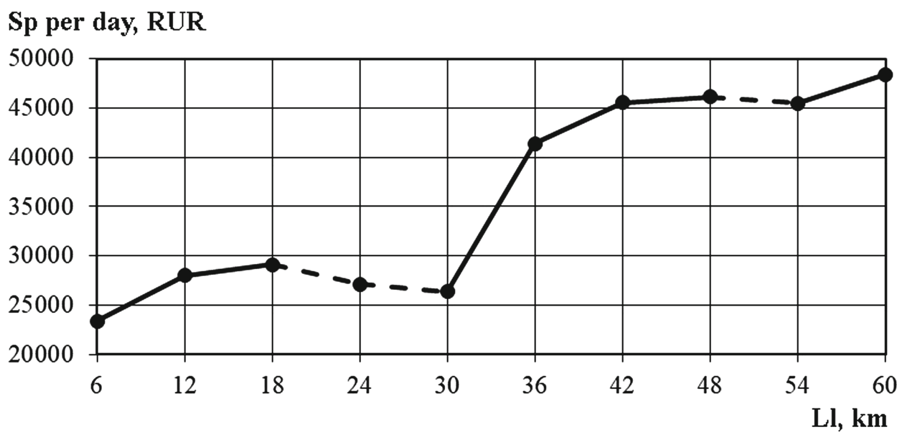

Fig. 1. Discrete dependence of production cost on the simultaneous use of a group of more lifting cars and increasing the distance of cargo transportation in the aggregate of micro road transport systems

4 Discussion of Results

In the considered conditions, the developed heuristic method of two-factor analysis allows, before the test, to establish a causal connection between the results of vehicles operation in a particular road transport system and changing significant factors.

Unequivocal answers are obtained to the question of what will happen to the production cost of transporting own construction materials by the own shipper's cars in cities, if we use (in the considered road transport system) groups of more lifting (loadable) cars at increasing distances. As shown in Fig. 1, the impact of the simultaneous use of a group of more lifting (loadable) cars and an increase in the distance of transportation of construction goods to the production cost in the aggregate of micro road transportation systems is described by a discontinuous curvilinear function that changes both upwards and downwards. Continuous, monotonously increasing curvilinear function, as scientists previously believed, has not been established.

The increase in production costs is due to an increase in the distance of cargo transportation and an increase in the cost of using more lifting cars. The decrease in production costs is due to the decrease in the number of rides, the output in tons and ton-kilometers, the total mileage and the change in the cost of transporting goods by items. Assessing the influence of two factors simultaneously on the resulting indicator (production cost) will allow the management of the enterprise, before carrying out a particular transportation, to establish the production cost of a group of vehicles of a certain cargo capacity at each possible distance, to analyze the causes of changes in production costs, and to work out the production solutions more reasonably.

The research results have a positive effect on improving the efficiency of car operation when transporting their own construction cargo with their own vehicles of a shipper (private enterprise) in cities, which determines the practical significance of the result.

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Analysis and Diagnostics of Competing Transport Processes on the Basis of the Bernstein – Russell – Narinyani Theorem

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Abstract. The paper considers an approach to the description, analysis and diagnosis of defects in competing multioperational technological transport processes on the basis of the use of the fundamental theorem of Bernstein - Russell - Narinyani on static parallelization of programs. Examples of formal descriptions of processes in the form of operator schemes are given. An addition to the Bernstein – Russell – Narinyani theorem is proposed in order to determine the competition between technological operations using material resources. A diagnostic interpretation of the theorem, variants of competitive dependencies between operations, and defects arising during their implementation are presented. The relevance of the analysis of internal parallelism of transport processes is shown. The information on the organization of the diagnostic subsystems and the problems of the practical application of the developed method of analysis and diagnosis of processes is provided.

Keywords: Transport process · Competition of operations · Operator scheme · Defects · Diagnostics

1 Relevance and Statement of the Problem

The relevance of developing new methods of analysis and diagnosis of competing transport technological processes is due to the following factors.

1. The development of transport systems is characterized by an increase in their productivity and technical equipment, application of various economic strategies, adaptation to changing external conditions, competition and the complexity of technological processes.
2. Competitions in transport exist at all levels of consideration between the following objects, subjects and processes:

– modes of transport for the transportation of goods and passengers;
– various organizations providing transport services;
– owners of rolling stock and railway infrastructure;

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- trains when driving along the same path; passing by turnout; arriving at the rail receiving yard of the station; departing from the departure park;
- cars when sorting at the station;
- trains when moving along public roads and on an adjacent non-public road;
- transport at the intersection of the railway track with the road;
- railway under construction and existing infrastructure facilities (buildings, communications, territories, etc.);
- workers sharing one equipment, tool, room, office document;
- users of one computerized workstation; etc.

3. Monitoring the correct functioning of transport systems and diagnosing processes is necessary for the timely detection of defects and minimization of resource losses from them. The occurrence of defects is caused not only by known causes (design and control errors, improper personnel actions, unforeseen situations, malfunctions and technical equipment failures), but also by competition in processes [1].
4. The task of analyzing and diagnosing competing multioperational transport processes has not been sufficiently studied in terms of adequate formal functional descriptions and diagnostic models. Known models and results of the theory of parallel computing processes used to increase the performance of systems can be effectively used to monitor and diagnose transport processes, with appropriate interpretation and development of methods [2–10]. This is due to the fact that parallelization of programs is associated with a detailed study of the information basis, and the control and diagnosis of transport processes have the ultimate goal of preventing the loss of material and other resources. It is advisable to carry out a theoretical analysis and functional diagnosis of transport processes at the level of operations, since it determines the composition, logical conditionality and configuration of the process. This ensures high diagnostic efficiency (efficiency and completeness of defect detection with minimal loss of resources and diagnostic costs).

2 Theoretical Part

According to the provisions of technical diagnostics, knowledge about the object, which gives formal representations of its proper functioning, is used to formulate defects as violations of these requirements (exceptions to the rules) [1]. Generalized conditions for the proper functioning of transport systems can be represented by describing the fundamental properties of technological and algorithmic systems in the form of requirements for the processes that are carried out in them. Table 1 presents a list of requirements for proper functioning and defects in processes at a substantial level.

In [9, 10], the descriptions of the defects from Table 1 were considered using the set theory and formal descriptions of processes in the form of operator schemes (with the construction of further diagnostic models, methods and algorithms for detecting

Table 1. Requirements for proper functioning and defects in processes

№	Proper functioning	Defects
1	The process is selective: it is defined on a finite set of operations	The operation is not from the specified set
2	The process is streamlined: it is given by technology, algorithm or other constructive method	The order of operations is violated
3	The process is productive: it leads to the required transformation of the source resources into final products	Operations and process do not lead to a result
4	The process is timely: it has a start and time limits for operations and the entire technology	No operation or technology is performed for the specified monitoring time

defects). However, the issues related to the formal analysis of competition in transport processes and the diagnosis of defects that arise in this case have not been fully studied.

The task of a formal description of the competition between the transport process operations and the corresponding defects implies the following diagnostic formulation:

– the requirement for proper functioning: the process does not compete with other processes, and there is no competition between operations in the process;
– possible defects due to competition: operations are not performed or are performed with the wrong resources, resources are distorted, and the required results are missing.

The proposed approach is based on the analysis of operator schemes of transport processes, based on the theory of parallel computing and focused on identifying competition between operators and detecting corresponding defects.

The characteristics of the operation include: purpose (function), belonging to a specific process, type, input and output resource variables, connections with other operations, control parameters (regulation, order). Representation of the process in the form of an operator scheme solves two basic problems:

– interpretation, i.e. finding an unambiguous correspondence between operations and the resource basis of the process (for rail transport - loading, sorting, cars, trains, equipment, tools, infrastructure, etc.) and the basis of the scheme (operators, resource variables);
– algorithmization, i.e. the establishment of a logical order on the set of operations leading to a result (for example, train departure, cargo delivery, etc.).

The operator scheme is a formalized description of the process as a set of logically determined implementations of a given technology using graphical notation, similar to program schemes [3–6].

In the set-theoretic formulation, operator schemes are represented by the following sets:

– operators Acon ∪ Arec = A, Acon ∩ Arec = $\emptyset$, Aicon ∈ Acon, Airec ∈ Arec, where Acon and Arec - converters and recognizers, respectively;
– input and output sets (tuples) of resource variables **In** ∪ **Out** = **M**, where **M** – set of resource variables (resource basis of the process), **In** ∩ **Out** ≠ $\emptyset$, $inA_i^{con} \subset \mathbf{In}$, $inA_i^{con} = (x, \ldots, z)$, $outA_i^{con} \subset \mathbf{Out}$, $outA_i^{con} = (x, \ldots, z)$, $inA_i^{rec} \subset \mathbf{In}, inA_i^{rec} = (x, \ldots, z)$;
– connections between operators $\mathbf{R} = \mathbf{V} \cup \mathbf{U}$, including resource connections $\mathbf{V} \subseteq \mathbf{In} \times \mathbf{Out}$, $V_{i,j} \in \mathbf{V}$, and control connections $\mathbf{U} = \mathbf{U}^{unc} \cup \mathbf{U}^{log}$, $\mathbf{U}^{unc} \cap \mathbf{U}^{log} = \emptyset$, $U_{i,j}^{unc} \in \mathbf{U}^{unc}$ (unconditional control), $U_{i,j}^{log} \in \mathbf{U}^{log}$ (logical);
– logical conditions **P**, $P_n \in \mathbf{P}$;
– values of logical conditions $\pi_i \in \{1, 0\}$.

Figure 1 shows a process scheme including:

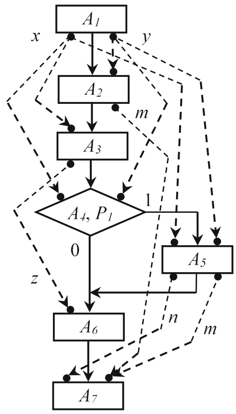

Fig. 1. Operator scheme of the processes

– operators A_1–A_7, including converters A_1, A_2, A_3, A_5, A_6, A_7 and recognizer A_4 checking logical condition P_1;
– resource variables x, y, n, m, z;
– control connections (solid lines), logical (solid with an index of the value of the logical condition 1 or 0), resource connections (dashed lines).

Figure 2 shows the operator schemes equivalent to the scheme in Fig. 1. They correspond to a given technology, but differ in operator permutations. This is typical for transport processes with reconfiguration, when they are performed in the changing conditions of the transport system operation [10].

The feasibility and prospects of using parallel computing models in the problems of control, monitoring and diagnostics of technological processes were proved in [9, 10]. The study of static computational parallelism is based on the analysis of dependencies between the operators of the scheme, for which purpose the independence of operators

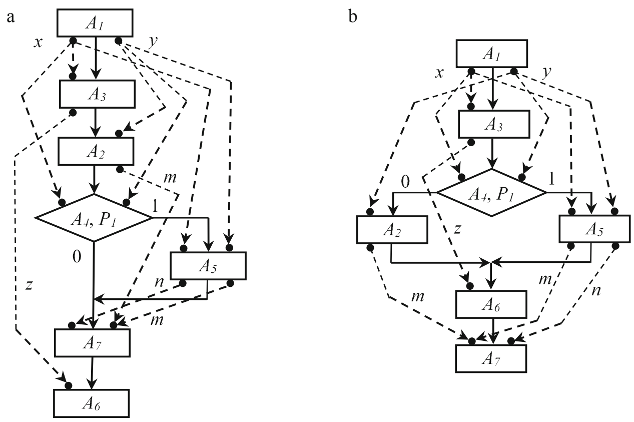

Fig. 2. Equivalent operator schemes of the processes: a - the first option, b - the second option

in resource variables is used based on the Bernstein – Russell – Narinyani theorem. The construction and use of multilevel structure, parallelization of sequential programs, analysis of process histories, calculation of lead functions and others are used as well [5–8].

The correct independent (parallel, asynchronous) execution of operators in program schemes is determined by the Bernstein – Russell – Narinyani theorem, which describes the necessary conditions for the absence of competition dependencies between operators for resource input and output tuples [5, 6]:

$$\left(inA_i \cap outA_j\right) \cup \left(inA_j \cap outA_i\right) \cup \left(outA_i \cap outA_j\right) = 0 \tag{1}$$

Unlike parallel computing processes that allow the simultaneous reading of the same data by different operations without destroying memory (i.e. copying), in transport processes, this kind of competitive dependence on the resources used by the operations should be taken into account differently, since in practice, the simultaneous access of different operations (in one or different processes) to material, financial and other resources is essentially a conflict [9]. This makes it necessary to supplement expression (1) with another term describing the intersection of the input resources of operations competing in the use of material resources (located at the beginning of the formula):

$$\left(inA_i \cap inA_j\right) \cup \left(inA_i \cap outA_j\right) \cup \left(inA_j \cap outA_i\right) \cup \left(outA_i \cap outA_j\right) = 0 \tag{2}$$

Formula (2) is supplemented by the Bernstein – Russell – Narinyani theorem on the condition of parallel (independent, disordered) execution of operations in transport processes.

For a railway technological process, expression (2) means asynchronous disordered (possibly simultaneous) use of the elements of the resource basis - railways, switches, cars, locomotives, trains, etc. Its failure, i.e. competition of operations on resource variables, entails a conflict situation, the recognition and prevention of which is an important task to ensure the stable proper functioning of the railway transport system. Lack of functional diagnostics of processes accurate to competing operations leads to loss of resources, process shutdown, incorrect result, etc. Examples in railway transport are train stoppages, car derailment, switch damage, lack of loading, etc.

The diagnostic interpretation of competition in transport processes based on the augmented Bernstein-Russell-Narinyani theorem is as follows:

– the use of expression (2) as a requirement of the correctness of the process, the transition from which to the definition of a defect is carried out as an exception to the rule;
– a complete enumeration of options for combining the values of four members in expression (2);
– assessment of the consequences of competition of operations, taking into account the events of start and end of operations, the presence and receipt of input and output tuples of resource variables;
– classification of defects and their combinations.

Figure 3 shows the competition of operations and defects in processes based on expression (2).

The four-digit binary code in the examples shows the value of each of the four terms (2), where 0 corresponds to the absence of intersection of the sets of resource variables of the first and second operations, and 1 to the intersection of sets.

Variant 0001 corresponds to the case when only output tuples of resource variable operations intersect, i.e. $\left(outA_i \cap outA_j\right) = 1$. In this case, the result of the last operation replaces the result of another operation. The specified defect leads to a distortion of the resource basis and the process as a whole. For example, in the above diagrams, the operators A_2 and A_5 compete in the output variable m.

Variants 0010 and 0100 are symmetrical and describe a dependency that requires one operation to follow, since the result of the first is the input resource variable of the second. At the same time, the input resource of the second operation is absent, which leads to a distortion of the resource basis and the process. The specified competition exists for all pairs of operators connected by resource connections (A_1A_2, A_1A_3, A_1A_4, A_1A_5, A_2A_7, A_3A_6, A_5A_7).

Symmetric variants 0011 and 0101 describe the combination of the above defects.

Variants 0110 and 0111 represent the combination of defects “absence” and “substitution”, and actually lead to a deadlock in the process, since input resource variables were not provided for both operations.

Variant 1000 corresponds to the case when only input tuples of operations intersect, i.e. $\left(inA_i \cap inA_j\right) = 1$, and is one of the most common in practice. It describes direct competition over the resources used, leading to the interception of the resource by an operation, which begins to be executed first, in the second. Thus, the second is not performed, which leads to a distortion of the process. Typical examples of rail transport are the following: occupation of a track by rolling stock off schedule, sending a locomotive crew to an out-of-turn route, unscheduled occupation of a repair section of a locomotive in a depot, and others. For example, this competition exists for operators

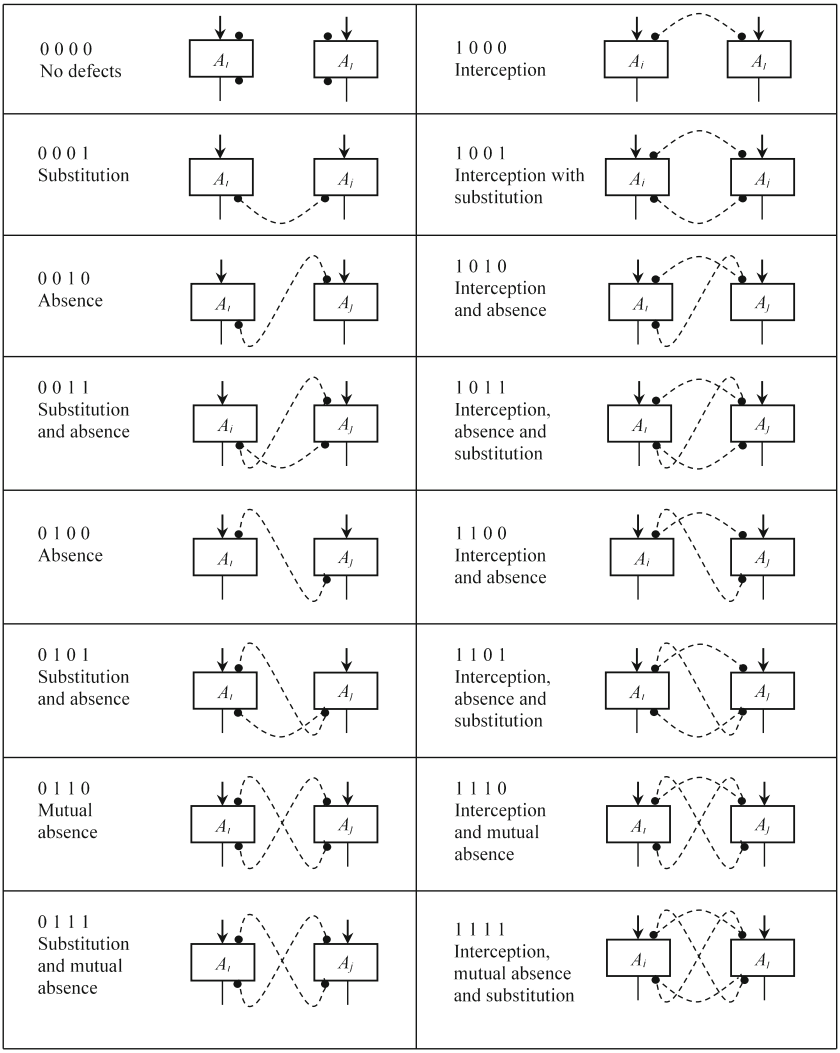

Fig. 3. Interpretation of competition of operations and description of defects in processes on the basis of the augmented Bernstein-Russell-Narinyani theorem

A_3, A_4 and A_5 in terms of the input variable x, for operators A_2, A_4 and A_5 in terms of the input variable y.

Symmetric variants 1010 and 1100 describe the combination of defects “interception” and “absence”, which leads to a substitution of the input resource variable.

Variants 1011 and 1101 are also symmetrical, describe the combination of several defects, and lead to a deadlock in the process.

Thus, failure to fulfill (2) leads to the occurrence of combinations of defects "interception", "substitution" and "absence", to a distortion of the resource base and incorrect execution of the transport process.

3 Results

The proposed method for analyzing and diagnosing competing transport processes is distinguished by the use of operator schemes and the diagnostic interpretation of the augmented Bernstein – Russell – Narinyani theorem. The effectiveness of the method is caused by the universality of the theorem and the implementation of the well-known principles of technical diagnostics.

The consequences of competition in transport processes allow presenting in detail a diagnostic interpretation of theorem (2). The original expression (1) has traditionally been used to study the internal static parallelism of the computing process, which is understood as the latent characteristic of the capabilities of asynchronous and independent execution of its operations. Thus, the analysis of competition between operations of the transport process is similar to the analysis of its internal parallelism.

The parallelism of transport processes is a natural consequence of the multiple nature of goods and transport, vehicles, infrastructure, etc., and entails the competitive dependence of operations. In transport systems, it is necessary to analyze processes that can potentially lead to competition, and take measures to eliminate it, based on the transformation of process schemes (modification of the resource basis; reconfiguration of the scheme, including reduction to a tiered-parallel (multilevel) or sequential form), using available tools in the field of parallel programming.

Figure 4 shows the asynchronous (maximally parallelized) operator scheme, which is an invariant for the schemes in Figs. 1 and 2, and reflecting the information-logical structure of the process. The issues of using it as a diagnostic standard, developing appropriate methods for detecting defects in technological processes, and organizing an automated diagnostic system are described in [9, 10].

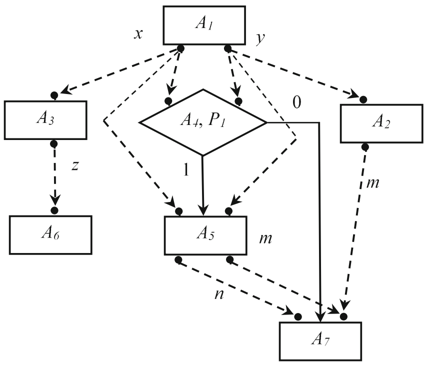

Fig. 4. Asynchronous operator scheme

4 Practical Usage

To diagnose the transport process during its actual implementation, it is necessary to implement a defect detection subsystem including diagnostic software (formal defect descriptions corresponding to Fig. 2, methods and algorithms for their detection) and diagnostic tools (software modules or a watchdog processor) [1, 9, 11]. Detection algorithms can be based on a comparison of labels (tags) of operations and corresponding resource variables of the operator scheme, for which their marking up is preliminarily carried out.

A rational solution is to diagnose transport processes in a tiered-parallel (multilevel) form [9], when the operator scheme is sequentially divided into tiers, inside each of which the operators have no competition according to (2).

For the schemes in Figs. 1, 2 and 4, tires include the following operators: the first is A_1, the second - A_2, A_3 and A_4, the third - A_5 and A_6, the fourth is A_7. The scheme in Fig. 4 actually reflects a tiered-parallel shape.

The diagnostic algorithm is such that when the process is carried out from the initial tier to the final one, the following checks are performed: "Does the operation belong to the current tier?" and "When moving to the next tier, are all the operators of the current tier fulfilled?". And a defect sign is formed with a negative answer.

The main problematic issues of the practical application of the proposed method of analysis and diagnosis of transport processes include the following [9, 12, 13]:

- the testability of the transport system, the availability of statistics on defects, taking into account their significance;
- the dimension of textual descriptions and operator schemes of the processes, the complexity of solving the problems of building and visualizing schemes of multi-operation processes;
- organizational and technical organization of the diagnostic subsystem;
- simulation computer modeling of correct and defective processes in conjunction with diagnostic tools;
- methods for assessing and reducing resource losses.

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Evaluation Model of Interaction Between Container Transport System and Regional Economy

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Abstract. The aim of this article is elaboration of the evaluation model of interaction between container transportation and regional economy as well as characterization of some interaction aspects. The relevance of research is confirmed by lack of models of transport industry mutual influence on regional economy as well as practical mechanisms to integrate of regional development industry programs. This results in misbalance of container infrastructure functioning and efficiency reduction of transport service for regional cargo owners. The general theoretical model is given and grounded which envisages multi-factor, mutual, directed to both sides influence of containerization on regional economic development. For evaluation of regional economic growth under the influence of container system development, dependencies were established of: reduction of cargo owners' expenses in case of containerization increase of cargo produced in the region; cost effectiveness increase of regional enterprises in case of transport costs reduction. Practical significance of research results is in possibility to evaluate priorities in provisioning of the container system with the use of the model, to work out regional strategies of social and economic development of the region and transport industry, to prepare the most efficient investment flows.

Keywords: Container system · Containerization · Regional growth · Evaluation of interaction · Regression model

1 Introduction

At present container service is one of the most cost effective means of transportation. It enables to ultimately unify and optimize transportation, enhance efficiency of handling operations, provide security of the equipment load. Therefore, the development of container traffic can positively influence the economy functioning.

Switching of cargo to container traffic from other means of transport and enhancement of containerization is one of high-priority tasks of economic development of the Russian Federation. Thus, in accordance with the President's Order "About national objectives and strategic tasks of development of the Russian Federation for the period until 2024" the goal was set up to increase railway container traffic volume by four times by 2024.

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As the end of the year of 2018 the coefficient of containerization of cargo carried by railways has grown up to 7.2% as compared with 6.6% in 2017. However, the growth was mainly provided by increase of through and inbound transportation in containers, whilst the coefficient of cargo containerization in domestic and outbound traffic is not exceeding 3% by our calculations. This provides irregularity of transport and high portion of empty container flow.

To increase the containerization level it is necessary to create properly organized regional infrastructure which is oriented not only to outbound flow handling but also ensures timely and reliable shipment of goods produced in the region. Not only conventional containerisable cargo is a case in point, but also commodity products as their transportation in containers is now possible by virtue of particularized park development and improvement of cargo packing resources.

For coordinated development of container transport system in compliance with regional needs it is necessary to have scientifically grounded instruments of evaluation of influence of transport technological development on economic growth of the region.

A large number of up-to-date investigations is devoted to evaluation of interaction between the transport system and regional economy, however, somewhat adverse approaches have been worked out in this sphere.

On the one hand, a number of investigations looks upon transport as an auxiliary industry, herewith, economic growth stimulates the development of transport. For instance, papers [1–4] are devoted to elaboration of regression models reflecting the influence of various regional macroeconomic indicators on transport development.

In papers [5–12] an opposite idea is formulated: transport development and investments to transport infrastructure spur economic growth of regions through intensification of commerce and reduction of logistical costs of manufacturers. In particular in [8–12] different approaches to modeling and evaluation of economic and social development of regions are discerned under realization of transport infrastructure projects. A number of papers is also devoted to correlation analysis of influence of transport indicators on regional economic development [11, 12].

In our view, a valid conclusion is drawn in the paper [13] about interaction of transport and regional economy. The authors point out that debates about priority in this interaction are incorrect, as the direction of that influence may change depending on a current economic situation. Thus, at periods of intensive economic growth the influence of economy is primary, it initiating development of transport system to meet consumer demand. But under realization of major transport projects the influence of the transport system is primary, it stimulating intensive economic development of regions and the country for years to come.

Therefore, interaction of transport and region is directed bilaterally, changing dynamically and is of stochastic nature. Currently certain aspects of this interaction have been studied, however, economic and mathematical model which reflects mutual dynamic influence of these subsystems is not given.

This present study is based on previous papers of authors [14–16].

2 Theoretical Model of Interaction Evaluation

The model is based on the following idea: the container transport system of the region is one of its subsystems, therefore there is mutual influence of container traffic and different regional industries. However, it is impossible to evaluate this interaction on a direct basis, it having a delayed effect and is exposed to a great number of stochastic parameters.

Containerization influence on economic development of the region is proposed to be evaluated from the standpoint of reduction of cargo owners' costs, growth of economic performance of the region as well as various social and economic factors related to container market development. There is also a feedback effect – economic growth of the region contributes to container transport system provisioning (through industrial-production growth, activation of commerce, investments and industry appeal boost).

For making the theoretical model let us introduce the following notation.

Let us assume that k is a regional cargo containerization coefficient computed as a portion of cargo transported in containers by volume of flow of cargo of the region. The volume of cargo traffic in containers is determined by demand of regional enterprises for container transportation (D) and is restricted by transport system provisioning level (A). Demand for container traffic correlates production volumes in the region (M). The technique of prognostics of demand for container transportation depending on industrial performance of the region is given in [16].

The growth of cargo containerization coefficient (k) of the region affects the value of cargo owners' transport costs (C), this in turn influencing cost-effectiveness rate of regional enterprises (R).

Cost-effectiveness rate of enterprises (R) facilitates increase of social-economic wealth of the region (W).

In its turn, the social-economic wealth growth makes it possible to increase investments to container infrastructure (I), this facilitating the increase of its organizational and technical development level (A).

The interaction of the indicated parameters is shown in Fig. 1.

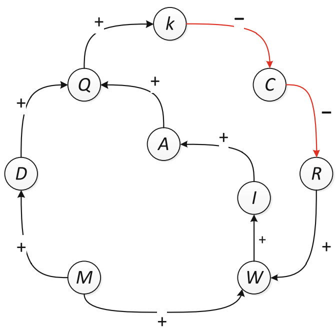

Fig. 1. Theoretical model of interaction of factors representative of container traffic and region subsystem development

Symbols in the diagram (Fig. 1) show direct (+) or inverse (−) relation among the indicated parameters.

Therefore, interaction between the region and container traffic subsystem is multi-factor, mutual and both side.

Thereinafter in the present paper the represented model fragment is formalized – evaluation of containerization effect (*k*) on transport costs (*C*) and cost-effectiveness rate (*R*) of regional enterprises.

3 Evaluation of Containerization Effect on Transport Costs of Regional Cargo Owners

A statistical study of cargo transportation costs in wagons and containers was made for evaluation of containerization effect on transport costs of cargo owners.

On the basis of RZD JSC statistical information 200 cargo dispatches were selected in each rolling stock type and costs of cargo owners per transport operation unit were calculated. For consistency of the calculation there were chosen the data about transportation of only containerisable cargo in standard containers and covered wagons.

The analyzed data are characterized by the following statistical parameters (Table 1).

Table 1. Features of statistical sampling of cargo owners costs in case of transportation in containers and wagons

Parameter	Cargo owners costs in case of transportation in wagons, r/tkm	Cargo owners costs in case of transportation in containers, r/tkm
Sampling size	200	200
Arithmetic middling	0.9249	0.3203
Standard deviate	0.7811	0.0973
Variation coefficient, %	84.45%	30.38%
Range of variation	3.6416	0.4768
Maximum value	3.8320	0.5787
Minimum value	0.1904	0.1019

The analysis showed a considerable variation in costs in the sampling, this being explained by differences in the rolling stock ownership and operating technology, as well as other stochastic factors. Therefore, for the purpose of modeling let us size the cargo owners' costs value as stochastical variable with the established distribution law and make use of Monte Carlo method.

Laws and statistical features of distribution were obtained through STATISTICA 10 software product.

The modeling results are shown in Fig. 2 and Table 2.

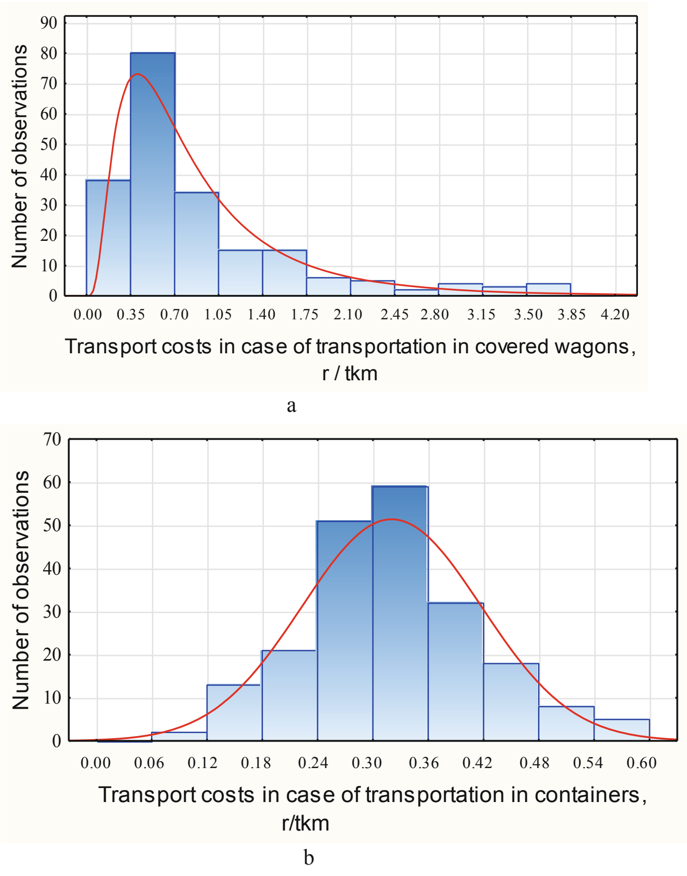

Fig. 2. Grouped data on cargo owners transport costs and distribution theoretical curves: a – in case of transportation in wagons; b – in case of transportation in containers

At different containerization rate transport costs of cargo owners per transport operation unit are calculated using the formula:

$$C = (1 - k)C_1 + kC_2 \quad (1)$$

where C_1, C_2 are transport costs in transportation in wagons and containers respectively, calculated as a random number using Monte Carlo method in compliance with the established law of distribution.

Table 2. Statistical features of cargo owners transport costs distribution in case of transportation in wagons and containers

Statistical features of distribution	Cargo owners costs in case of transportation in covered wagons, r/tkm	Cargo owners costs in case of transportation in containers, r/tkm
Law of distribution	Lognormal	Normal
Stochastic average	0.9150	0.3671
Mode	0.6629	0.3671
Standard deviate	0.7811	0.0973
Standard error	0.0544	0.0067
Pearson criterion	$X^2 = 12.22$ $X^2_{crit}(9; 0.05) = 16.91$ $X^2 < X^2_{crit}(9; 0.05)$	$X^2 = 6.39$ $X^2_{crit}(7; 0.05) = 14.07$ $X^2 < X^2_{crit}(7; 0.05)$

Let us carry out a number of experiments, applying random numbers to the formula (1) each time. The result of the experiment is shown in Fig. 3.

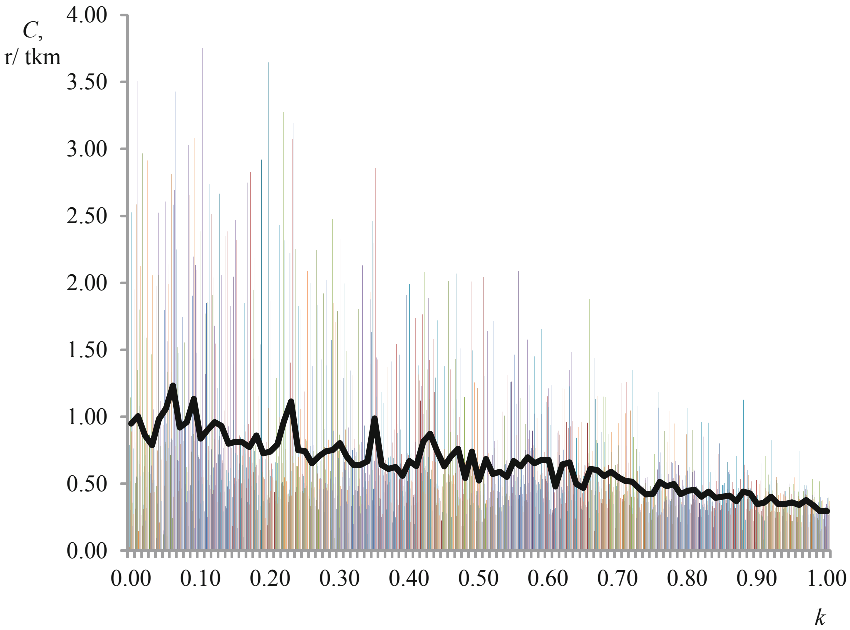

Fig. 3. Results of cargo owners transport costs modeling through Monte Carlo method

Chart bars (Fig. 3) show the results of separate experiments, the line shows the mean value from experimental ones.

Adjustment of transport costs mean values was made through the least squares method and linear dependence was obtained, which is described by the model: C = −0.0065k + 0.9747. There was also found a confidence interval for the mean with probability 95% by the formula:

$$C_{\min,\max} = C \pm 1.96\frac{\sigma}{\sqrt{n}}, \quad (2)$$

where n is a number of experiments.

The calculations results are shown in Fig. 4.

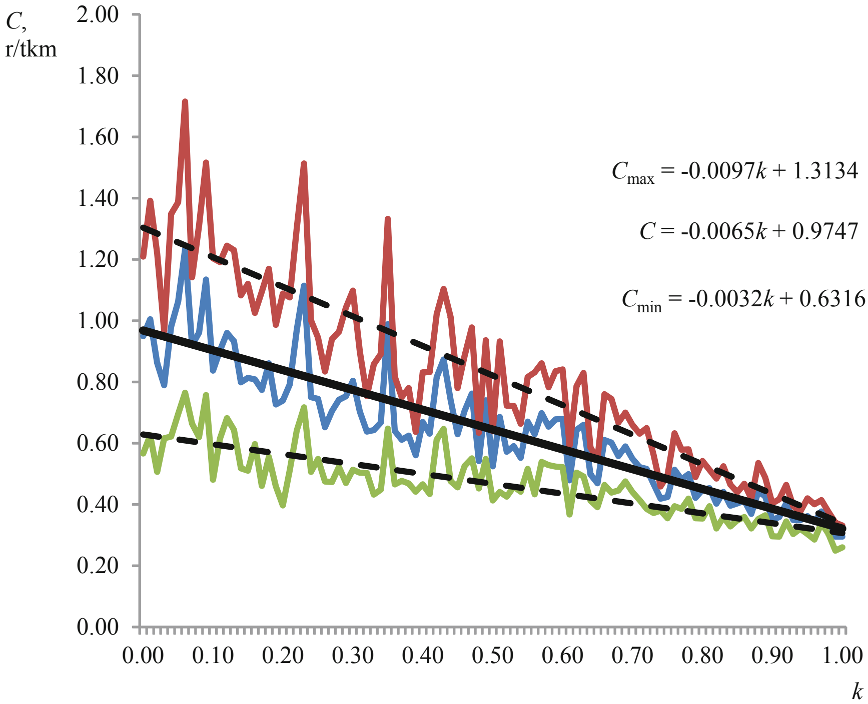

Fig. 4. Regression dependence of cargo owners' transport costs on containerization coefficient

Therefore, prognostics of mean transport costs of regional cargo owners at various containerization levels will be provided on the basis of a regression model: C = −0.0065k + 0.9747.

However, the costs will not exceed C_{max} = −0.0097k + 1.3134 and will be not less than C_{min}= −0.0032k + 0.6316 with 95% probability.

4 Evaluation of Transport Costs Influence on Cost-Effectiveness Rate of Regional Enterprises

Let us estimate dependence of regional enterprises cost-effectiveness average rate on cargo owners' transport costs.

Cost-effectiveness of production is usually calculated as income from realization of products (services) to production and realization costs ratio. The coefficient shows how much income an enterprise has from each pecuniary unit that was spent on production and realization of products. This indicator may be calculated for both separate enterprises, industries and the region in total.

For the purpose of this study let us take into consideration that transport costs are included into production and product realization costs and write the formula of cost-effectiveness coefficient estimation as follows:

$$R = \frac{P}{E + C}, \tag{3}$$

where P – income of regional enterprises from product realization; E – costs on production and product realization of regional enterprises (excluding transport ones); C – transport costs of regional enterprise.

For the purpose of estimating the nature of $R = f(C)$ dependence let us refer to official statistics about cost-effectiveness rate of enterprises, profit of enterprises from realization, costs on production and product realization, costs of cargo owners on railway transportation. Taking into account the fact that in certain industries there are differences in cost-effectiveness average rate and structure of costs, let us carry out the investigation through the example of a separate economic activity "Manufacturing activity". Target region – Sverdlovsk region.

The evaluation task of transport costs influence on cost-effectiveness rate of Sverdlovsk region manufacturing industry is formulated in the following way: to what extent cost-effectiveness rate (R) will vary only through change of transport costs (C) excluding profit influence (P) and non-vehicle expenses on production and realization (E).

In order to solve the problem let us make use of deterministic analysis and method of chain substitutions. We have multiply additive factor model:

$$R_i = \frac{P_i}{E_i + C_i}, \tag{4}$$

In order to estimate the influence of each factor (P, E, C) on R according to the method of chain substitutions the following algorithm is used:

$$R_i = \frac{P_i}{E_i + C_i}, \tag{5}$$

$$R_i^{add1} = \frac{P_{i+1}}{E_i + C_i}, \tag{6}$$

$$R_i^{add2} = \frac{P_{i+1}}{E_{i+1} + C_i}, \tag{7}$$

$$R_{i+1} = \frac{P_{i+1}}{E_{i+1} + C_{i+1}}, \tag{8}$$

cost-effectiveness change under the influence of all factors:

$$\Delta R = R_{i+1} - R_i, \tag{9}$$

cost-effectiveness change through profit:

$$\Delta R(P) = R_i^{add1} - R_i, \tag{10}$$

cost-effectiveness change through non-vehicle expenses:

$$\Delta R(E) = R_i^{add2} - R_i^{add1}, \tag{11}$$

cost-effectiveness change through transport costs:

$$\Delta R(C) = R_{i+1} - R_i^{add2}. \tag{12}$$

For comparability of calculation let us turn from absolute change values to relative ones:

$$\Delta R(C)_i^{\%} = \frac{\Delta R(C)_i}{R_{i-1}} 100, \tag{13}$$

$$\Delta C_i^{\%} = \frac{\Delta C_i}{C_{i-1}} 100. \tag{14}$$

On the basis of quarterly statistical data over a 12-year period the following model of cargo owners transport costs influence on cost-effectiveness of Sverdlovsk region manufacturing industry was formed (Fig. 5).

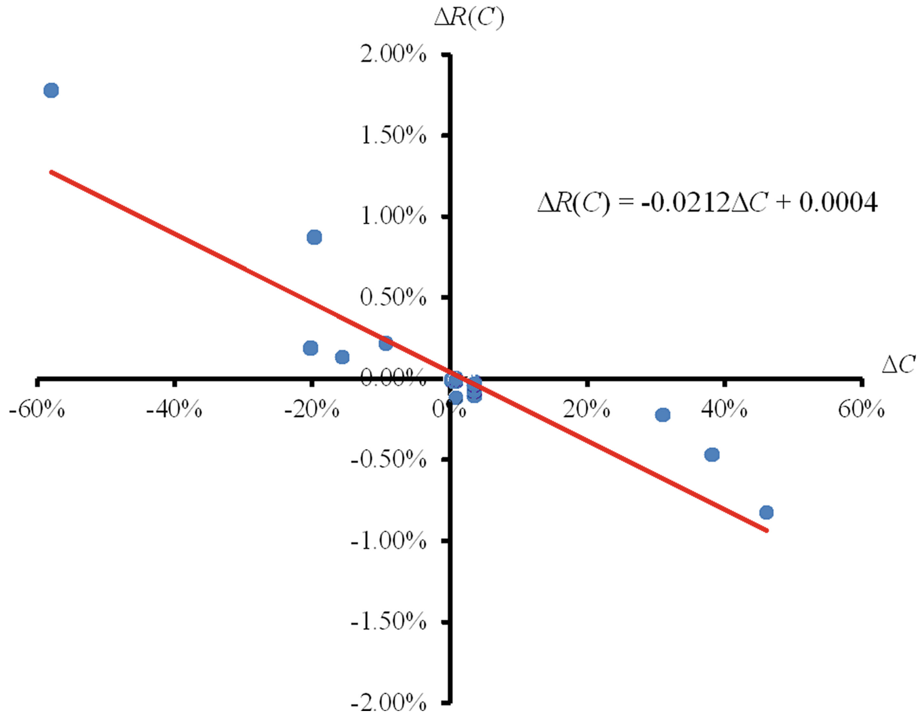

Fig. 5. Regression dependence of cost-effectiveness change on transport costs change

Therefore, $\Delta R(C) = -0.0212\Delta C + 0.0004$ linear regression model is obtained which makes it possible to prognosticate the change of production cost-effectiveness under the influence of growth or reduction of cargo owners transport costs. The coefficient of pair correlation for the data under consideration was −0.907, which indicates intimate inverse dependence between indicators. Determination coefficient for linear regression model was 0.82, this means that in 82% of cases the given model adequately describes cost-effectiveness change under the influence of transport costs.

5 Generalized Evaluation of Containerization Influence on Cost-Effectiveness Rate of Regional Enterprises

Let us generalize the results of modeling and ascertain the influence of containerization coefficient on cost-effectiveness of regional enterprises.

Calculations will be made through the following algorithm (Fig. 6).

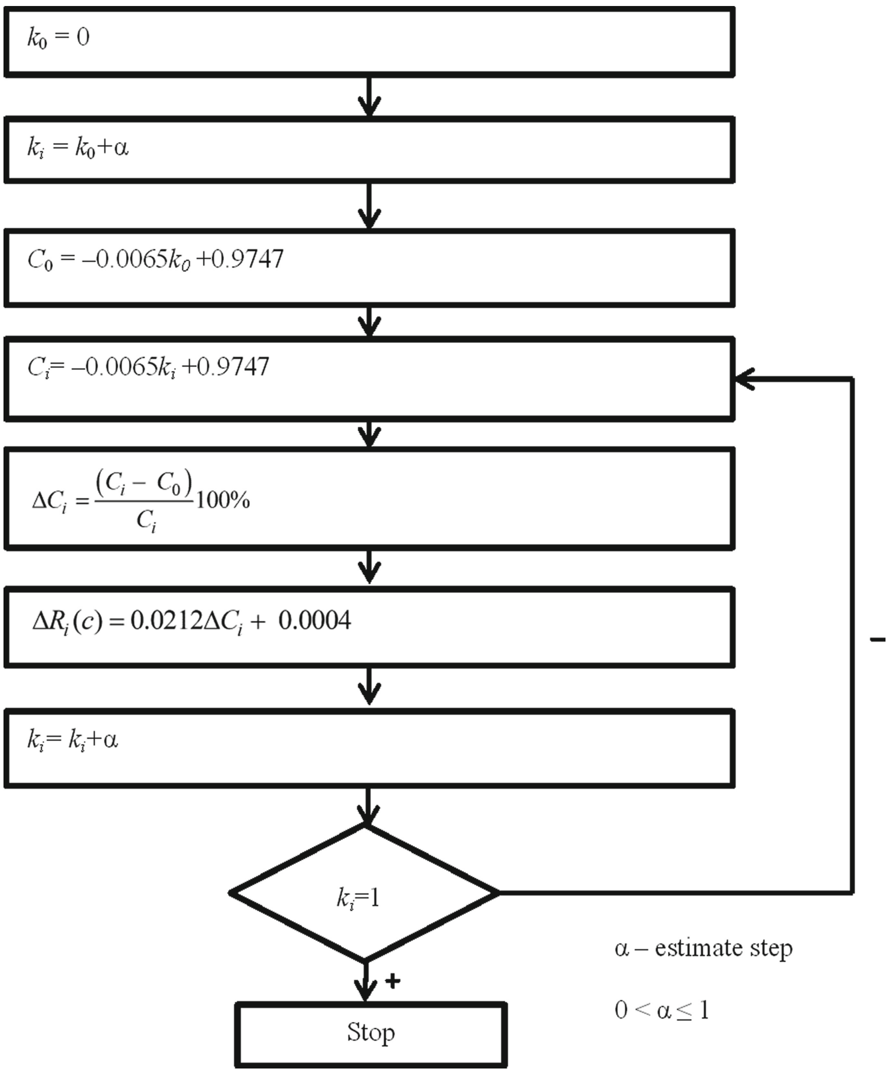

Fig. 6. Evaluation algorithm of influence of cargo containerization level on cost-effectiveness change of regional enterprises

On the basis of the shown algorithm the following dependence of regional enterprises cost-effectiveness on containerization level was received (Fig. 7).

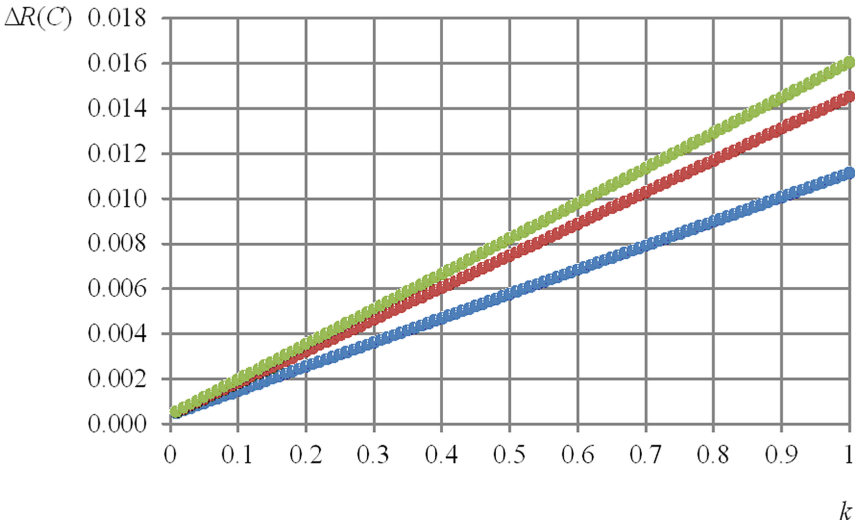

Fig. 7. Evaluation of influence of cargo containerization level on cost-effectiveness change of regional enterprises

On the basis of the represented model we may build forecasts of average cost-effectiveness rate of regional enterprises under various containerization level. Thus, for example, cost-effectiveness rate of Sverdlovsk region manufacturing industry production over the period of 2018 is 16.50%. Containerization coefficient of loading of the region in inbound and outbound traffic over the same period is –0.0297.

Let us build forecasts of cost-effectiveness growth in case of containerization level change to 0.5. Let us assume that $k_0 = 0.0297$, $R = 16.5 \cdot (1 + \Delta R)$. In this case in compliance with the established dependence the average cost-effectiveness rate of Sverdlovsk region manufacturing industry production reaches 16.62%.

6 Conclusion

The model is presented which describes dynamic mutual influence of development of container traffic and the region. Containerization influence on regional economy growth is viewed from the standpoint of reduction of cargo owners transport costs and growth of social-economic wealth of the region. Therewith we take into consideration that increase of containerization coefficient is restricted by regional transport infrastructure development and cargo base structure. In this regard, inverse influence evolves – economic growth stimulates investments to transport industry, this predetermining further rise of container traffic.

The represented model allows coordinating programs of regional development of separate industries and container traffic system, estimating priorities in organizational and technical development of container system, building up the most efficient investment flows and forecasting the wealth growth of regions.

In the present paper a model fragment is formalized – evaluation of containerization influence on transport costs and cost-effectiveness rate of regional enterprises on the basis of correlation-regression analysis, method of statistical testing (Monte-Carlo), factorial economic analysis.

Not only general evaluation model of interaction between container transportation system and a region have practical implications, but also submodels establishing dependencies amid factors. Thus, the model of containerization coefficient effect on transport costs and production cost-effectiveness rate may be of use for validation of efficiency of capital investments of enterprises into container infrastructure development.

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Organization and Movement of Exit Routes from Empty Cars

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Abstract. The article discusses the issues associated with the organization of empty cars by type of rolling stock and by owners, possible points of their assembly; the analysis of the plan for the formation of empty cars is carried out, in order to identify the station for concentrating empty cars by type of rolling stock and their routes to them. The analysis of groups of wagons, which can be organized into exit routes, is carried out. The criteria of the optimization of task set for the promotion of empty cars and the improvement of the quality indicators of operational work for JSC "Russian Railways" ("RR") are well-grounded.

Keywords: Empty · Plan · Sending · Groups · Quality · Promotion

1 Introduction

The control system of railway service moved from a state-planned economy, in which it was necessary to fulfill a specified volume of transportation with minimal costs, to a market-driven one, where there was competition for transportation between operator companies; and the operating efficiency of the operator company and the carrier began to be estimated by the amount of realized profit.

Under such conditions supplementary requirements for the technology of the transportation process make appearance, associated with the implementation of the principles of focus on customer, the presence of the maximum list of services provided.

In the current context of unstable economic conditions and severe competition in the field of transportation, the issue of improving the quality of services provided on railway is extremely important. The implementation of a customer-oriented approach, starting from transportation planning and ending with the direct performance of the transportation process, should ensure the use of reserve capacity of railways and the necessary estimated capacity of stations to satisfy the requirements of customers at all stages of goods traffic.

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2 Materials and Methods

However, an insufficient coordinated interaction between the participants of the freight transportation market: rolling stock operators, freight owners, a carrier – leads to a violation of the technology of stations for servicing private tracks.

At the stations a significant number of wagons are accumulated, belonging to different owners and complicating local work. At the same time, the reliability of station for freight operation fulfilling the principal functions is reduced: to serve the users with railway transport services, performing operations on the reception and departure of trains, on the supply and cleaning of wagons, and the loading and unloading of goods in accordance with customer requests. The customer service for railway transport is not steady, and railways suffer losses due to the excess of the working fleet of cars and their unproductive waits at the stations [1].

At the ports of the Far East, freight traffic is growing by 6%. According to the Central Directorate of Traffic Control, loading of goods of the first class had priority rates than in the first quarter, primarily due to coal, whose transportation increased by 9.2% or 7.7 million tons compared to 2016. Cargo of the 3rd class also grew by 3.6%. The shipment of scrap metal, chemicals, fertilizers and containerized cargo grew most of all.

The following is an analysis of the work of the Far Eastern Railway for 2016–2018: Fig. 1.

The loading in May 2019 on the Far Eastern Railway amounted to 3 million 657 thousand tons, which is 9.7% less than in the same period last year.

Cargo turnover in May 2019 increased by 4.3% compared to the same period last year and amounted to 18.4 billion tariff ton-km. Cargo turnover, taking into account the empty run of cars during the same time, increased by 3.7% and amounted to 23.8 billion ton-km.

Loading for 5 months of 2019 amounted to 19 million 666 thousand tons, which is 2.3% less than for the same period last year [2].

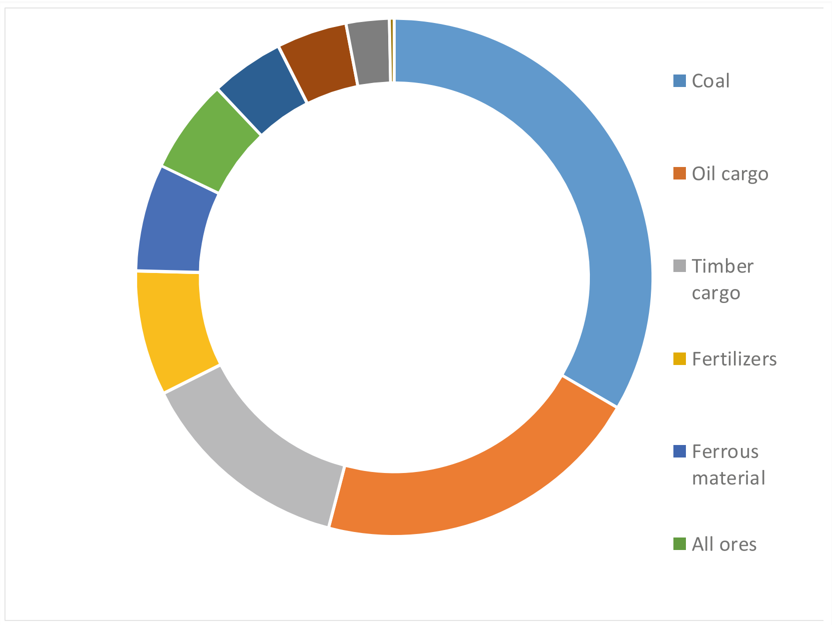
Also this year, Blucher, Cape Astafieva, Cape Churkin, Posyet and Vanino reached maximum values for processing rolling stock. On May 20, 2018, a total of 4932 railcars were unloaded at the port railway stations of the Far Eastern Road with an average daily value of 4194 – this is a record figure for the entire duration of the work of the trunk.

Empty car flows follow from the directions of port stations at the loading station, such as: Kuzbass, Komsomolsk-on-Amur, Krasnaya Rechka, Kruglikovo, Krabovaya, Dzemgi, Birobidzhan, Izvestkovaya, Postyshevo, Berkakit, Uyar, Sukhovskaya and others.

The largest stations which carry out loading on the Far Eastern Railway are: Khabarovsk II, Komsomolsk-sorting and so on.

Unloading stations are port stations: Vanino, Posyet, Nakhodka, Vladivostok, etc. Accordingly, empty car flows follow directions: unloading station (port station) – loading station.

Empty car flows are organized into trains in accordance with the plan for the formation of empty trains [1].



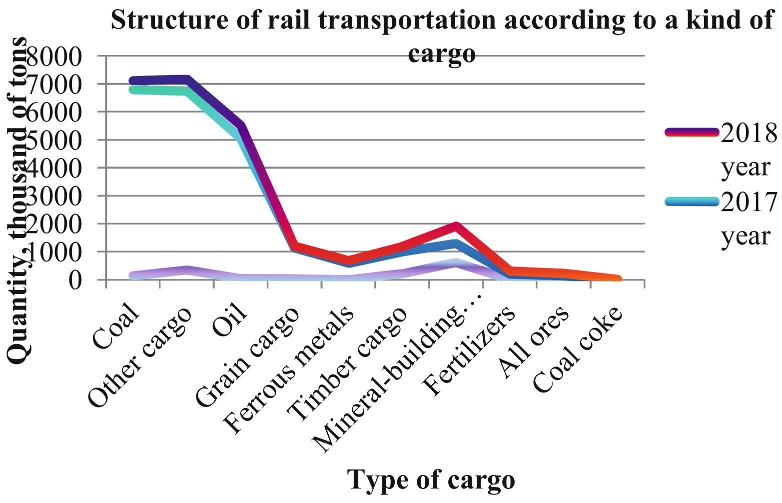


Fig. 1. The work of the Far Eastern Railway

At the stations where the formation of individual trains from empty cars of the inventory stock is not provided, these cars are included in freight trains according to the formation plan in accordance with the parameters of the technical plan and the daily plan of train and freight operation.

If the formation plan for a given station does not indicate the destination of trains to be formed, which should include empty cars of this kind and the state of the owner, in this case such cars are sent in accordance with the “Rules for operation, number-specific accounting and billing for the use of freight cars of the property of other countries”.

After unloading empty cars upon notification of the Council Directorate may be sent as “wagon” assistance with the consent of the owner-owned railway administration.

At stations where the formation of individual trains from empty own and leased cars is not provided, cars are sent to the destination station indicated by the senders of empty cars in the transportation documents, in accordance with the plan for the formation of freight trains.

If the formation plan for a given station does not indicate the destination of trains to be formed, which should include empty cars of this kind and the state of the owner, then such wagons are sent on trains in accordance with “Rules for operation, number-specific accounting and billing for the use of freight cars of the property of other countries” (Fig. 2).

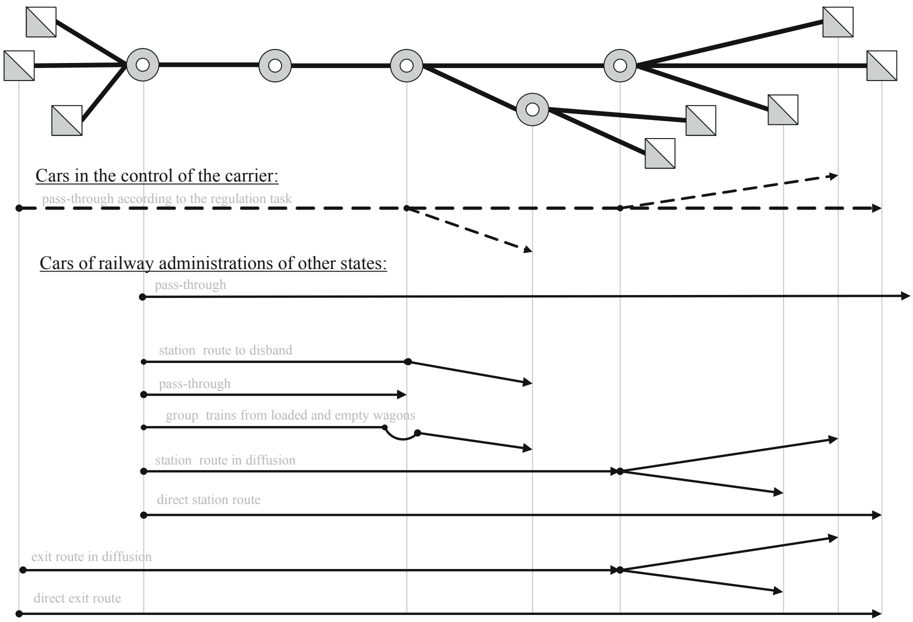


Fig. 2. Organization of the assignment of formation plan from empty cars between unloading stations, following technical stations and loading stations

Empty wagons released up after unloading upon notification of the Council Directorate may be sent as “wagon” assistance with the consent of the owner-owned railway administration [3].

Design specification:

Each assignment of trains from empty cars, included in the formation plan, is characterized by a value appraisal:

$$E_{ac.emp.} = E_{ac.emp} + N_{emp}\left(\sum E_{sec.emp.} + \sum E_{tr} + E_{des.st.emp.}\right), \quad (1)$$

where $E_{ac.emp}$ – the value appraisal of the accumulation of empty trains at the formation station, rubles/day;

N_{emp} – empty car traffic volume, included of this assignment, cars/day;
$\sum E_{sec.emp.}$ – the amount of specific (per 1 empty car) value appraisal of the passage of empty routes in sections, rubles/car;
$\sum E_{tr}$ – the amount of the specific value appraisal of the transit of through trains at technical stations, rubles/car;
$E_{des.st.emp.}$ – specific value appraisal of car detention and processing operations at the train destination station from empty cars, rubles/car.

At large unloading stations, which systematically unload entire routes, the formation of routes specialized in the type of rolling stock from empty cars is arranged. The organization of such routes is carried out, as a rule, without downtime of cars under accumulation. If the unloading of routes is carried out partially, as well as in cases where the trains from empty cars exceed the trains of loaded routes, at the unloading station there will be detention empty cars under accumulation. The time spent by cars under accumulation in each case is determined in accordance with the organization of work with main tracker trains established by the technological process [4].

The formation plan and the results of the calculation of the plan for the formation of empty routes according to the criteria of distance, costs are presented on the Fig. 3.

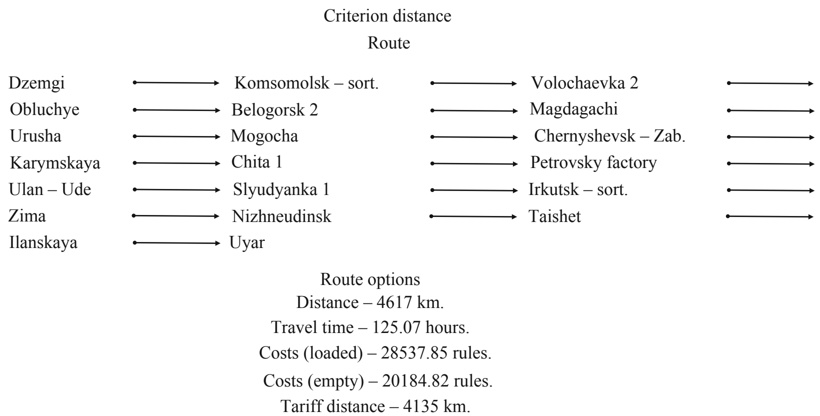


Fig. 3. Results of the calculation of the plan for the formation of empty routes

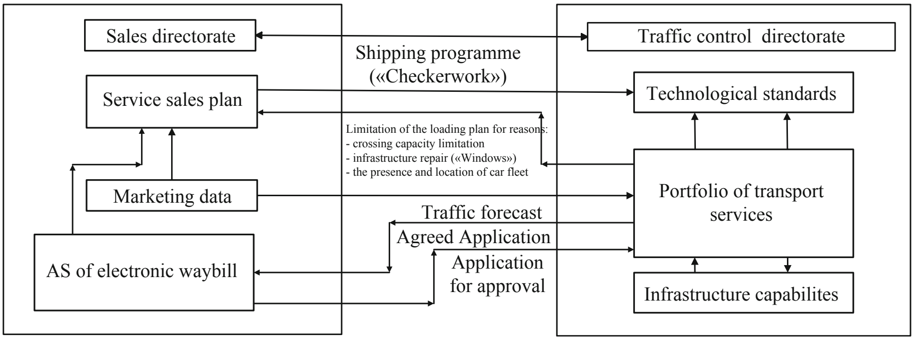


Fig. 4. Distribution of responsibility in the regulation process

The technical regulation of operational work carried out by the Central Directorate of Traffic Control establishes technical standards for the regions and is aimed at (Fig. 4):

- enforcement of the stock transport order of goods for the system;
- in general, according to the established nomenclature of cargo and the types of wagons;
- distribution of the car fleet between the roads of the system in accordance with the capabilities of the infrastructure by type of rolling stock and by car ownership;
- efficient use of available capacity, cost-effective directions in order to minimize operating costs for transportation;
- saving fuel and energy resources;
- receiving a profit;
- acceleration of delivery time.

Regional directorates calculate technical standards of operational work of stations belonging to the region. Established technical standards include:

- enforcement of the assignment for the carriage of goods according to the established nomenclature;
- distribution of the car fleet by type of rolling stock between stations, depending on the volume of goods transported and the equipment of the cars, the maximum use of the carrying capacity and capacity of the cars;
- the most efficient use of crossing capacity. In the process of developing technical standards for the operational work of network units, the following principal tasks are solved:
- determination of the values of quantitative indicators of the transportation process, corresponding to the forecasted volumes of traffic;
- determination of values of indicators characterizing the quality of operational work of railway transport;
- calculation of the required resources for performing transportation on the system and their distribution between its units.

In order to improve the quality and efficiency of solving these problems on the railway system of the Russian Federation, the introduction of an automated technical regulation system for transportation management levels - AS TR developed in accordance with the end-to-end technology for technical regulation (includes management levels: network, road and departmental) proceeds to completion [16].

The operational performance indicators planned for the stations of the regions provide for the management of the operational work of each station in support of the assignment for:

- distribution of wagons at stations;
- loading and unloading;
- optimization of local work aimed at reducing the time spent by cars at the department, ensuring the rational use of traction and loading resources;
- maximum use of carrying load and capacity of carriage;
- selection of cost-effective areas in order to reduce operating costs;
- saving fuel and energy resources, making a profit and speeding up the delivery period of goods.

The technology for the formation of a shift - daily work plan for railways and their sections is regulated by the Instruction for the operational planning of train and freight work of railways [5].

The operational planning of train and freight work should most accurately reflect the real process of organizing operational work for the completion of the transportation plan, taking into account the specific conditions for the interconnection of all parts of the railway line involved in the formation of car traffic volumes, the formation and advance of trains.

The main data for the development of an operational plan for shift and daily work are:

- transportation plan and monthly operating standards;
- standards for the use of rolling stock;
- standards for the transfer of wagons and trains at division points;
- amount of traffic, as well as the size of the departure of trains from technical stations;
- train position;
- data on the progress of loading and unloading;
- the presence of railroad engines in the operated fleet.

The tasks of operational planning of train and freight work include:

- determination of the amount of traffic for a specific period, both at division points and at sections;
- development due to the change in the amount of traffic of tasks for sorting, district and large cargo stations for the formation and departure of trains;
- determination the size and procedure for the transfer and distribution of local cargo, ensuring loading with empty cars, and the organization of transportation of goods by exit routes;
- providing trains with railroad engines and locomotive crews;

- the size of the unloading as a whole, by the type of rolling stock and each station.

Cargo planning of goods into wagons for each day is carried out on the basis of a summary loading plan. The summary loading plan for the next day is formed on the basis of:

- applications of cargo shippers for transportation specified according to the schedules of car supply for the planned day - based on the results of the cooperation between the Transport Service Centre, shippers and wagon operators;
- possibilities for securing applications and orders for the carriage of empty cars of the carrier's fleet;
- availability and possibility of well-timed supply of a private park;
- current restrictions on the carrying capacity of the sites and the estimated capacity of the station.

The project of summary loading plan for the next day is drawn up at the Transport Service Centre (Sales Directorate) on the basis of agreed applications by adjusting the schedule for the supply of wagons for loading on a planned day announced by the consignor (at the application stage) for the following reasons:

- inability of the cargo shipper to present the goods for departure on a planned day;
- failure to drive own and leased cars on a planned day;
- existence of accounts due to customers;
- presence of convention bans and other restrictions on loading [6].

The project of summary loading plan is transferred from the electronic waybill system to the Automated Traffic Control System – 2 road network database no later than 12 h ahead of the scheduled day and contains a list of all agreed consignors' requests indicating the number of wagons and tons to be loaded on a specific date [17].

The project of summary loading plan should be presented with the following details:

- by type of cargo;
- by type of rolling stock;
- loading regions and destinations;
- with the allocation of wagons of the carrier's fleet, own and leased cars (with an indication of the operator) and wagons belonging to the CIS and Baltic countries.

At the daily planned meeting, the heads of the management districts (HMD) of the centralized traffic control center (CTCC), in collaboration with the station managers, organize to implement the car supply plan and, accordingly, ensure the project of summary loading plan submitted by the Transport Service Centre and to their control areas.

As a result of HMD planning, a draft loading plan for the control area is formed, which takes into account the possibilities of providing a consolidated loading plan for own and leased empty cars and empty cars of the carrier's fleet based on:

- their presence in the area of management;
- access of cars for unloading;
- regulatory measures of the CTCC;

- preparation of cars for car preparation point (washing and steaming station);
- availability of a reserve of empty cars of the carrier's fleet and park of own and leased cars;
- fulfillment of the norms of the monthly technical loading plan.

At a daily planning meeting held until 3 p.m. Moscow time, the deputy head of the traffic service in coordination with the HMD plans to provide a summary plan for loading per carrier (to region).

As a result of planning, by adjusting draft plans for ensuring loading of management districts and issuing additional instructions for adjusting and occupying empty cars of the carrier's fleet, a draft plan for ensuring loading of the railway (region) is formed.

3 Results

Analysis of the efficiency of the use of gondola cars and the dependence of the number of shipments on the downtime of the cars in the reserve at loading stations indicates the expediency of partial or complete consolidation of the fleet of cars under a single control. The trend of consolidation is currently observed in the market of operator services due to mergers and acquisitions of companies [7]. The Russian Railways' efforts to create a consolidated gondola fleet have a significant impact on the transportation market.

For example, since the beginning of 2018, the Far Eastern Transport Service Centre has carried out a number of projects aimed at reducing the load on the infrastructure of the sorting stations of the Far Eastern Railway. By means of ensuring the execution of shipping documents by appointment to one railway loading station, it has become possible to exclude sorting along the entire route, which allowed the formation of full-fledged technical routes with little to no additional switching service.

Over the 12 months of last year, 1736 trains were sent from the port and border stations of the Far Eastern Railway, which followed the sorting stations of the area without rehandling.

The economy in operational costs (economic impact) due to a decrease in the load on the road infrastructure for the 12 months of 2018 amounted to more than 36 million rubles. This result has been achieved due to the almost complete exclusion of switching service on the making up of trains at port stations, as well as the elimination of accumulation and sorting at the sorting stations of the Far Eastern Railway.

In addition, the quality of some performance indicators has been improved. In the direction of Vanino – Chegdomyn – Vanino, the car's turnover was reduced by 1.5 days. In a number of areas, the actual delivery time has been reduced from 1 to 3 days. The potential risks of claims for delayed delivery of goods by more than 9 million rubles were reduced.

4 Discussion

These days the Far Eastern Transport Service Centre does not stop there and is implementing more complex engineering projects. A unique technology was developed and approved for interaction between Russian Railways and railway rolling stock operators to regulate the targeted use of empty open cars departing from the Posyet railway station, which, depending on the operational conditions, allows reconsigning along the route [8].

The technology consolidates the owners of rolling stock Mechel Trans LLC, New Forwarding Company JSC, Railtransholing – Logistic LLC, Neftetransservice JSC, FGK JSC into a common car pool and is successfully used in the work. Thanks to the consolidation of the owners, in the Posyet – Neryungri – Gruzovaya – Posyet direction it has become possible to reduce the wagon turnover by 2 days and redistribute more than 300 wagons to other directions of transportation, without reducing the loading volume, and also to exclude “radial” routing of wagons to Verkhnezeisk station. As a result, the operational load on the Izvestkovaya – Novy Urgal section was reduced.

5 Conclusions

In addition to a more rational use of the road infrastructure and lower operational costs for sorting and forming, the concept of consolidation of the owners ensured the rapid decision-making on the redistribution of loading resources. Proposals for changing the formation plan are presented in Fig. 5 [9].

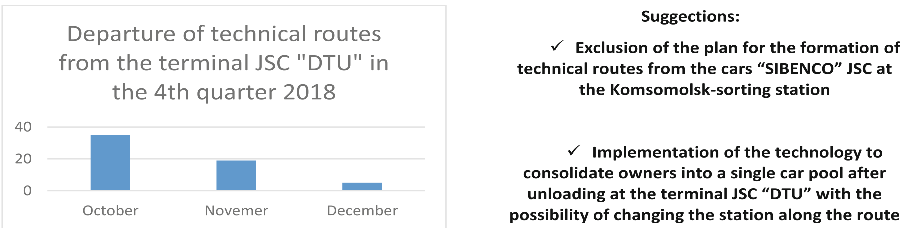


Fig. 5. Proposals for changing the formation plan for “SINENCO” JSC

Another proposal is the formation of technical routes on the tracks of JSC “Daltransugol” (“DTU”). This work has been successfully implemented since April 2018, but unfortunately, in the IV quarter of 2018 there was a tendency to reduce the number of formed routes.

In October 35 routes were sent, in November 19 routes, in December only 5 routes. The reason for the lack of motivation for the formation of “Daltransugol” JSC by its own technical means was the change in the formation plan, which provides the allocation of 2 accumulation paths for “SIBENCO” JSC at Komsomolsk-sorting station (Terentyevskaya, Leninsk – Kuznetski). This situation actually postponed the work on the formation of direct routes, was from JSC "DTU" to the public path of Komsomolsk-sorting station.

In this regard, in order to increase routing when sending empty gondola cars from the terminal of "Daltransugol" JSC, we suggest considering the possibility of eliminating the formation of technical routes from the cars of "SIBENCO" JSC ownership at Komsomolsk-sorting station [10].

At the first stage, this will give an incentive to the formation of technical routes by means and forces of "Daltransugol" JSC on the ways of non-public use of the Terminal 1 and Terminal 2 fleets of "SIBENCO" JSC's private cars. Given the volumes of unloading own gondola cars, "Daltransugol" JSC will need to form from 1 to 4 routes daily, with 0.3 routes currently average per day.

At the second stage, "SIBENCO" JSC will be proposed a technology for consolidation into a single wagon pool of the main owners of wagons unloaded at the terminal, with the possibility of changing the destination station along the route. With an increase in the percentage of consolidation of the rolling stock, the load on port and sorting stations is gradually decreasing. Throughput and processing capabilities of the road have become available. In a set of measures aimed at optimizing the work, in the context of the consolidation of the rolling stock, which is aimed at improving the level of transport service for customers, ensuring guaranteed export of their products; it is also a sustainable engineering solution for the Far Eastern Railway [11].

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Conditions for Driving of the Connected Trains on the Operating Domain of Far Eastern Railroad

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Abstract. The article discusses the possibility of increasing the carrying capacity of a railway line in terms of positive dynamics of coal export and its loading on rail transport, including the Pacific ports direction. There is a limit of train handling capacity on operating domain of Far Eastern Railroad on all directions to ports. It's needs to research all possible options to accelerate of advance of a moving traffic by rail. Lack of reserve of train handling capacity on domestic railways combined with violation of the system of the transport complex has led to the fact that the industry cannot reach the previous rate of development. The article is devoted to the possibility of the admission of the connected trains on double-tracks of the Far East railroad at their constant driving, and during of summer track works. The main actions for increase in throughput and carrying ability are determined by priority.

Keywords: Connected train · Train handling capacity · Moving traffic · Carrying capacity · Mass of a train · Length of train

1 Introduction

Over the past decade, large-scale investments have never arrived in the industry, only the renewal of the freight car fleet and the construction of the infrastructure of the non-use tracks have taken place.

The lack of investment has led to an increase in the limit of transport and transportation capacity of the railway network and, as a result, to unmet demand for transport. The dynamic growth of traffic volumes has always been matched by the development of the railway network [1].

Lack of reserve of train handling capacity on domestic railways combined with violation of the system of the transport complex (Private Park, problems of interaction of related structures and companies, etc.) has led to the fact that the industry cannot reach the previous rate of development. The company's production unit and railroads are making considerable efforts to stabilize finding coherent solutions to splice problems, including the interaction with shippers, moving to fixed schedule, reducing costs etc. [2, 3].

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The situation is exacerbated by the surplus of freight cars that has emerged in recent. The situation in the railway transport market did not improve in 2015. The surplus of cars (taking into account the faulty fleet) increased by 20% to 252.000 units (about 21% of the total fleet), and the number of cars involved in moving traffic by rail decreased by 6% to 947.000 pieces, according to the materials of the agency “Infoline-Analytics” (Fig. 1).

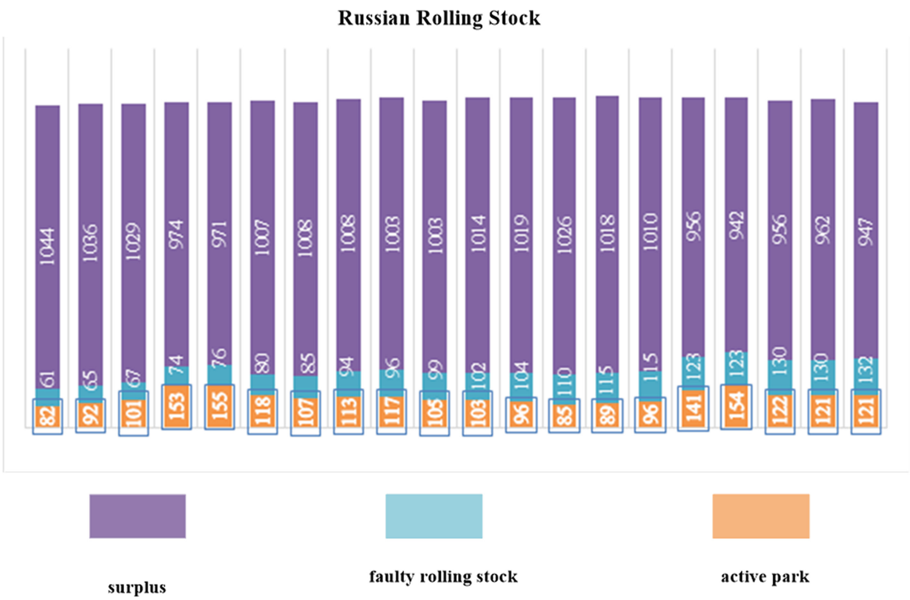

Fig. 1. Cars’ Surplus in Russian Railway

At the same time rail freight turnover of Russian Railways is increased [4, 5]. On the Fig. 2 there is data about contrast of rail freight turnover in Russia and in other countries.

2 Research Methods

Graphical and analytical methods, mathematical modeling, scientific methods of statistical data collection and processing, modern achievements in terms of general principles and methods of risk management are used to solve the problem of connected trains.

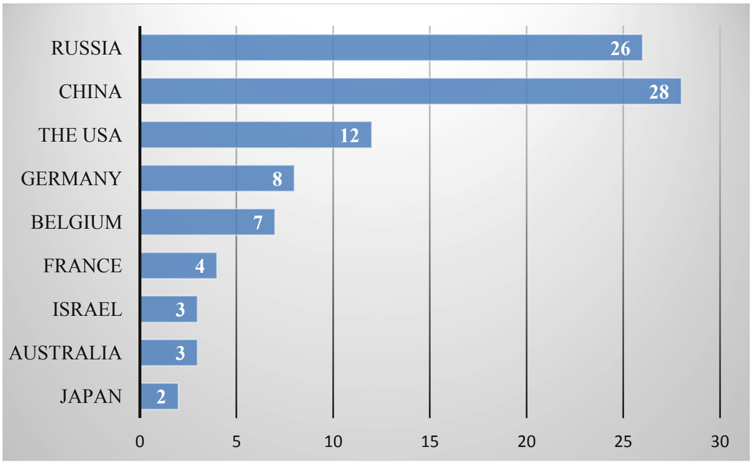

Fig. 2. Ratio of rail freight turnover (million t-km) to the length of the railway network (thousands of km) Source: official annual reports of Russian Railways; Jane World Railways 2017–2018 years

3 Main Part

Analysis of the work of the section of Khabarovsk II - Nahodka-Vostochnay on making up trains and passing of connected freight trains was carried out according to the data for 2017–2018. It consists of comparison of amount of connected trains of its marshaling for the section and transit, which come from the Trans Baikal Railway and the section of Arkhar - Khabarovsk II. It identifies of preferred directions of such trains, also positive and negative effects on such indicators as the average mass of the train and the section speed of traffic.

For 12 months of 2017, on the section of Khabarovsk II - Shkotovo (on the section of Nahodka-Vostochnaya connected trains do not follow due to the difficult grading of track) was missed:

- 1281 connected train in the even direction, including 26 trains accepted on Arkhar's joint from the Trans Baikal railroad and 39 trains from Arkhar's site - Khabarovsk II;
- 857 connected trains in the odd direction which for this site are trains of making up.

Even connected trains follow along the section of Khabarovsk II - Nahodka-Vostochnaya mainly to the stations Artyom-Primorsky III - 562 trains, Siberian - 212 trains, Lesozavodsk I - 100 trains and Angular - 65 trains. Odd connected trains follow mainly to Khor - 516 train stations, Vyazemskaya - 158 trains and Dormidontovka - 54 trains.

Main stations for making up of connected trains, their number, and average length in nominal cars, average weight and service speed are given in Table 1.

Table 1. Features of connected trains in 2017 and 2018

DS	Features of connected trains								Influence over connected trains on performance			
	Number of trains		Average weight, ton		Average length, car		Average service speed, km/h		Average weight of train, ton		Average service speed, km/h	
		2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
	y.e.	y.e.	y.e.	y.e.	y.e.	y.e.	y.e.	y.e.	y.e.	y.e.	y.e.	y.e.
Even direction												
Khabarovsk II	685	522	12077	12009	127	127	46.4	44.9	+28.1	+20.2	−0.2	−0.86
Krasnaya Rechka	–	37	–	11524	–	124	–	47.5	–	+1.1	–	−0.01
Khor	–	416	–	11433	–	123	–	41.7	–	+10.3	–	−0.2
Bikin	15	26	11813	11389	129	123	41.0	44.6	+0.2	+0.5	–	−0.01
Ruzhino	33	7	11305	11884	126	126	42.7	39.8	+0.5	+0.1	–	−0.01
Total Khabarovsk II – Artyom Primorskiy	273	160	12067	12055	126	126	43.8	42.2	+28.8	+33.2	−0.2	−1.09
Odd direction												
Artyom-Primorskiy III	180	689	4359	4084	159	148	40.3	41.1	+5.1	+20.3	–0.01	−0.44
Artyom-Primorskiy I	178	–	4334	–	158	–	35.4	–	+4.7	–	−0.02	–
Uglovaya	18	12	4409	4109	161	149	41.9	41.8	+0.5	+0.3	–	−0.01
Even direction												
Ruzhino	157	72	4334	4009	158	145	40.9	36.7	+2.3	+1.0	–0.02	−0.06
Filaretovka	–	52	–	4184	–	152	–	45.4	–	+0.7	–	−0.01
Total Shkotovo – Khabarovsk II	540	857	4309	4059	157	147	44.5	44.4	+12.7	+22.5	−0.05	−0.53
Total on direction	**1680**	**2073**	**7677**	**7346**	**143**	**138**	**42.8**	**42.6**	**+41.5**	**+55.7**	**−0.25**	**−1.62**
Total of general motion	**1797**	**3522**	**10222**	**8345**	**126**	**132**	**41.2**	**43.1**	**+43.1**	**+77.4**	**−0.26**	**−2.53**

According to the data from Table 1 bar graphs show the ratio of the number of connected trains making up at the station on the section Khabarovsk II - Nahodka-Vostochnaya for 2017 and 2018 (Figs. 3 and 4).

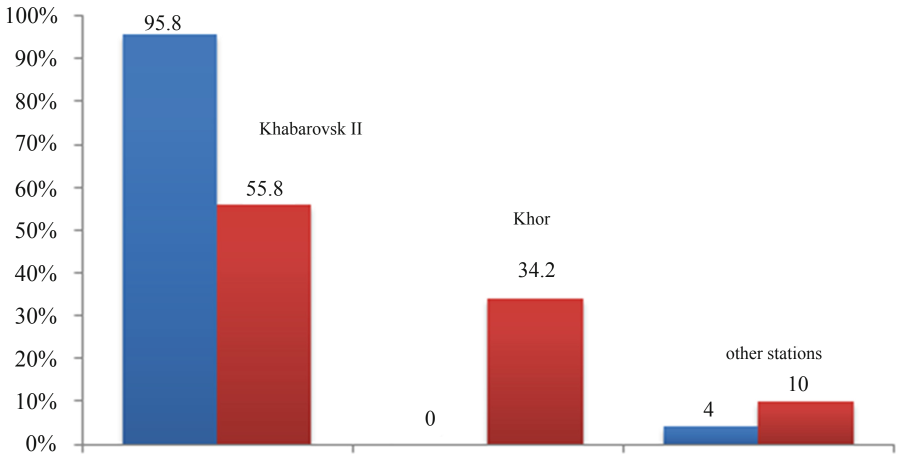

Fig. 3. Percent ratio of number of even connected trains according to railway yard

Thus, in 2018, at the station of Khabarovsk II the volume of work on making up even connected trains was reduced on 40%. And the making up of trains was transferred mainly to the station Khor. At the station Artyom-Primorsky I the making up of odd trains was excluded and execution of this operation was transferred to Artyom-Primorsky III station.

In 2019 the amount of connected trains has been increased on the section of Khabarovsk II - Nahodka-Vostochnaya on 76 trains in the even direction and on 317 trains in the odd direction. From Khabarovsk II to Shkotovo 1.216 connected trains were passed, which resulted in an increase in the average mass of train by 33.2 tons, but decreased in the service speed by 1.09 km/h. In the odd direction 857 trains were passed; which caused an increase in the average mass by 22.5 tons and a decrease in the service speed by 0.53 km/h.

In the main motion 3.522 connected trains were passed, which increased the average mass of the train on the Far East Railway by 77.4 tons (in electric traction by 125.6 tons), but reduced of the service speed by 2.53 km/h (in electric traction by 0.58 km/h). The economic effect of passing connected trains in the main motion is 18.41 million rubles.

Make connected trains' way is used to increase the moving traffic by rail of individual sections as well as improve the technical and economic performances of their operation and can be considered as a temporary and permanent action [6].

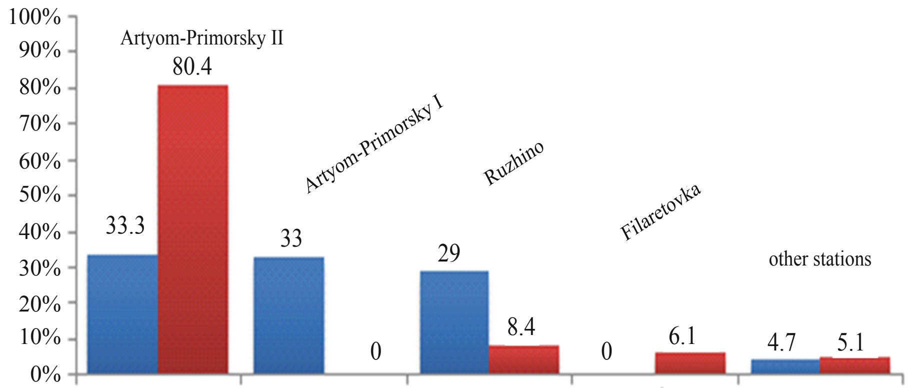

Fig. 4. Percent ratio of number of odd connected trains according to railway yard

4 Experimental Result

In order to ensure the movement of connected trains, the following conditions are required:

1. long passing sidings (double norm) on the part of separate way station;
2. special interposition of the additional main track on the running line to the marshaling and classification yard (it allows to connect and disconnect the trains without delays of other trains).
3. insure of required train-to-train interval by catenary system.

An analysis of development of the track shows that some of them have long passing sidings. They allow to use passing connected trains. But at all stations the connection of trains will take place for the station border (Table 2) [7].

Table 2. Number of stations for connection of trains

Number of stations	Number of passing sidings	Capacity of the longest track in nominal cars
1	6 - 2	63
1	7 - 4	66
1	6 - 2	99
1	8 - 3	95
1	5 - 3	61
1	8 - 3	108
2	1 - 1	69
1	5 - 2	66

As we can see in the Table 2 stations have no passing sidings with double length for connected trains. Therefore, their connection will be carried out fragmentary when the train will be passing to other track or abroad of the station.

By analyzing approaches to stations, it can be seen that there are no special interposition of an additional main track on the running line.

As for the third condition a train-to-train distance calculation must be performed to justify its execution.

In order to ensure the normal operation of the catenary system, train-to-train distance is calculated during the movement of connected trains by dividing the normal distance by the running speed, minutes:

$$I = 0.06 \cdot \frac{l'_{bl} + l''_{bl} + l'''_{bl} + l_n}{v_x}. \quad (1)$$

Due to the fact that when passing connected trains there is a large load on the network. It is necessary to take into account the train-to-train distance on the way fed by the feeder. Its calculation is depending on the state of the traction power supply system for the established weight standards of freight trains according to established technique [8–10].

Thus, for a double-track section of the train-to-train distance ***jf*** on the track fed by feeder **f**, the min is determined by dividing the full time of train travel of the set mass by the number of trains simultaneously powered by this feeder.

$$j_f = t_{xf}/n_{of}, \quad (2)$$

Each feeder $\boldsymbol{f}$ can simultaneously power $\boldsymbol{n_{of}}$ of trains:

$$n_{of} = n_o \cdot C_f. \tag{3}$$

Several trains can be at the same time in a zone of power supply of substation proceeding from the power of each of estimated elements of power equipment for an alternating current system of 25 kV:

$$n_o = \frac{1.1 \cdot I_{apm}}{2 \cdot I_{pl}^{nb} + 0.65 \cdot I_{pl}^{nm}}, \tag{4}$$

where I_{pl}^{nb} I_{pl}^{nm}- current of substation's branch according to the greatest and smallest charging, A;

$\boldsymbol{F_{пл}}$ - is the number of feeders feeding the substation's branch;
$\boldsymbol{I_{aptn}}$ - effective current of traction substation, A;
$\boldsymbol{\alpha_{nf}}$ - coefficient depending on number of ways: for double track$\boldsymbol{\alpha_{nf}}$ = 0.9;
$\boldsymbol{C_f}$ - a factor which takes into account the dimensions of movement along the tracks fed by the feeders of substation;
$\boldsymbol{N_f}$ - the number of trains per day on the track fed by feeder $\boldsymbol{f}$.

At the same time calculating the interval, the variants of passing train along the section shown in the Fig. 5. It shows a pass of single trains of set mass, a pass four of single trains to the station of their combination and further package, and a connection of two trains and a pass of them before single. This different arrangement affects on calculation of the train-to-train distance.

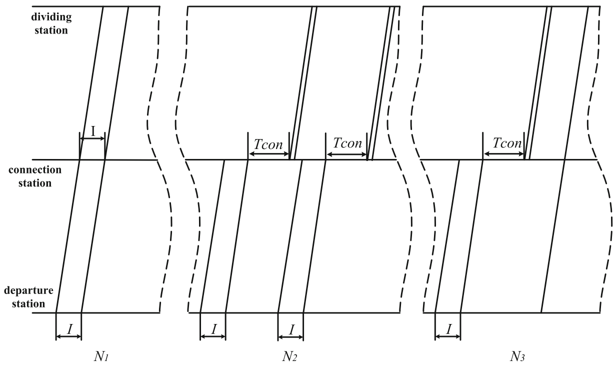

Fig. 5. Variants of train handling

Values of train-to-train distance during normal mode of operation and conditions of catenary system and mass of train are given in Table 3:

Table 3. Minimum calculation of train-to-train distance (minutes)

Mass of trains	Calculation mode of distance	
	Normal	Constrained
6000-6300-6000 t	10	14
3200–3200 t	12	15
6300-7100-6300 t	10	15
6300-8300-6300 t	11	16
6300-12600-6300 t	18	20
6300-9100-6300 t	18	20
12600-6300-12600 t	20	25

We can see from the table, that the state of the catenary system and increasing of mass of train increase the train-to-train distance.

So, the analysis of conditions shows that the formation and passing of connected trains is connected with a number of difficulties at the operating domain of Far Eastern Railways. All three requirements are not fully met.

Combination and passing of connected trains, according to the regulatory documents, is allowed if there is a serviceable train radio communication between the Train Dispatcher and the driver of the head locomotive, as well as between it and other drivers of the connected train. While loaded and unloaded trains connect the first one is loaded. Such trains handling should be carried out, as a rule, on the main tracks of field location.

The analysis of basic conditions revealed the main factors which influence on the train-handling capacity of passing of connected trains [11–13] (Fig. 6).

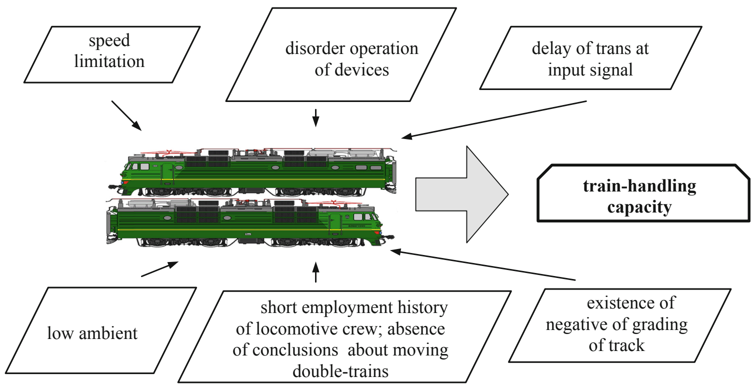

Fig. 6. Main factors which influence on the train-handling capacity of passing of connected trains

To check the technical capabilities of the stations, the train-handling capacity of reception and departure sidings and tracks is calculated.

The total time of track occupation during handling operations with freight trains, depending on the length and specific features of tracks, is determined by formula, minutes:

$$T = \left(n'_{tr}t^{tr}_{zan} + n'_{r}t^{r}_{zan} + n'_{f}t^{f}_{zan} + n'_{j}t_{zanj}\right) \cdot (1 + \rho), \tag{5}$$

Where:

$\boldsymbol{n'_{tr}}$ - the number of transit trains passing through the yard from the approach, trains;
$\mathbf{n'_p}$ - the number of divisible trains of all categories, trains;
$\boldsymbol{n'_f}$ - the number of trains of all categories sent from the yard (except pick-up and clean-up trains with operation on the section), trains;
$\boldsymbol{t^{tr}_{zan}}, \boldsymbol{t^{r}_{zan}}, \boldsymbol{t^{f}_{zan}}$ - time of technological operations on-track with trains of corresponding categories and different accessibilities (outlet ends), minutes;
$\boldsymbol{n'j}$ - the number of angular flow transmissions or local cars and trains for breaking up in receiving yard, trains;
$\boldsymbol{t_{zan}}$ - time of occupation of track by train set according to technological process, minutes;
P - required factor for passing sidings of non-rail-way junctions of double-track p = 0.2.

Coefficient of effective using of tracks is determined by formula:

$$K = \frac{T}{\alpha \cdot \beta \cdot 1440 \cdot m - \sum T^{pr}_{post}}, \tag{6}$$

Where:

$\boldsymbol{\alpha}$ - is a factor taking into account the influence on the use of passenger and pick-up trains, $\alpha = 0.6$;
$\boldsymbol{\beta}$ - coefficient shows influence on passenger and pick-up trains receiving and departure yards, $\boldsymbol{\beta} = 1$;
m - number of ways;
$\sum \boldsymbol{T^{pr}_{post}}$ - time of occupation of tracks by freight trains, performance within a day of other constant operations, which are not changing in proportion to the amount of the train traffic, and works on routine maintenance, planned types of repairing and snow removal.

The results of calculations you see at the Table 4.

Table 4. Calculation of time of occupation of tracks

Stations	Directions	Number of RDS	t_{zan}^{tr}	t_{zan}^{soed}	$\sum(n_i \cdot t_i)$	T, minutes	K
Arkhar	even	6	15	40	1175	1410	0.28
Obluchie	even	6	15	40	1175	1410	0.28
	odd	8	15	40	1120	1344	0.20
Bira	even	7	15	40	1175	1410	0.24
	odd	5	15	40	1120	1344	0.32
Birobidzhan	odd	5	15	40	1120	1344	0.32
In	odd	1	15	40	1120	1344	1.70
Khabarovsk II	odd	8	82	100	5292	6350.4	0.93

The table shows that at the stations where the connection and dividing takes place there are enough reception and departure sidings. In addition, the percentage of transmitted connected trains affects the amount of throughput. The graph is shown in the Fig. 7.

With a small proportion of passes of connected trains, it does not matter how many trains follow. With its increase (more than 0.3), the mass of connected trains significantly affects the amount of required capacity and, therefore, the reserve.

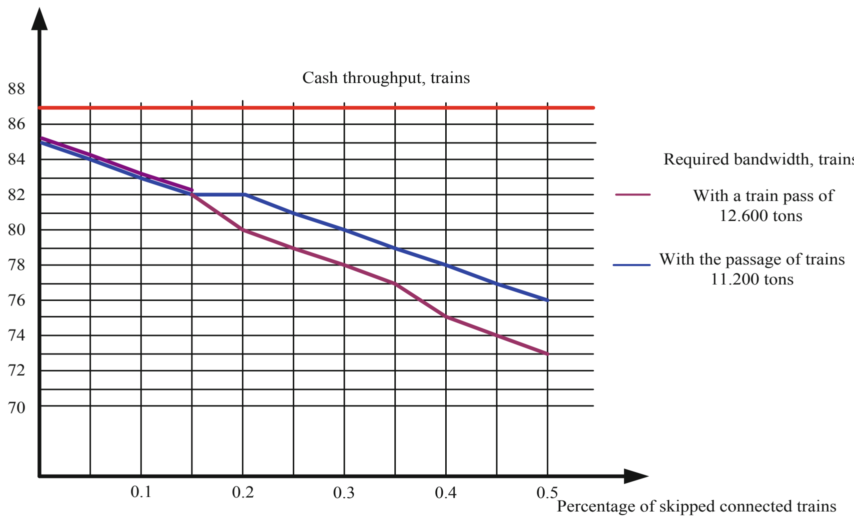

Fig. 7. The graph of the capacity throughput on the proportion of connected trains passing through the section

5 Summary

The problem of application of passing connected trains is not solved and removal of trains is present. Therefore, the search for an optimal way to organize train traffic and use the advanced achievements of scientific and technological progress remains relevant.

On the sections that have exhausted the capacity, it is advisable to organize the driving of connected trains, otherwise, to master the increasing size of the movement, it is necessary to strengthen the technical equipment or build a new line. At the maximum intensity of train traffic on the section, driving connected trains slightly reduces the available capacity, but significantly increases the carrying capacity. Due to the increase in carrying capacity the required amount of traffic grow. So if the train weight is 6300 tons every next 10 million tons of cargo per year will require additionally 7 trains per day and 5 trains per day if the train weight is 7100 tons [14]. The degree of change in throughput and carrying capacity depends on the number of trains combined and the share of connected trains in total traffic. In conditions of optimal use of capacity, the feasibility of regular driving of connected trains should be justified by technical and economic calculations. In cases of underutilization of capacity, the organization of connected trains can only be recommended as a temporary measure during the “windows” or temporary increase in traffic.

The application of the pass of connected trains usually does not solve the problem and the removal of trains is present. Therefore, the search for the optimal way to organize the movement of trains and the use of advanced scientific and technological progress remains relevant [15].

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Reliability of Multimodal Export Transportation of Metallurgical Products

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Abstract. The export supplies of metal products represent one of the traditional areas of specialization of Russia in the international trade relations. The feature of such deliveries is the dependence of the contract price on the chosen method of transportation of the delivered products to foreign partners. An important aspect is to ensure the reliability of transportation. The authors of the article proposed a new criterion for the total costs presented, allowing to take into account the direct costs of transportation and losses due to a decrease in the turnover of cash with an increase in delivery time. A mathematical model for evaluating the reliability of transportation is presented and calculations are performed. Attention is paid to the construction of the information platform for the analysis of transport and technological schemes and to ensure the interaction of transportation participants. The formation of a single information space and the provision of semantic compatibility in data exchange based on the ontological approach are recommended. The approach proposed by the authors of the article is used to compare the three main competing options for transporting metal products from Russia to Germany. It has been established that multimodal transportation using rail, sea and road transport is most preferable.

Keywords: Reliability of transportation · Multimodal transportation · Hardware products · International trade · Cost optimization

1 Introduction

The characteristic feature of economically developed countries is the orientation not only on the domestic, but also on the foreign market. This fully applies to Russia, where the opportunities for economic growth due to increased domestic consumption are close to saturation. At the first stage, those sectors of the economy that have strong traditions in the production of competitive goods, one of which is the products of metallurgical enterprises, have good prospects for expanding foreign trade sales. Metals and products from them, according to the Federal Customs Service of Russia, in the

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structure of Russia's exports in 2017 and 2018 occupied about 10%. To a certain extent, it can be considered that the supply of metallurgical products to foreign markets is Russia's specialization in the international division of labor.

Of all types of metal products (hardware) produced in Russia, the most popular among foreign consumers is steel wire, which accounts for 80% of the export of this segment of metal products. Fasteners, mesh, nails, welding consumables and other products of technological processes are much less in demand, since their production, as a rule, is established in the territorial proximity to large consumers. Germany remains one of the leading importers of wire among the countries of the European Union. The main consumers of this type of metal products are located in the cities of Hanover, Dormagen, Frankfurt an der Oder and Hemer.

The specific of the production of hardware and its delivery to consumers is as follows [1]:

- the need to quickly take into account the market needs in terms of volume and product range and the ability of the supplier to organize the execution of a specific order within the required range within the required time frame;
- the prevalence of one-time bids over regular deliveries;
- the low degree of concentration of consumers of products;
- the low capacity of cargo flows, the high proportion of small-scale shipments and the variety of conditions for the supply of products to consumers;
- the 1.5–2 times excess of time for delivery of products to remote consumers over the duration of production of the ordered consignment of goods.

In this regard, in most cases, the effectiveness of the foreign trade export transactions depends on their logistics support and reliability [2, 3]. The transportation of large volumes of goods over considerable distances can increase the transaction price significantly, therefore [4, 5], the chosen transport and technological transportation scheme can affect the competitiveness of products in foreign markets [6–8].

If there is a common land border, the supply of metals and metal products from Russia to the countries of the European Union is carried out either by road or rail, or using the multimodal transportation scheme, when products are transported by road to the railway station. If there is no common land border, and a country importing Russian metallurgical products has access to the sea, then the multimodal transportation using land and sea transport is realized.

2 Methods

According to M. Porter, the following basic strategic approaches are distinguished:

- the cost-benefit strategy, where the company seeks to secure the lowest costs;
- the differentiation strategy in which the company seeks to offer a unique product or service on the market that provides a competitive advantage;
- the focusing strategy, within which the company concentrates on any market segment or consumer groups.

In this regard, in modern conditions it is necessary to provide a clear understanding of customer needs in order to provide a unique market offer, as well as to be able to flexibly adapt internal business processes to form a value proposition that is in demand on the market (Fig. 1).

At the same time, the development of information technologies made it possible for the consumers of logistics services using various digital platforms to have a significant impact on reducing transportation prices due to network effects [9]. In this regard, the role of supporting and developing long-term and sustainable relationships with the customers, for which, in the formation of the transport and logistics strategy, it is also necessary to determine the conditions of delivery, the types of transport used, select logistics intermediaries, assess possible risks, threats and opportunities [10].

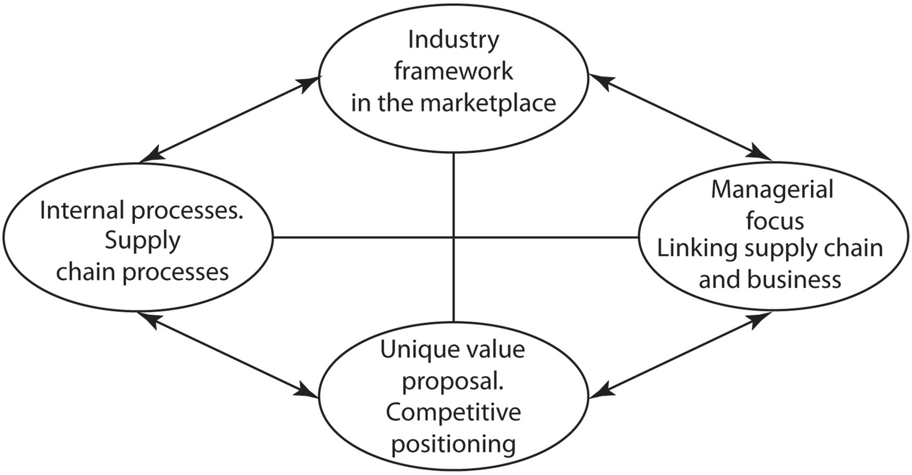

Fig. 1. Four forces of the M. Porter model

The specificity of the problem determines the method of its solution, which consists in creating a mathematical model and calculating the total cost for various options of transport and technological schemes (Fig. 2). According to the results of the calculation, the option with the lowest total costs taken is selected.

The mathematical model of the total costs is given by:

$$З_{пр.} = (C + \tau + \delta) \cdot (1 + \gamma)^{\frac{T}{365}} \rightarrow min, \quad (1)$$

where:

C - the cost of a ton of supplied metal products, rubles/t;
τ - costs of transportation and related technological operations (transportation, loading, unloading and temporary storage at terminals, customs clearance, etc.), rubles/t;
δ - the cost of services of transport and other enterprises, including insurance of emerging risks, rubles/t;

γ - the annual interest rate on capital;
T - the duration of transportation, including the time spent on terminal processing (loading, unloading and other operations) at the supplier, consumer and terminals along the route and the time spent on moving metal products between the terminals, days.

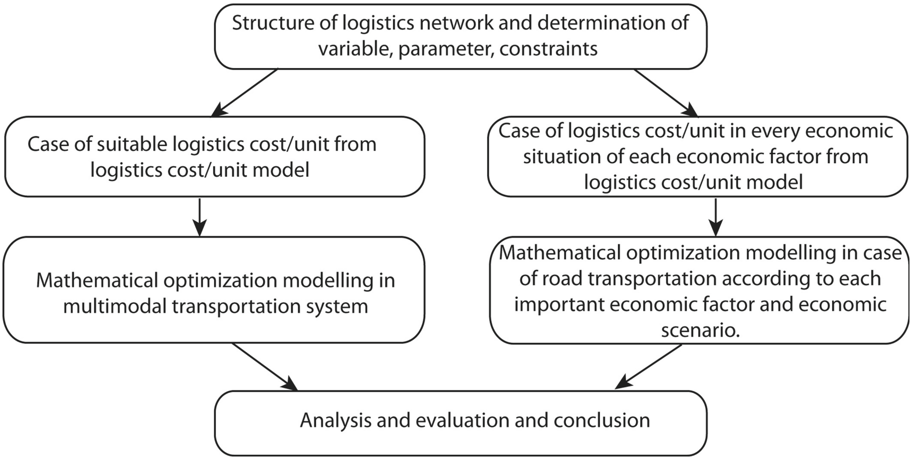

Fig. 2. Structure of mathematical optimization model

If the technological operations are carried out by the supplier or the recipient on their own, then the costs of their implementation are not separately taken into account in the amount of τ and are not included in separate items in the price of the contract. At the same time, there may be situations when the cost of the supplied metal products C depends on whether the supplier carries out technological operations agreed with the buyer when sending the products.

Risk management in the delivery of goods provides for losses compensation in the event of adverse events. The generally accepted method is insurance. It is generally accepted that insurance not only allows you to compensate for losses that occur, but also helps to increase the reliability of transportation by increasing the technological discipline of transportation participants and monitoring compliance with all requirements for transportation by an independent insurance company.

Given the need to ensure the reliability of transportation, the cost of services of transport, freight forwarding and logistics enterprises must take into account the costs of insurance of emerging risks. The amount of costs for these purposes is determined by the contract with the insurance company. Since the insurance market in this area is relatively stable, the costs of risk compensation usually depend on the price of the supply contract, which includes the cost of the supplied metal products and payment for services of companies involved in the delivery of goods and performing transport and related technological operations.

Reliability management is the implementation of measures to ensure the achievement and maintenance of the supply agreement of the economically sound reliability level agreed upon by the parties. Accordingly, the reliability of the transport system should be understood as its ability to fulfill the safety requirements agreed upon between the customer and the transport service provider, the quantity and condition of the transported cargo, delivery time, and the ability to maintain and restore the specified level of transport support.

The concept of failure is fundamental to the formation of a theory of reliability of cargo transportation systems. Failure may be complete or partial. Based on the definition of reliability, a refusal should mean the loss or damage of the goods during the delivery process, as well as the failure to meet the agreed delivery time for the goods to the recipient. If the goods are not delivered to the recipient, then the refusal will be complete. If a part of the transported cargo is damaged (lost) or is late in relation to the agree delivery time, then the refusal is partial.

The mathematical model for assessing the reliability of transportation according to the selected parameters (cargo safety or compliance with the terms of transportation) will have the form:

$$P(t) = \frac{N_0 - n(t)}{N_0} = 1 - \frac{n(t)}{N_0}, \tag{2}$$

where:

N_0 - the number of transport process implementations completed in time t;
n(t) - the number of implementations of the transport process during time t that have deviations from the agreed requirements for the quantity and/or condition of the cargo being transported and/or violation of the delivery time.

At the stage of concluding the contract, the parties agree on an a priori (planned) level of reliability, which they accept as economically viable. Based on the results of the delivery, an a posteriori (actual) level of reliability is calculated, which is the basis for presenting penalties and adjusting the delivery fee, if agreed upon by the delivery agreement.

The calculation of the reliability of transportation according to the selected parameters (the quantity and/or condition of the transported cargo and/or violation of the delivery time) for the sequential execution of technological operations is determined by the formula

$$P = \prod_{i=1}^{n} P_i, \tag{3}$$

where:

Pi – reliability of i-the technological transportation operation.

Reliability of delivery decreases with an increase in the number of participants in the supply chain, since the likelihood of damage or loss of cargo and violation of the agreed terms when transferring goods from one delivery participant to another increases.

From the analysis of literary sources, various algorithms for estimating the costs of maintaining the reliability of the logistics system are known, the essence of which is to divide the process into separate operations, calculate the costs of each operation, calculate the probability of failure for each operation, calculate the costs caused by failure for each operation [13–15].

Each operation, the processing of transportation orders, including the formation of a delivery schedule and forecasting, the release of goods from the warehouse, transportation, delivery to the warehouse to the consumer is made out of various documents that represent an information stream. For multimodal transportation to ensure cost and reliability calculations, the prerequisite is the creation of a single information space that allows the use of data on all operations [16, 17]. An important task is to ensure semantic compatibility in the exchange of data between all participants (Fig. 3). The data should have a common structure for all customers and providers of the logistics process.

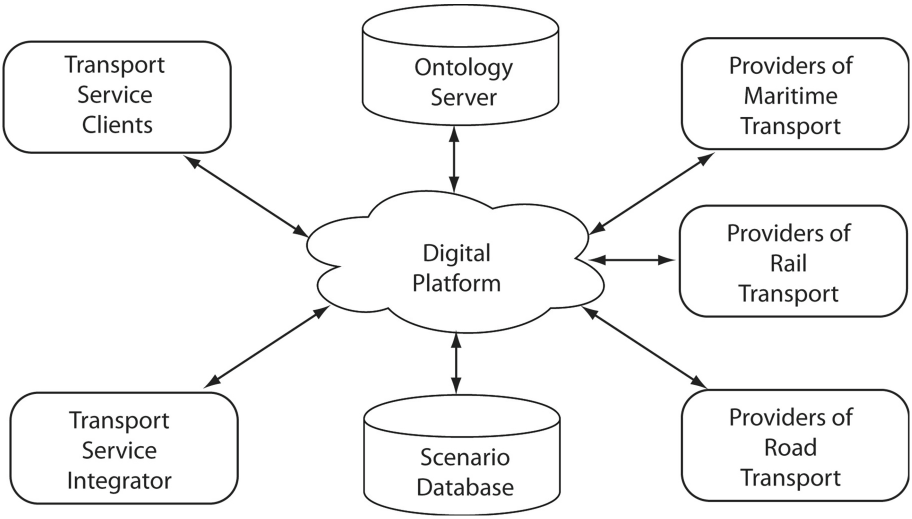

Fig. 3. Digital multimodal transport platform

3 Results

The described method for solving the problem of choosing the method of transportation of metal products was implemented using the example of one of the largest hardware and metallurgical enterprises in the South Urals. The total costs and the duration of the transportation of steel wire by land to countries that share a land border with Russia are calculated.

The important feature of such deliveries is the possibility of their implementation by the supplier own forces, without the participation of freight forwarding and logistics enterprises, since the supplier has its own motor vehicles and rail transport, which carries out wagon and container shipment.

There are some foreign consumers of Russian metal products in the countries that have seaports and do not have a common border with Russia. In this case, the supply of metal products can be carried out by several options of transport-technological schemes and the task of choosing the preferred option is complicated. A solution to this problem has been completed using the example of the supply of steel wire to Germany (Hanover). The direct supply options for road transport through transit countries and multimodal transportation successively by rail and road, as well as through the seaports of Russia and Germany, were examined (Table 1).

Table 1. Comparison of the duration of transportation and cost costs of competing options for transporting steel wire to Germany from Russia

Variant of steel wire deliveries on the route Magnitogorsk (Russia) – Gannover (Germany)	Duration of transportation (*T*), day	Increased transportation time in comparison with the fastest option, day	Relative value of the total cost of transportation (τ), %	Cost of transportation compared to the cheapest option, %
1. Multimodal container rail-road transportation	21.9	+10.9	100.0	+28.9
2. Unimodal direct transportation by road train as part of a truck tractor and semi-trailer	11.0	–	82.9	+11.8
3. Multimodal container transportation using rail, sea and road transport	34.0	+23.0	71.1	–

For two options (with minimal costs and the shortest duration), the structure of time and money costs for transportation was determined taking into account all stages of transportation (Table 2).

The calculation of the reliability of steel wire transportation to Germany from Russia according to the considered options is carried out according to the formula (3). Under the condition of equal reliability of performing homogeneous technological operations of transportation by logistics enterprises, the value of P is determined by the number of individual technological operations in the transport-technological scheme of transportation n. The number of terminals and sections along the cargo movement route is higher for multimodal container transportation using rail and sea transport than for transportation by road.

In the calculations, terminal operations are assumed to be 0.97, and operations related to the movement of goods - 0.95. Taking such initial data, the calculation of the reliability of transportation of steel wire will take the form:

– transportation by road train as part of a truck tractor and semi-trailer:

$$P = 0.98^4 \cdot 0.95^3 = 0.79;$$

– multimodal container transportation using rail and sea transport and the delivery of goods from the seaport to the consumer by road:

$$P = 0.98^7 \cdot 0.95^4 = 0.71.$$

Based on the calculation results, it can be concluded that the option of multimodal container transportation using rail and sea transport is less reliable, since it includes a larger number of technological operations and, accordingly, a larger number of logistics intermediaries. The calculated value of the reliability of transportation is explained not so much by the probability of damage or loss of cargo along the route, but by the risks of delays in delivery to the consumer.

Table 2. Structure of the duration of transportation and cost costs of options for transporting steel wire to Germany from Russia

Stages of the delivery process	Duration of stages of transportation (T), hour	The share of the cost of the stage to the total cost of transportation (τ), %
Road train transportation as part of a truck tractor and semi-trailer		
1. Loading at the supplier and implementation of export customs procedures	24.0	1.4
2. Transportation to the border between Russia and Belarus	101.0	59.8
3. Customs operations at the international multilateral road checkpoint Roslavl - Zvenka	3.5	
4 Transportation to the border between Belarus and Poland	37.0	34.2
5. Customs operations at the checkpoint Brest - Tiraspol	3.5	
6. Transportation to Hanover (Germany)	90.0	4.6
7. Acceptance of cargo and its processing at the terminal of the recipient	4.0	–
TOTAL:	263.0	100.0

(*continued*)

Table 2. (*continued*)

Stages of the delivery process	Duration of stages of transportation (T), hour	The share of the cost of the stage to the total cost of transportation (τ), %
Multimodal container transportation using rail and sea transport and the delivery of goods from the seaport to the consumer by road		
1. Movement of the container to the recipient for subsequent loading	–	9.7
2. Waiting for the container in loaded and empty condition at the city freight railway *station*	240.0	0.5
3. Delivery of the container to the place of loading, placement of cargo in the container, removal from the place of loading	3.0	1.3
4. Storage of a loaded container in a temporary storage warehouse, implementation of export customs procedures	72.0	2.3
5. Loading operations for the placement of the container on the railway platform	–	0.9
6. Transportation to the port of departure to Avtovo railway station	240.0	23.3
7. Container handling at the terminal at the port of departure (reception from the railway, accommodation on board, paperwork)	96.0	7.9
8. Freight of a sea vessel for transporting a container along the route St. Petersburg - Hamburg	135.0	14.7
9. Container handling at the terminal at the port of destination (reception from the railway, accommodation on board, paperwork)	24.0	7.3
10. Road transport to Hanover	6.0	32.1
11. Processing of the container at the terminal of the recipient	–	–
TOTAL:	816.0	100.0

4 Discussion and Conclusion

If there is a common land border between Russia and the importing country of metal products and the distance of transportation to the recipient of metal products is less than 350 km, it is more economical to use for direct delivery of automobile transport. If the transportation distance is longer, then railway transport should be used, arranging transportation in containers or wagons. At the same time, the difference in the quoted total costs for carriage by road when compared with rail is no more than 10%, while delivery times can vary by 2 times.

In the absence of a common border between the importing country of metal products and Russia and the access of the importing country to the sea, three main options for organizing transportation compete:

1. Unimodal direct transportation by road train as part of a truck tractor and semi-trailer.
2. Multimodal container rail-road transportation.
3. Multimodal container transportation using rail, sea and road transport.

The calculations were carried out on the example of transportation of metal products along the route Magnitogorsk (Russia) - Hanover (Germany).

The fastest is direct road transportation, the duration of which is 11 days, which is 2 times faster than multimodal container rail-road transportation and 3 times faster than multimodal container rail-sea transportation with the delivery of metal products to the recipient from the seaport by road.

In all cases, the delivery of metal products is more expensive than the selling price of the steel wire itself. The most economical is transportation with the inclusion in the supply chain of maritime transport. Based on a standard batch of steel products weighing 20 tons, this option is one third cheaper than multimodal container rail and road transportation, and direct road transportation is not less than 10%.

The option of multimodal container transportation using rail and sea transport is less reliable, but is acceptable for this type of supply.

The criterion of the total reduced costs proposed by the authors of the article takes into account not only direct costs, but also losses due to an increase in the terms of the turnover of funds invested in the purchase of metal products. The terms of delivery of the goods and the annual interest rate on the associated capital are entered as elements in the formula (1).

Based on the fact that the price of the product itself is relatively low, it is inexpedient to strive to accelerate delivery by increasing its cost. The most rational should be recognized as the option of multimodal container rail-sea transportation with the delivery of metal products to the recipient from the seaport by road, ensuring the minimum transportation cost, as well as acceptable delivery times and reliability level.

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The Methodology of Calculating Route Network of Long-Distance Passenger Trains in the Conditions of Fluctuating Passenger Flows

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Abstract. The article is devoted to the definition of the route network of long-distance passenger trains. The problem of calculating the route network of passenger trains is usually solved as a static problem, that is, the calculation does not take into account the fluctuations of passenger traffic in a given period of time. This leads either to an increase in the mileage of free seats, or to a shortage of them, since passenger traffic is not evenly distributed on the days of the week. If the task of calculating the route network of passenger trains is formulated as dynamic, that is, to model it taking into account the fluctuations of passenger traffic in time and take into account the uneven passenger traffic in the forward and reverse directions, this will lead to increased efficiency of the use of rolling stock. In this paper, the method of calculating the route network of long-distance passenger trains with fluctuations in passenger traffic over time is considered.

Keywords: Route network of long-distance passenger trains · Fluctuations of passenger traffic · Uneven passenger traffic · Dynamic model of account

1 Introduction

The structure of passenger service planning in railway transport is divided as follows:

- long-term planning - is a determination of the need for vehicles, transportation infrastructure, and the staff for the future (from 2–5 to 5–7 years) based on a long-term forecast of passenger flows in order to ensure the possibility of implementing the following planning and management stages in a high-quality and cost-effective manner;
- annual planning - is the development (adjustment) of the plan for the formation of passenger trains, the calculation of their circulation patterns, frequency and composition, as well as the determination of the need for vehicles, technical devices, equipment and materials, the staff for a new schedule based on the analysis and

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forecast of passenger flows, a comprehensive analysis of quantitative and qualitative indicators of the current schedule;

- operational planning - is the determination of the daily need for vehicles, equipment and materials, the staff for the coming short-term period (from 1 to 60 days) based on an operational forecast of passenger flows and available technical support in order to achieve maximum efficiency and quality of passenger transportation.

To date, scientists have proposed different approaches to solving the problems of planning long-distance passenger transport by rail. Existing methods aimed at optimizing the number and destination of passenger trains for a certain period of time, taking into account the determination of the number of train stops depending on the demand of passengers [1–4] allow to minimize the mileage of free seats, as well as to find the optimal travel time for each passenger. The number of stops in passenger trains affects not only the travel time, but also the energy costs. Therefore, the optimization of the number of stops of passenger trains on the route directly affects the efficiency of the use of rolling stock. To date, combined methods for the calculation of the number and destination of passenger and freight trains are used [5, 6]. These models allow us to determine the impact of passenger train delays at stops on the cost of transportation and the impact on passenger demand, as well as to determine the time of delays, at which passenger demand will not be reduced and the number of freight trains will remain. Special attention is paid to the impact of passenger train delays at stops. Thus, in [7, 8] the results of studies on the impact of delays of passenger trains at stops in big transport hubs on the schedule of trains are presented. Studies were conducted on the concentration of passengers on platforms when boarding a train [7]. The influence of this factor on delays of passenger trains, comfort of passengers, efficiency of use of rolling stock, safety of finding of passengers on platforms is defined. The studies [7, 8] also determine the minimum delay time, which does not lead to a failure of the schedule of passenger trains, as well as to calculate the probabilities of different delay times from the number of passengers boarding, disembarking and being in the train.

When calculating the route network of passenger trains, an important issue is the convenience of the schedule for passengers. When developing a passenger-oriented train schedule in the works [9–11], the elasticity of passenger demand is taken into account. The elasticity of demand of passengers should be based on the services provided: schemes of trains, types of cars provided, the intervals between the arrival and departure of trains, the regularity of the schedule and the minimum travel time for the passenger. The development of a passenger-oriented schedule is a complex mathematical task with many factors influencing the result. To solve it in [12] the algorithm of the theory of complex networks was applied. This methodical creates a complex network with the characteristics of a small world. The main criteria for optimizing the route network are the degree of passenger comfort, travel time, the degree of congestion of stations and the efficiency of the use of rolling stock. The model is used in operational planning.

To improve the efficiency of the use of rolling stock and improve the convenience of the schedule, the method of unequal sizes of traffic trains in the forward and reverse destinations is also used. In works [13, 14] the methods directed on increase of efficiency of use of a rolling stock at the maximum satisfaction of passengers are presented. Analysis of calculations in [13] showed that the schedule with unequal sizes of trains in forward and reverse directions better takes into account the demand of passengers and leads to more efficient use of rolling stock.

An important issue of annual planning when calculating the route network of passenger trains is the calculation period (T_{calc}). The calculation period of the route network of passenger trains is the period of time for which the formation plan is calculated: day, week, month, etc. To date, there is still no definite answer as to what period to take when calculating the route network, and therefore for what period to consider the initial data, that is, passenger flows: for the month of maximum traffic, to determine the maximum monthly sizes of train movements, and then to determine for each train the frequency of circulation, or vice versa for a month of minimum traffic, in order to determine the core of the schedule, and in the operational planning to determine the need for additional trains, or take the average daily passenger traffic, in order to avoid such outcomes as 1 train per month, etc. This question arises only because the task of calculating the route network of passenger trains is to be solved traditionally as a static problem, that is, the calculation does not take into account fluctuations in passenger flows in a given period of time. If the task of calculating the route network is formulated as dynamic, that is, it is modeled taking into account the fluctuation of passenger flows over time, then there is no need to determine the calculation period (T_{calc}). The paper [15] presents a model for calculating the number and destination of passenger trains with changing passenger demand over time. Not only the plan of formation, but also the scheme of circulation of passenger trains is considered, the required fleet of rolling stock, capacity of lines is taken into account.

If we summarize all of the above, it is necessary to calculate the route network of passenger trains in such a way that the model takes into account:

– meeting the demand of passengers for transportation;
– change of passenger demand in time (by days of the week, months, seasons);
– uneven passenger demand in forward and reverse directions;
– minimizing the mileage of free seats;
– limitation of the required rolling stock fleet;
– restrictions on the capacity of the infrastructure.

2 Method

To solve this problem, it is necessary to understand whether it is possible to determine passenger flows for calculation with a sufficient degree of reliability. If this problem is used to solve operational problems, the determination of daily passenger flows is possible with a high degree of probability, but if this problem is solved for annual planning, then the determination of daily passenger flows is a very difficult task. The analysis of change passenger traffic in time proved that passenger flows have a daily unevenness by the days of the week, which has its own dynamics and regularity for each region. This makes it possible to determine the coefficients of deviation from the average daily passenger flow for each day of the week. Therefore, the dynamic task of calculating the route network of passenger trains can be used both in operational planning and in the annual one. At the same time, it is important that operational planning takes into account only the daily unevenness of the passenger flow structure, and in annual planning seasonal (monthly) unevenness should also be taken into account.

In connection with the foregoing, the model for calculating the route network of passenger trains should take into account fluctuations in passenger traffic by day of the week, as well as the unevenness of passenger traffic in the forward and reverse directions.

The methodology for calculating the route network of passenger trains with fluctuations in passenger flow over time can be formulated as a linear programming problem with the following condition

- condition for the full coverage of predetermined passenger flows by train destinations:

$$\delta_{ik} a_j x_{jt} \geq \sum\nolimits_{i=1}^{I} \delta_{ijk} y_{ijt}; \quad \forall j; \forall k; \forall t; \tag{1}$$

- condition of direct passenger communication - this condition allows to exclude the possibility of passenger chances along the route when simulating the distribution of passenger flows by train destinations:

$$P_{it} = \sum\nolimits_{j=1}^{J} \delta_{ij} y_{ijt}; \quad \forall i; \forall t; \tag{2}$$

- the condition of stationarity, that is, the condition of equality of the number of arriving and departing trains with the same train composition for each station for the considered period of time:

$$\sum\nolimits_{t=1}^{T} \sum\nolimits_{j=1}^{J} \delta_{jsg}^{dep} x_{jt} = \sum\nolimits_{t=1}^{T} \sum\nolimits_{j=1}^{J} \delta_{jsg}^{arr} x_{jt}; \forall g; \tag{3}$$

with: P_{it} – being the value of i passenger flow correspondence for the time t (people);

y_{ijt} – number of passengers of i passenger flow correspondence in a train with j destination in the time t (people);
x_{jt} – number of trains with j destination in the time period t;
T – total number of days in the considered period;

$$\delta_{js}^{dep} = \begin{cases} 1, & \text{if a train with } j \text{ desination } g \text{ composition} \\ & \text{departs from } s \text{ station;} \\ 0, & \text{otherwise.} \end{cases}$$

$$\delta_{js}^{arr} = \begin{cases} 1, & \text{if a train with } j \text{ desination } g \text{ composition} \\ & \text{arrives at } s \text{ station;} \\ 0, & \text{otherwise.} \end{cases}$$

The limitations of the capacity of sections and stations will be presented as follows:

$$N_k^{sec} \geq \sum\nolimits_{j=1}^{J} \delta_{jk} x_{jt}; \qquad \forall k;\ \forall t; \tag{4}$$

$$N_s^{st} \geq \sum\nolimits_{j=1}^{J} \delta_{jsg}^{dep} x_{jt}; \qquad \forall s;\ \forall t; \tag{5}$$

with: N_k^{sec} being the daily through-put capacity of k section in forward and reverse directions;

N_s^{st} – daily capacity of s station.

To fulfill the limit on the available fleet of cars, one needs to know the number of train-sets in circulation, which is equal to the time of the train's turnover divided by the train's circulation period:

$$K_{set} = \frac{2T_{way} + T_{form} + T_{turn}}{T_{circ}} \tag{6}$$

with $2T_{way}$ – being the travel time in forward and reverse directions, hours;

T_{form}, T_{turn} – technological stops time during formation and turnover correspondingly, hours;
T_{circ} – train circulation time (time between train departures from formation stations), hours.

At the same time, the train circulation period (T_{circ}) can be found as the quotient between the calculation period of the route network of passenger trains (T_{calc} - the period of time for which the route network is calculated; day, week, month, etc.) and the total number of trains given destination. Then, for this problem, the train's circulation period can be found by:

$$T_{circj} = 24 \frac{T_{calc}}{\sum_{t=1}^{T} x_{jt}}; \quad \forall j; \tag{7}$$

Since for this task the possibility of unequal sizes of movement by days of the week and through indexing of train destinations in the forward and reverse directions is provided, for each train destination the travel time will be taken into account only in one direction and the time spent under technological operations ($T_{form} + T_{turn}$) is regarded as the arithmetic mean between the two values. Then formula (6) will have the following form:

$$K_{set\,j} = \sum\nolimits_{t=1}^{T} x_{jt} \frac{T_{way\,j} + \frac{T_{form\,j} + T_{turn\,j}}{2}}{24T_{calc}} = \sum\nolimits_{t=1}^{T} x_{jt} \frac{2T_{way\,j} + T_{form\,j} + T_{turn\,j}}{12T_{calc}}; \quad \forall j; \tag{8}$$

The limitation on the current car fleet looks as follows:

$$N_l^{wag} \geq \sum_{j=1}^{J} m_{jl} K_{set\,j}; \quad \forall l; \tag{9}$$

with N_l^{wag} - being the current fleet of l cars.

Based on formula (9), the limit on the available fleet of cars of various types will have the form:

$$N_l^{wag} \geq \sum_{j=1}^{J} m_{jl} \sum_{t=1}^{T} x_{jt} \frac{2T_{way\,j} + T_{form\,j} + T_{turn\,j}}{12T_{calc}}; \quad \forall l; \tag{10}$$

The criterion of optimality is the minimum operating costs:

$$F = \sum_{j=1}^{J} \sum_{t=1}^{T} E_j x_{jt} \rightarrow \min \tag{11}$$

with E_j being the cost value of j train.

3 Results

Let us consider a model sample problem. Data: values of *daily average* passenger flow correspondence (P_i), train capacity (a_j), cost values of trains (E_j) are shown in Fig. 1. It is required to calculate traffic volume, taking into account daily unevenness for 3 days. Daily unevenness coefficients by days (ε_t), will equal: $\varepsilon_1 = 1.5$; $\varepsilon_2 = 0.5$; $\varepsilon_3 = 1.0$. Daily through-put capacity of sections will equal: $N_1^{sec} = 7$; $N_2^{sec} = 10$; $N_3^{sec} = 16$. Daily station capacity will equal: $N_1^{st} = 8$; $N_2^{st} = 7$; $N_3^{st} = 12$.

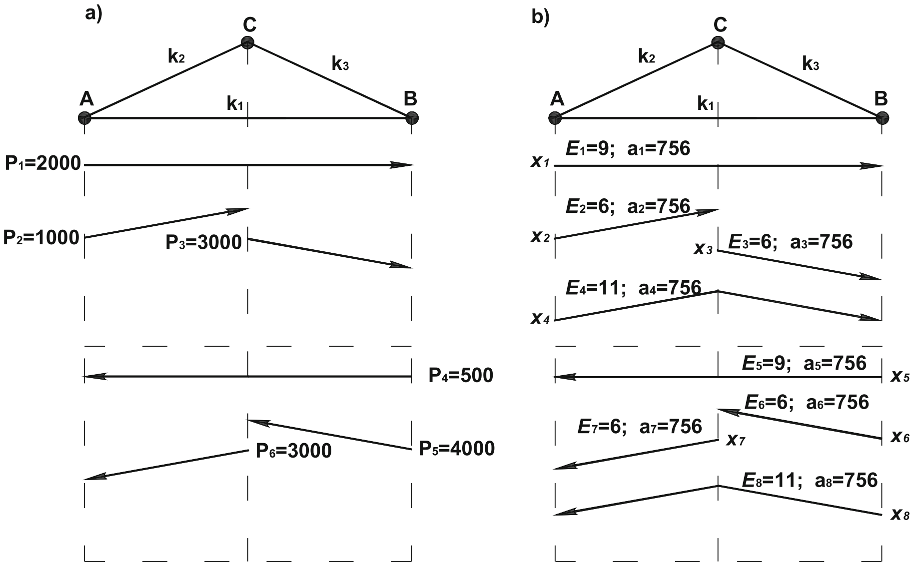

Fig. 1. Calculation network scheme

The posed linear programming problem is solved as an integer problem. We will calculate the route network of passenger trains for three days. The calculation results are shown in Table 1.

Table 1. Daily distribution of train flows for calculation sample

Days (t)	Train destinations							
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
$t = 1$	4	0	3	3	2	3	0	6
$t = 2$	2	0	1	1	0	1	0	2
$t = 3$	3	0	2	2	1	2	0	4

As can be seen from the results, the volume of daily traffic, as well as in the forward and reverse directions, were distributed unevenly. This example shows that this model allows you to distribute train flows so that train capacity is used as efficiently as possible with unequal passenger flows in the forward and reverse directions and with daily fluctuations in passenger flows. Avoiding coupled traffic allows you to more efficiently use rolling stock, reduce mileage of vacant seats, and reduce the required fleet of passenger cars. It is worth noting that this problem can be applied only with unified composition schemes.

4 Conclusions

When setting the dynamic problem of calculating the route network of passenger trains, the range of tasks is significantly expanded: firstly, the volume of train traffic is determined depending on the change in passenger flow per unit of time, which allows us to simulate the distribution of passenger flows and will lead to an increase in the quality indicators of the use of rolling stock; secondly, it becomes possible to optimize the rolling stock over the network due to a more rational use of rolling stock; thirdly, the problem of distributing the reserve fleet of cars over the network is being solved from the point of view of reducing the empty mileage of reserve cars to the stations for the formation of additional trains during peak periods.

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The Optimizing Container Transportation Dynamic Linear Programming Model

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Abstract. Over the past thirty years, optimization modeling techniques have begun to be actively used in supply chain planning and management. Given the specifics of planning tasks in supply chains, linear programming and its methods such as dynamic programming, stochastic programming and scenario planning have become the most popular. These methods make it possible to optimize the supply chain across numerous databases, each of which corresponds to a scenario describing different options for development in an uncertain future. Despite quite intensive research in this area, dynamic and stochastic programming is still underused by managers to solve application tasks in various fields, including supply chain management. Hence, there is a need for development of new planning models in logistics and supply chain management in the context of incomplete information and methods that are used to investigate situations of risk and uncertainty.

Keywords: Distribution logistics · Dynamic linear programming · Scenario planning

1 Introduction

Dynamic and stochastic linear programming models have begun to be actively used in planning and, in particular, in management of supply chain over the past thirty years, as evidenced by a large number of scientific publications related to this problem [1, 3–7]. Some papers cover the wide area of research in infrastructure improvement projects [8–15]. Believing that the analysis of such a number of works and the models presented in them is the object of an independent and rather special mathematic study, it was decided to change the approach: not to direct search to all sorts of theoretical models, but to focus on those that are of applied relevance and are at the junction of stochastic and dynamic programming. At the interface between stochastic and dynamic programming, the following methods have been proposed in recent years:

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– multistage stochastic programming – (MSP);
– multistage stochastic decomposition – (MSD) – a new stream representing a bridge between stochastic programming and approximate dynamic programming;
– multistage stochastic programming: a scenario tree based approach to planning under uncertainty [3];
– dynamic sampling algorithms for multistage stochastic programs with risk aversion.

The analysis of these works shows that the main tools of accounting for uncertainty and risk in mathematical programming models are trees of decision-making and scenario planning based on their analysis. It should be noted that optimization models and, in particular, dynamic and stochastic programming models are used to solve the problem of optimization of the logistics network, inventory management and transportation routing, but these models are not yet actively used in logistics.

In this work, we consider the task of optimizing the transportation of container cargo from the Magnitogorsk metal-calibration plant (JSC MMK-METIZ) to the container site of the railway commodity station in the city of Magnitogorsk, which are shipped weekly by JSC TransContainer from the railway commodity station to the consumers. A mathematical model of this problem is proposed in the form of a dynamic multi-period linear programming model, which allows to find the optimal number of containers loaded, stored in a warehouse and sent to the railway freight station, as well as to equalize the uneven loading of finished products into the containers at JSC MMK-METIZ and its dispatch to consumers from the railway freight station. The deterministic position of this problem was considered, which does not take into account the failures in the shipment of containers from the railway freight station of the city of Magnitogorsk that actually occur in the practice of MMK-METIZ OJSC. Some of them are due to the fault of JSC TransContainer for the following reasons:

– The other goods, such as household items, could be the priority for JSC TransContainer, which could result in that the containers from the plant could not get to the nearest train;
– the lack of flatcars for shipment of private containers of shipping lines, including containers of JSC MMK-METIZ;
– JSC TransContainer, being a monopolist, often uses the platforms of the incoming empty containers at its discretion, and loaded containers could stay idle at the station expecting shipment.

Undoubtedly, the failures are also due to the fault of JSC MMK-METIZ for the following reasons:

– irregularity of fulfillment of the plan of loading of containers at the plant;
– delays in the shipment of containers due to unavailability of the documents;
– idle of the containers due to expectation of the day of shipment to the appropriate direction; and other reasons.

Consequently, the deterministic formulation of this problem leads to unrealistic plan for loading and shipment of containers from the plant to the container site of the railway commodity station. One of the possible solutions is the formulation of this task in the form of a stochastic programming model. In Shapiro's monograph [5] the method of solving the problem of supply chain optimization including stochastic programming and scenario planning is considered. Based on the method outlined in this work, we shall consider the logic of creating a dynamic multi-period model of mathematical programming and its optimization in several scenarios.

2 Materials and Methods

The methodology is based on an integrated approach to the research issues regarding the dynamic programming and scenario planning. To identify the considered problem of dynamic linear programming, the methods of system analysis and synthesis, methods of scenarios planning, as well as the method of induction were used to select the optimal container shipment strategy. In the process of tactical and strategic planning of the supply chain, there is a need for optimization across numerous databases, each of which corresponds to a scenario describing different options for decision-making under uncertainty. Key uncertainties in the scenarios formation include the demand for finished products, raw material inputs or new production technologies. Although the reasons for the consideration of different scenarios are intuitively clear, the methods for their systematic identification and building require consideration. Methods of creation and analysis of models including multiple scenarios are based on two overlapping disciplines: stochastic programming and scenario planning. The interrelation of these disciplines is shown in Fig. 1.

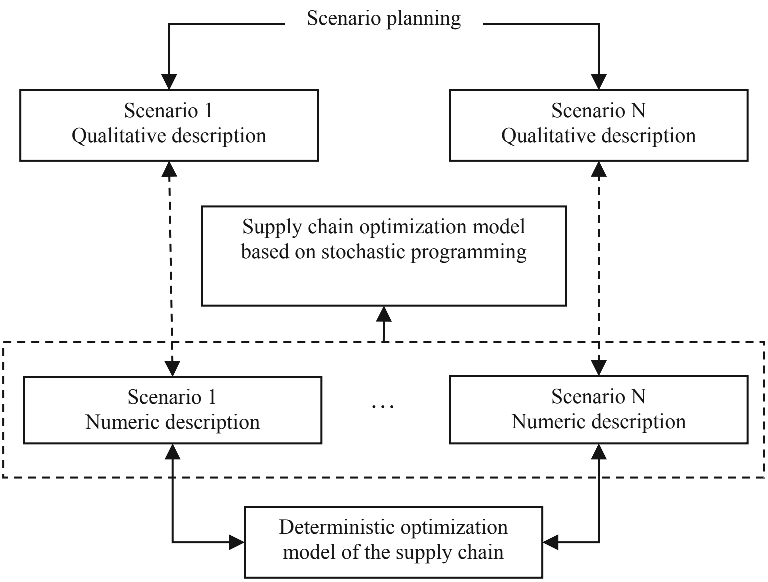

Fig. 1. Interrelation between stochastic programming and scenario planning [3].

The use of the deterministic model enables us to take into account uncertainty by analyzing N scenarios, each of which refers to a different set of initial data. At each stage of modeling, such data are designated as certain, as a result of which the term deterministic model appeared. Optimization of deterministic models cannot determine plans that provide for the risks. As shown in Fig. 1, the stochastic programming model, which studies uncertainty and risks deeper, can be built on the basis of a deterministic optimization model by its expanding in view of simultaneous consideration of multiple scenarios. In particular, the stochastic programming model calculates the optimal contingency plan and risk insurance plan for each scenario. The probabilities of the risk associated with each scenario are also taken into account at optimization. Of course, the objective function of the model is to minimize the total expected costs of the supply chain or maximize the total expected net revenues. For example, if for each of the three scenarios we get net income R1, R2, R3 with probability p1, p2, p3, then the model tends to maximization $(p_1 \times R_1 + p_2 \times R_2 + p_3 \times R_3)$.

Also, as shown in Fig. 1, there is a loose but important relationship between stochastic programming and scenario planning. The purpose of the scenarios planning is to assist managers in identifying consistent, credible and comprehensive scenarios of the company's strategic plans in the future. This methodology is based on the processes aimed at expanding the views of the company's management regarding its future and achieving general agreement in the choice of strategy. From a methodological point of view, stochastic programming models combine "decision trees" describing an uncertain future with linear or mixed integer programming models describing decisions on acquisition and resources allocation. The "decision tree" was invented in the 1950s as an addition to the utility theory, which provides an axiomatic structure that characterizes decision-making under uncertainty. Scenario planning theory formalizes the rational attitudes of the decision-maker to the risks inherent in an uncertain future. It is not aimed at creating optimization models that can be used to justify the importance of decisions. Nevertheless, modelling systems based on scenario planning and decision analysis are developing and widely used in practice. Stochastic programming in the late 1950s was considered as an independent direction of linear programming. At the most abstract level, its mathematical properties are very complex, requiring the integration of probability theory and mathematical programming. The central theoretical problem is to transform the uncertainties described by a set of continuous distributions into a finite number of scenarios, thus allowing the creation and solution of a final mathematical programming model. Stochastic programming models are now widely used in practice due to the development of scenario planning theory. At the same time, theoretical complications are sometimes ignored, although the combination of complex stochastic models with mathematical programming remains complicated.

The application of the stochastic programming and scenario planning methodology to the task of choosing the optimal strategy for container handling, taking into account the significant unevenness of their loading and dispatch from the railway freight station, is complicated for the following reasons. First, it was noted above that failures can occur both when loading containers and at their shipment from a railway freight station. Each of these failures occurs with its own probability pi, which complicates formation of scenarios, since there can be many scenarios, but the implementation of each of these scenarios is a rare event. Second, the critical factor is the time period t in which the failure occurred. For example, if failure in shipping containers occurred at the beginning of the planned period (in the first week of the month), then until the end of the month the alignment of the plan is possible (dispatch of the additional containers on the following week). If the failure occurred at the end of the planned period, it is obvious that this is not possible, i.e. the initial plan will not be executed.

In this connection, the following questions arise: (1) is scenario planning possible in this case; (2) if so, what useful information will we get by optimizing for different scenarios? In our view, the answer to the first question is positive. Scenario planning is possible if we limit our consideration to a small number of failures and their corresponding scenarios that lead to the greater costs (for example, a one-week delay in shipping containers from a railway freight station). In this case, optimization according to different scenarios will provide an answer to the question of what additional resources we should have to fulfill the shipment plan (containers, cars, loading facilities and equipment). The logic of creating a dynamic multi-period model of mathematical programming and its optimization in several scenarios is shown in Fig. 2.

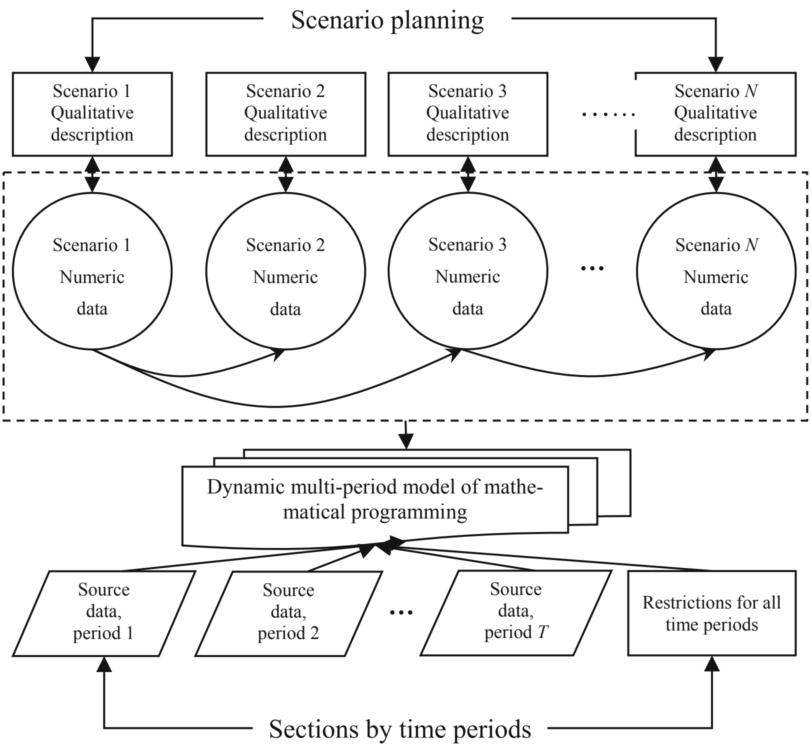

Fig. 2. Logic of creation of dynamic multi-period model of mathematical programming.

It should be noted that a dynamic multi-period model of mathematical programming based on the basic scenario (scenario 1) is created first. When creating a basic scenario, we assume that there are no failures in the process of loading and shipment of containers during the entire planning period, i.e. the deterministic formulation of the problem is considered. Then, scenarios are created that reflect failure situations (delays in shipping containers from a freight train station): scenario 2 – failure occurred during period 1 (first week), scenario 3 – failure occurred during period 2 (second week), and so on.

Obviously, for each of the planning periods, there are individual inputs and limitations (for example, for the number of goods to be loaded in containers/shipped in time t), there may also be general limitations for all time periods (for example, the total volume of goods delivered in the entire planning period). The influence of these initial data and limitations on the creation of a dynamic multi-period model for choosing the optimal strategy for sending containers according to several scenarios is reflected in Fig. 2. In the problem under consideration, we assume that all scenarios (failures) are equally probable p1 = p2 = … = pN = 1/N and only one failure can occur during the planning period (month).

3 Results

The results are based on the approach deriving from mathematical formulation of the problem. Mathematical methods of control in the view of incomplete information, including the problems of creating dynamic and stochastic multi-period models of linear programming, are considered in a wide range of papers by prof. A. Bochkarev and P. Bochkarev, who proving that the mathematical model of the considered problem is given, as a model of dynamic linear programming, which allows to determine the optimal number of loaded, ordered and stored containers, in which the total cost of the containers shipment would be minimal.

Let's introduce the following legend:

$i \in \{1, \ldots, I\}$ – the set of indices of the containers types;
$j \in \{1, \ldots, J\}$ – the set of indices of the ways of the containers shipment;
$t \in \{1, \ldots, T\}$ – the set of indices of the periods in planning;
$x_{i,j,t}$ – number of containers of i- type loaded by j- method, in time period t, units;
$x_{i,j,t}^{\max}$ – maximum number of i-type containers that can be loaded by j- method, in time period t, units;
$y_{i,j,t}$ – number of type i containers loaded by the j- method and sent to the railway freight station, in the time period t, units;
$a_{i,j,t-1}$ – number of stored containers of type i loaded by the j- method at the beginning of time period t;
$a_{i,j,t}$ – number of stored containers of type i loaded by the j method at the end of time period t;
$c_{i,j,t}^{1}$ – the cost of sending one type i container loaded by the j-th method in the time period t;

$c^2_{i,j,t}$ – fee for presentation of the type i container loaded by the j-th method in the period of time t before the appointed date;
q_i – weight of cargo (gross weight) container of the i-th type, t;
$Q_{i,t}$ – number of goods shipped in type i containers during the time period t, t;
Q_t – number of goods to be loaded into containers in time period t, t;
Q^*_t – number of goods that can be shipped in the time period t, t;
Q_0 – total volume of cargo deliveries for the entire planning period, t.

The optimal ratio between loaded, shipped and stored containers can be obtained from the solution of the following special linear programming problem. We need to calculate the variables $x_{i,j,t}$ and $y_{i,j,t}$ that convert the linear form to the minimum (1)

$$Z = \sum_t \left(\sum_i \sum_j \left(c^{(1)}_{i,j,t} y_{i,j,t} - c^{(2)}_{i,j,t} \left(a_{i,j,t-1} + x_{i,j,t} - y_{i,j,t} \right) \right) \right) \to \min; \quad (1)$$

under conditions expressed by formulas (2)–(10)

$$\sum_i \sum_j \left(a_{i,j,0} + \sum_t \left(x_{i,j,t} - y_{i,j,t} \right) \right) \le a_{i,j}, \forall i,j,t \in \{1,2,\ldots,T-1\}; \quad (2)$$

$$\sum_i \sum_j \left(a_{i,j,0} + \sum_t \left(x_{i,j,t} - y_{i,j,t} \right) \right) = 0, \forall i,j,t = T; \quad (3)$$

$$\sum_i \sum_j x_{i,j,t} \le x^{\max}_{i,j,t}, \forall t; \quad (4)$$

$$\sum_i \sum_j q_i\, x_{i,j,t} \ge Q_t, \forall t; \quad (5)$$

$$\sum_i \sum_j q_i\, y_{i,j,t} \ge Q^*_t, \forall t; \quad (6)$$

$$\sum_i \sum_j q_i\, y_{i,j,t} \ge Q_{i,t}, \forall t; \quad (7)$$

$$\sum_t x_{i,j,t} = \sum_t y_{i,j,t}, \forall i,j; \quad (8)$$

$$x_{i,j,t} \ge 0, y_{i,j,t} \ge 0, a_{i,j,t} \ge 0, \forall i,j,t; \quad (9)$$

$$x_{i,j,t} - \textit{the whole}; \quad y_{i,j,t} - \textit{the whole}. \quad (10)$$

Analysis of the data presented in [2], shows, first, that the cost of shipment of the loaded containers (line 7) consists of three components: the cost of road transport (line 3), the cost of freight commodity station (line 5) and depreciation charges for lifting equipment and vehicles (line 6). Secondly, the shipment of goods by 40-foot containers is cheaper than the shipment by 20-foot containers per 1 ton of cargo (line 9). Third, the costs for sending stuffed containers by own transport are only lower for 20 foot containers. Transportation of 40-foot containers by own vehicles will be more expensive, because for this purpose new purchased semi-trailers-container carriers are used, and, accordingly, depreciation is accrued. It should be noted here that for the own vehicles intended for transportation of 20 foot containers, depreciation is not charged due to its complete wear and tear.

The objective function (1) is the sum of the costs for the loaded containers shipment minus the fees for untimely provision of cargos earlier than the appointed time.

The warehouse capacity conditions are indicated in the form of inequality, which corresponds to formula (2). According to the results of the previous period, all containers must be taken out from the warehouse, so that at t = T the warehouse capacity should be equal to zero, this limit corresponds to the formula (3). The limit on the number of i-type containers to be loaded by j method in time t is given by form (4). The limitation on the number of container cargos that require loading in period t is given by formula (5). The limitation on the number of container goods that can be shipped within the time period t is represented by formula (6). A limit on the amount of cargo shipped in containers of i type is represented by formula (7). The restriction, presented as formula (8), allows to balance the number of loaded and shipped containers during the entire planning period $t \in \{1, \ldots, T\}$.

In solving this problem it is necessary to take into account the restrictions on the nonnegativity and the integer number of variables $x_{i,j,t}$, $y_{i,j,t}$ and $a_{i,j,t}$. These restrictions are expressed by formulas (9)–(10).

4 Discussion

In the above statement, the problem is determined, i.e. it does not take into account possible changes in the volume of rates for the planning periods and the possible unevenness (delay) of shipments from the railway freight station. It is proposed to take into account these limitations by the method of scenarios planning. The baseline scenario assumes that the planned and actual values of the loaded $x_{i,j,t}$, shipped $y_{i,j,t}$ and stored $a_{i,j,t}$ containers are the same. In case of discrepancy between the planned and actual values of these indicators, it is necessary to create a new scenario. Suppose that the failure – the delay in sending containers from the railway freight station for one week – occurred during the first week (t = 1). Thus, in the first planning period there was a variance from the plan, which gives us the basic scenario, and the fact, therefore, it is necessary to consider scenario 2, the mathematical formulation of which is considered below. It is needed to calculate the variables $x_{i,j,t}$ and $y_{i,j,t}$ that convert the linear form (11) to a minimum

$$\mathrm{Z} = \sum_{t} \left(\sum_{i} \sum_{j} \left(c^{(1)}_{i,j,t} y_{i,j,t} - c^{(2)}_{i,j,t} \left(a_{i,j,t-1} + x_{i,j,t} - y_{i,j,t} \right) \right) \right) \rightarrow \min; \quad (11)$$

under conditions expressed by formulas (12)–(21)

$$\sum_i \sum_j \left(a_{i,j,0} + \sum_t \left(x_{i,j,t} - y_{i,j,t} \right) \right) \leq a_{i,t}, \forall i, j, t \in \{2, \ldots, T-1\}; \tag{12}$$

$$\sum_i \sum_j \left(a_{i,j,0} + \sum_t \left(x_{i,j,t} - y_{i,j,t} \right) \right) = 0, \forall i, j, t = T; \tag{13}$$

$$\sum_i \sum_j x_{i,j,t} \leq x_{i,j,t}^{\max}, \forall t \in \{2, \ldots, T\}; \tag{14}$$

$$\sum_i \sum_j q_i \, x_{i,j,t} \geq Q_t, \forall t \in \{2, \ldots, T\}; \tag{15}$$

$$\sum_j q_i \, y_{i,j,t} \geq Q_t^*, \forall t \in \{2, \ldots T\}; \tag{16}$$

$$\sum_i \sum_j q_i \, y_{i,j,t} \geq Q_{i,t}, \forall t \in \{2, \ldots, T\}; \tag{17}$$

$$\sum_t x_{i,j,t} = \sum_t y_{i,j,t}, \forall i, j; \tag{18}$$

$$x_{i,j,t} \geq 0, y_{i,j,t} \geq 0, a_{i,j,t} \geq 0, \forall i, j, t \in \{2, \ldots, T\}; \tag{19}$$

$$x_{i,j,t} = const, \; y_{i,j,t} = const, \forall i, j, t = 1; \tag{20}$$

$$x_{i,j,t} - the\,whole; \quad y_{i,j,t} - the\,whole. \tag{21}$$

Thus, the objective function (11) has not changed and continues to represent the cost of the shipment of the loaded containers minus the fees for provision of the cargo earlier than at the scheduled date for the entire planning period $t \in \{1, \ldots, T\}$.

Limitations (12)–(21) generally correspond to limitations (2)–(10), but variable values $x_{i,j,t}$ and $y_{i,j,t}$ are at $t \in \{2, \ldots, T\}$ and we add new limitations for variables $x_{i,j,t} = const, \; y_{i,j,t} = const, \forall i, j, t = 1$.

It is obvious that the delay in the containers shipment from the railway freight station may occur during the entire planning period $t \in \{1, \ldots, T\}$, that is, during any week, so it is necessary to consider alternative scenarios and build their mathematical models, which will be similar to the model (11)–(21) scenario 2.

In the second part of the article, a numerical example will be presented to illustrate the effectiveness of the proposed mathematical programming model for the problem of choosing the optimal strategy for the containers shipment and its optimization in several scenarios.

5 Conclusion

The analysis of the work on the application of dynamic and stochastic linear programming models in supply chain management showed that the main tools for accounting for uncertainty and risk in mathematical programming models are decision trees and scenario planning based on their analysis. In this work we propose a mathematical model of a dynamic multi-period problem of shipping loaded containers (see formulae (11)–(21)), which allows to take into account possible changes in the volume of deliveries by planning periods and possible irregularity (delay) of shipments from the railway freight station. It is proposed to take these limitations into account by the method of the scenarios planning.

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Theoretical and Multiple Model of Transport Multi-operational Reconfigurable Processes

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Abstract. The aim of the study is to create an adequate and effective in the application theoretical model that describes multi-operational technological processes in railway transport at the level of operations, connections and resources. The article presents a theoretical and multiple operational-event model of the technological process, distinguished by its description in the form of "technology - implementation - a set of events", adapted to reflect changes in technology and processes, as well as the possibility of narrowing multidimensionality and the formation of private models. Based on the definition of technology as a process plan, the set of implementations of technology and the set of events in the process are introduced into the expression of a process model. To analyze the options for implementing the technology, the concept of spatial-temporal process reconfiguration is used as a change in the relative position of its operations. The possibilities of obtaining private models by narrowing the multidimensionality of the complete process model are presented. A formal system of defects in the process is developed on the basis of the set-theoretic formulation of a defect. It is shown that the use of the theoretical and multiple operation-event model of processes allows solving actual engineering problems (formalization, schematization, standardization, visualization) and is promising for developing mathematical and algorithmic support of automated monitoring and diagnostic systems.

Keywords: Technology · Process · Operations · Model · Sets · Events · Implementation

1 Relevance and Problem Statement

The relevance of developing a theoretical-multiple model of transport technological processes is due to the following factors:

– the need to formalize the descriptions of processes, with a reflection of the basic properties (multidimensionality, multioperation, logical causation, normalizability, repeatability, variability), to solve the problems of their automated storage, processing, analysis, improvement of quantitative and qualitative indicators, production control, detection of inconsistencies with the prescribed technology and detection of defects [1, 2];

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- advantages of system analysis, set theory and graph-scheme approach for theoretical research, optimization and diagnostics of transport processes as a set of operations prescribed by a given technology, with material, financial, information and other resources [3–17];
- the perspective developing of effective methods and algorithms for automated diagnostics of technological processes based on their theoretical and multiple models and formal formulations of defects in processes [9, 10, 13, 15–20].

2 Theoretical Part

The substantive description of the technology includes in general: purpose and general requirements; composition and characteristics of operations (function, place and time of operation); used resources (material, information and others); management methods (order and sequence of operations, temporal characteristics); links between operations (including the transfer of intermediate results); final product (result). Forms of technology presentation are flow charts, instructions, regulations and other documents approved by leadership and accepted for execution by staff.

To develop a technology model, we represent it as a set of operations ordered in space and time with managers and resource relations between them, as shown in the diagram in Fig. 1, where O1–O4 - technology operations, S and T - coordinates of space and time.

Define the basic model sets:

- O - the set of technology operations, $O_i \in$ O, $i = 1, \ldots, i_k$; O $\subseteq$ A $\times$ F $\times$ M, where A - the set of technology operations acts, $A_i \in$ A; F - the set of operations functions, $F_i \in$ F; M - a set of resources (material, financial, informational and others) used in operations;
- P - the set of predicates characterizing the conditions for the technology implementation, $P_l \in$ P, $l = 1, \ldots$, lk;
- R - the set of relations between operations, R = U $\cup$ V; U - the set of control connections, U $\subseteq$ O $\times$ O $\times$ P; V - the set of resource connections, V $\subseteq$ O $\times$ O $\times$ M;
- S - the set of spatial coordinates of operations;
- T - the set of operations in time coordinates.

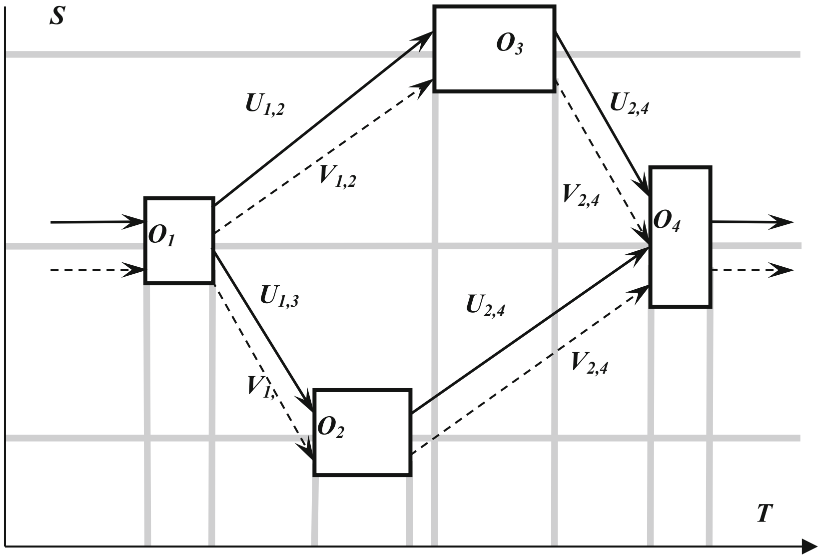

Fig. 1. Illustration of technology model definition

The theoretical-multiple representation of technology with this formulation is a model:

$$\mathrm{TL} = <\mathrm{O}, \mathrm{P}, \mathrm{R}, \mathrm{S}, \mathrm{T}>, \quad (1)$$

which corresponds to the definition of technology as a typical regulated order of operations (actions) on specified initial resources to obtain the required final product, which has the properties of mass character (applicability for different initial resources and fulfillment conditions) and determinism (a predetermined ordered set of actions taking into account predicate values) [7, 16].

In (1), the characters correspond to the initial letters of the terms technology, operation, predicate, relation, space, time, which makes it possible to apply the name “OPRST-model”.

In contrast to the well-known approaches [5–8], it is advisable to define technology as a process plan and introduce into the expression of a process model such sets as the implementation of technology and events in the process. Then the process model can be represented as:

$$\mathrm{TP} = <\mathrm{TL}, \mathrm{RL}, \mathrm{E}>, \quad (2)$$

where the implementation of RL in the general case is the display RL: TL $\times$ TL $\rightarrow$ E, and E - the set of events in the process.

To reflect in model (2) the properties associated with changes in technologies and processes, we introduce a number of definitions, applying the principle of superposition.

Unified model of changing processes $TP^{var.proc.}$ with a fixed (the only) technology is the set of models that differ in two components - implementation and events:

$$TP^{var.\,proc.} = \{TP_n\},\ TP_n = <TL,\ RL_n,\ E_n>, \tag{3}$$

where n = 1, … , nk - the sequence number of the implementation and process.

Later in the indexing, it is assumed that the subscripts denote the numbers of elements in the sets, the superscripts - belonging to a set or group of objects with an indication of the symbol of the set.

Integrated process model with variable technology $TP^{var.tec.}$ is the set of models that differ in three components:

$$TP^{var.tec.} = \left\{TP_{m,n}\right\},\ TP_{m,n} = \ <TL_m,\ RL_{m,n},\ E_{m,n}>, \tag{4}$$

where m = 1, … , mk - the sequence number of the technology.

The feasibility of using this approach to model variable technologies and processes is confirmed by the fact that a single execution of the technological process for a given technology (i.e. its implementation) is unique in terms of the totality of events, parameters and results.

Thus, the functioning of an automated transport system that repeatedly performs a given technology in changing conditions of the life cycle is described in general (1)–(4) at the system level.

Solving the problem of analyzing and comparing technology implementations requires defining and studying the properties of a set of events E_n for a set of realizations.

To do this, we represent it in the form of activation of the elements of the OPRST model, namely, changes in space and time of the values of the corresponding features:

$$E_n \subseteq g_n \times s_n \times t_n, \tag{5}$$

where g_n - the set that includes signs of activation of operations, predicates, resources and relations; s_n - the set of signs of activation of spatial coordinates of events; t_n - the set of activation signs of the time coordinates of events.

The signs of activation include: a_i - the sign of the operation activation, $a_i \in$ a; p_l - the sign of the predicate activation, $p_l \in$ p; $u_{i,j}$ - the sign of the control connection activation, $u_{i,j} \in$ u; $v_{i,j}$ - the sign of the resource communication activation, $v_{i,j} \in$ v; other signs according to the basic sets in (1).

An elementary event in the process model is described by the triple $e_y = (g_i,\ s_i,\ t_i)$, where $e_y \in E_n$, $y = 1, \ldots, y_k$. In particular, if $g_i = a_i$, then the event describes the activation of the i -th operation.

To describe and compare the options for implementing the technology, we introduce the concept of spatial-temporal reconfiguration of the process, based on the definition of configuration as the relative location of its operations [5, 14–16].

When formulating expressions for the configuration and reconfiguration of the process, we use (1)–(5) and the following definitions.

For the implementation of RLn, there is the order CSn of events En by spatial coordinates and the order CTn of events En by time coordinates.

The configuration is characterized by a predicate indicating the invariance of orders in different implementations:

$$CF_q(\mathrm{RL}_n, \mathrm{CS}^q, \mathrm{CT}^q) : \mathrm{RL}_n \subset \mathrm{RL}^q \Leftrightarrow (\mathrm{CS}_n = \mathrm{CS}^q) \wedge (\mathrm{CT}_n = \mathrm{CT}^q), \quad (6)$$

where RLq - implementations with q configuration.

The configuration defines a set of TP q processes that coincide up to the order of events for which the relation is true:

$$\mathrm{RL}_n \subset \mathrm{RL}^q \Leftrightarrow \mathrm{TP}_n \subset \mathrm{TP}^q. \quad (7)$$

Thus, a configuration is a measure of the assessment of the presence or absence of changes in repetitive implementations of a technology, showing that the processes carried out according to one technology coincide with the accuracy of the mutual arrangement of events signs.

The technological process configuration is called an ordered pair of configurations:

$$\mathrm{RC_r} = \ <\mathrm{CF_r}, \mathrm{CF_{r+1}}>, \quad (8)$$

where CF_r and CF_{r+1} - the current and next configurations, $r = 1, \ldots, r_k$.

The set of process reconfigurations are Cartesian products.

$$\mathrm{RC} \subseteq \mathrm{CF} \times \mathrm{CF}, \quad (9)$$

where $RC_r \in \mathrm{RC}$. Given (3), (6) and (7), the set of reconfigurable processes can be represented as:

$$\mathrm{TP^{rec}} = \mathrm{TP}^q \cup \mathrm{TP}^{\mathrm{rec}.q}, \quad (10)$$

where $\mathrm{TP}^{\mathrm{rec}.q}$ - the subset of processes reconfigurable with respect to TP^q.

The formal definition of reconfiguration according to (8)–(10) corresponds to the understanding of reconfiguration as a fact of transition of the process (when implementing a given technology) from one configuration to another while preserving the set of operations and connections between them.

The analysis of transport process management methods shows their manifold and joint application not only within one automated system, but also for a single technology. Typical process control methods include the following:

- coordinate, indicating the place and time of the process and its operations;
- algorithmic, determining the transfer of control from operation to operation;
- event, incl. on the readiness of resources used in the operation.
- Accordingly, we define the following list of technology implementations types:
- coordinate implementation of $\mathrm{RL^{coor}}$, for which operations are uniquely distributed over spatial and temporal coordinates;

– algorithmic implementation of RL^{alg}, when operations unambiguously have predecessors and successors on control connections;
– asynchronous implementation of RL^{asyn}, when an operation is started when resources used in it are ready, or when all operations that provide it with resources are completed.

When formulating and recording a process model, we will indicate the set of the theoretical-multiple model of the technology, the type of implementation and the set of the event features.

In general, the theoretical-multiple operational-event model of the technological process is represented by the expression:

$$TP = \langle TL\,(A, F, M, P, V, U, S, T),\ RL, E\,(a, f, m, p, v, u)\rangle. \qquad (11)$$

In this case, the completeness and multidimensionality of the model is achieved by:

– the presence in the model of such major components of the technological process as the totality and functions of operations, the method of control and relations between operations, the spatial and temporal parameters of the process;
– descriptions of various types of resources used in technology (materials, equipment, finance, information), due to the inclusion of the corresponding subsets in the main sets: $M = M^{mat} \cup M^{equip} \cup M^{fin} \cup M^{inf} \cup \ldots$, $V = V^{mat} \cup V^{equip} \cup V^{fin} \cup V^{inf} \cup \ldots$,

Partial models of processes are formulated as a result of excluding unused elements in (11). The narrowing of the multidimensional nature of the main model (11) is carried out according to the following components: sets in the TL technology model; subsets of resources and links in M and V; type of implementation RL; the composition of signs in the totality of events E.

For example, the model $TP = \langle TL\ (A, P, U), RL^{alg}, E\ (a, p, u)\rangle$ represents the process in the form of the implementation of a formalized algorithm (the technology can be specified by the algorithm circuit).

The completeness of the model (11) is confirmed by the possibility of determining correspondences of particular models and well-known formal descriptions used in the theory of timetables, theoretical programming and the theory of parallel computing.

With $TP = \langle TL(A, F, P, S, T), RL^{coor}, E(a, f, p)\rangle$ the model represents a network graph, with $TP = \langle TL(A, S, T), RL^{coor}, E(a)\rangle$ Gantt chart [19].

Standard program diagrams correspond to $TP = \langle TL(A, F, P, U), RL^{alg}, E(a, f, p, u)\rangle$, to operator diagrams of programs correspond to $TP = \langle TL(A, M, P, U), RL^{alg}, E(a, m, p, u)\rangle$ [20].

A model of the form $TP = \langle TL(A, M, P, V), RL^{asyn}, E(a, m, p, v)\rangle$ corresponds to asynchronous computations [21].

The theoretical-multiple formulation of the technological process diagnostic model has the form [9–11, 16, 17]:

$$DM^{TP} = \langle TP, D^{TP}\rangle, \qquad (12)$$

where D^{TP} - the process defect system. Using (2), we will reveal it through the defects of theoretical-multiple descriptions of technology, implementation, and a set of events:

$$D^{TP} = D^{TL} \cup D^{RL} \cup d^{E}. \quad (13)$$

This allows defining three groups of defects in processes: defects in technology, defects in the implementation of technology, defects in the collection of events.

When formulating defects according to the elements of the model sets, we take the following provisions [4, 10, 11, 13]:

1. the defect of the model element is a discrepancy of an actual element required by one of the listed replacement options:
   - on the empty item,
   - on another element of the same model set,
   - on the element that does not belong to a given set;
2. if C_i - any element of the model set, then the following statement is true:

$$(C_i^{fact} \neq C_i^{req}) \Leftrightarrow (C_i\#\varnothing) \oplus (C_i\#C_j) \oplus (C_i\#H_c), \quad (14)$$

   where C_i^{fact} - the actual value of the element, C_i^{req} - the required value; sing # means replacement; C_j - another element of the set C, to which C_i belongs; H_c - an element of the model that does not belong to C, $H_c \notin$ C; ⊕ - Exclusive OR;
3. the corresponding formulation of the element defect according to (14) is:

$$D^{elem} = D^{emp} \oplus D^{oth} \oplus D^{not}, \quad (15)$$

   where $D^{emp,}$ D^{oth} и D^{not} respectively, are defects in replacing an element of a set by an empty element, another element of a given set by an element that does not belong to a given set;
4. defects in the set of a model include defects in its elements according to (15) and defects in the presence of excess elements:

$$D^{C} = D^{elem} \cup D^{ext}, \quad (16)$$

   where $D^{emp,}$ D^{oth} and D^{not} respectively, where excess is an element that is not part of the theoretical-multiple model of this technology.

Thus, the theoretical-multiple formulation of defects in the framework of the developed model is represented by (15) and (16).

According to the definition of the main sets of the model, for the operation of the technology and the relations between them, expressions are allowed:

$$D^{O} = D^{A} \cup D^{F} \cup D^{M}, D^{R} = D^{U} \cup D^{V}.$$

Many defects for the technology represented by the OPRST model are:

$$D^{TL} = D^{O} \cup D^{P} \cup D^{R} \cup D^{S} \cup D^{T}.$$

We define a set of defects in technology implementations as inconsistencies for the types of implementations:

$$D^{RL} = D^{RLcoor} \cup D^{RLalg} \cup D^{RLasyn},$$

where D^{RLcoor}, D^{RLalg} and D^{Rlasyn} - sets of defects in coordinate, algorithmic and asynchronous implementations.

The sets of defects in process events are represented by expressions:

$$d^{E} = d^{o} \cup d^{p} \cup d^{r} \cup d^{s} \cup d^{t},\ d^{o} = d^{a} \cup d^{c} \cup d^{m},\ d^{r} = d^{v} \cup d^{u},$$

where d^{o} - defects of operation signs; d^{p} - defects of predicate signs; d^{r} - defects of bond signs; d^{s} and d^{t} - defects of signs of spatial and temporal coordinates of events;

The system of defects in the theoretical-multiple formulation, which is the basis of the diagnostic model of the technological process, is represented by a tree in Fig. 2

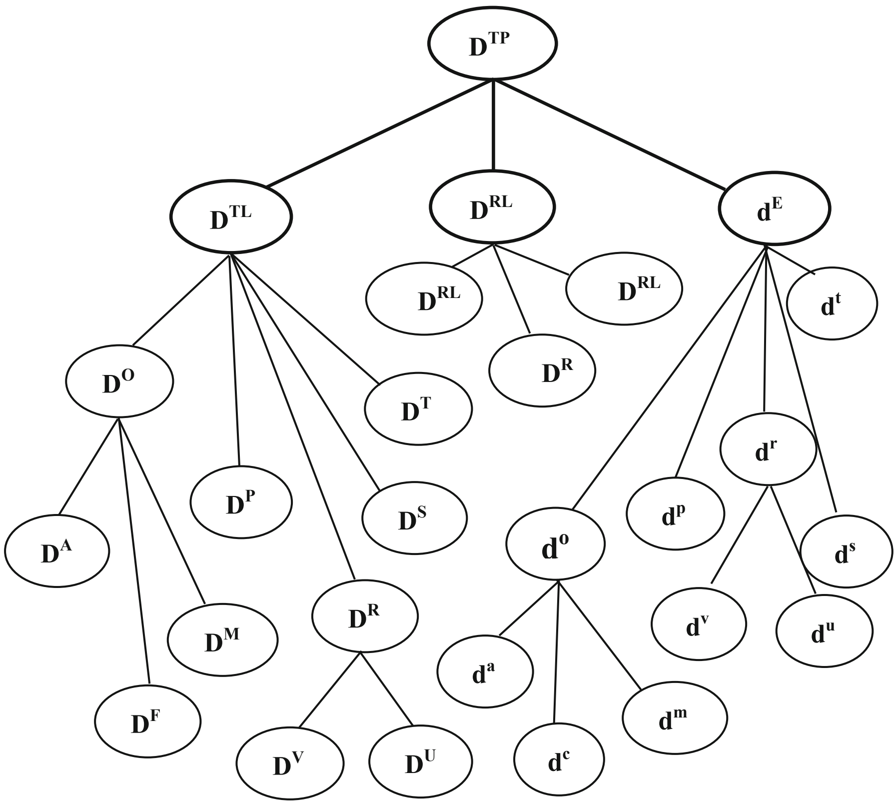

Fig. 2. The system of defects in the process based on the theoretical-multiple model

3 Practical Significance

As shown in [9, 10, 13, 15–17], the use of the theoretical-multiple model of transport multi-operational processes allows developing on their basis diagnostic models of processes as the basis of mathematical and algorithmic support of automated monitoring and diagnostic systems, as well as solving formalized description problems, standardization and visualization [18].

An important feature of the developed model is its adequate representation of reconfigurable technological processes that are present in existing automated transport systems in rail transport [9, 10, 13, 15–17].

The narrowing of the multidimensionality of the basic model (11) is necessary to reduce the dimension of practical problems. In practice, the use of private models has a significant effect when creating software for detecting defects of specific types and problem-oriented automated systems for monitoring and diagnostics of technological processes [13, 17].

The diagnostic model of the process, based on the theoretical-multiple model, was used to develop effective algorithms for detecting defects in transport technological processes as part of automated monitoring and diagnostics systems [9, 15, 17].

4 Conclusion

The developed theoretical-multiple model of transport multi-operational reconfigurable processes is based on the system representation "technology - implementation - a set of events"; adapted to reflect changes in technology (due to the main sets), processes (using configuration and reconfiguration) and process management methods (due to coordinate, algorithmic and asynchronous types of technology implementation); allows to form partial models, for a number of which a correspondence is established with those known from in the scheduling theory, the theory of program schemes and the theory of parallel calculations.

A theoretical-multiple approach with mathematical maturity and versatility needs to be developed in the direction of creating efficient tools for processing data on technologies and processes (including using typical graphic schemes) for the following reasons:

- the complexity of the practical modeling of interacting processes of large dimensionality;
- the need to comply with the standards in the system of transport industry certification.

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Optimization of Fleet Size and Structure While Serving Given Freight Flows

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Abstract. A transition of vehicles into private ownership has led to a decrease of effectiveness of their use. In this case fleet size and structure is often not coordinated with freight flows. That is why in order to make decisions on effective investment of funds it is necessary to apply appropriate optimization models. For this reason in the paper a new flow model for optimization of structure and vehicles use technology while serving given freight flows is proposed. The optimization model uses an investment distribution graph, where a money flow unit is compared to amount of transported freight and to possible income using a particular vehicle type. The optimization model is realized as a computer program that allows carrying out different experiments applying different initial data and helps to determine the most effective solutions in a dynamic market environment. As an example, the authors created a model for three conditional regions and three relatively interchangeable types of vehicles. Results of one of the experiments are presented in the paper.

Keywords: Freight flows · Fleet size · Optimization model · Effective investment of funds · Optimization of fleet size and structure

1 Introduction

A transition to market economy in Russia has led to an appearance of big number of vehicles private owners (more than a thousand of owners). Investments should pay off, but a possible economic success depends on many factors that should be considered:

– fluctuating structure of freight flows;
– competitive advantages concerning interchangeable types of vehicles;
– competition between different private owners;
– regional conditions affecting the transportation process;
– presence of restrictions, etc.

That is why in order to make decisions on effective investment of funds in this sphere it is necessary to create an appropriate optimization program and a calculation technology.

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2 Literature Review

A problem where it is necessary to determine the number of vehicles or containers that optimally balances service requirements against the costs of purchasing and maintaining the equipment is defined as a fleet sizing problem [1, 2]. Fleet sizing is used in many spheres: trucking, passenger transportation, rail freight transportation, automated guided vehicle systems and etc. That is why scientists from different spheres contributed to the solution of this problem. According to the literature survey by Ganesharajah [3] all models used to solve the fleet sizing problem are divided into deterministic and stochastic.

First scientific works dedicated to the solution of fleet sizing problem using deterministic models appeared in the USA in 1950-s. In the early studies scientists treated the fleet sizing problem as a non-dynamic problem. Studies accomplished by Feeney [4], Leddon and Wrathall [5] are the examples of this approach. The problem is formulated as a linear programming problem and is solved with the use of standard simplex algorithm. Sheraly and Tunchbilek in [6] describe a model to determine the minimum number of wagons to satisfy the demands at various points in time. To solve the fleet sizing problem they propose a heuristic procedure that decomposes the planning horizon to reduce the computational requirements. The fleet sizing problem applied to container transportation was investigated by Korean scientists Koo, Lee and Jang. In their paper [7] they propose a two phase approach. The first phase is connected with the use of the optimization model proposed by Maxwell and Muckstadt in [8] to determine the lower bound of the fleet size. Phase 2 is an iterative process where a tabu search algorithm is used to improve vehicle routing while the fleet size is increased until the feasible solution has been found.

The first use of the stochastic phenomena for relaxing assumptions in deterministic models was described by Turnquist and Jordan in [9]. It was the first try to consider the impact of travel time uncertainty of vehicle fleet sizing. In [10] Beaujon and Turnquist underline the importance of the interactions between the size and utilization of vehicle fleets. They describe a general model to optimize both sets of decisions simultaneously under dynamic and uncertain conditions. Authors also discuss the network approximation to the optimization model and a solution procedure that includes the Frank-Wolfe algorithm to estimate the values of variance. Yafeng and Hall [1] treated the problem of fleet sizing in center-terminal transportation networks from the standpoint of inventory theory. The approach they propose permits to find the probability of stock-out as a function of fleet size. Bojovic in [11] demonstrates the approach of solving the fleet size problem from the standpoint of general system theory. An alternative approach to solve the fleet sizing problem was proposed by Lesyna [12]. He uses discrete-event simulation to determine the optimal wagon fleet size for the needs of DuPont.

To sum up, all of the examined models are appropriate to solve the fleet sizing problem applied only to one vehicle type (for example, wagons, trucks, containers) that is why they cannot be used to determine the fleet size required to satisfy the transportation demand of a region or a whole country because in transportation process can be used more than one vehicle types. In order to overcome this restriction and to determine the most effective distribution of funds on purchasing different vehicle types we propose a new optimization program based on existing experience of creating flow models [13–16].

3 Description of the Model Used in the Optimization Program

This paper describes a program for optimization of fleet size and structure while serving given freight flows. The optimization model in this program considers three big regions for investments in vehicles, for example, the Far East region, the Ural region and the Central region. To carry out calculations it is necessary to assign initial data: value and structure of freight flows in each region that can be served by relatively interchangeable types of vehicles – covered wagons, containers and trucks. That model has several restrictions: on available funds, on linking a part of the freight flow to a specific vehicle, on the buying availability of vehicles and etc. The Restrictions may vary depending on a region. A task is to determine a fleet size and structure that could bring the biggest income considering the fact that penalties for unexecuted transportations are registered in contracts between vehicle owners and freight owners.

The problem is formalized as a flow problem on a graph of a particular structure. The graph has a source and a drain. Money flows go along the arcs of the graph (Fig. 1).

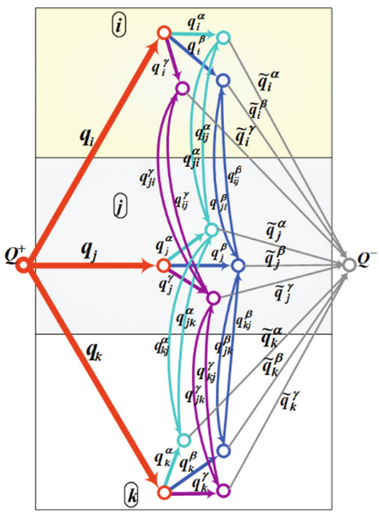

Fig. 1. Calculation flow structure

There is a common source of funds Q^+ (source) and a drain Q^-, and at the same time $Q^- = Q^+$.

Three regions are considered in the model – i, j, k. Possible investments are denoted as flows q_i, q_j, q_k. In region i money flows have the following distribution:

q_i^{α} – on trucks,
q_i^{β} – on containers,
q_i^{γ} – on covered wagons.

Possible investments in vehicles in other regions we denote similarly – q_j^{α}, q_j^{β}, q_j^{γ}, q_k^{α}, q_k^{β}, q_k^{γ}.

To serve regional freight flows may be used vehicles from neighbour regions. In the model it is displayed with the use of flows q_{ij}^{α}, q_{ji}^{α}, q_{jk}^{α}, q_{kj}^{α}, q_{ij}^{β}, q_{ji}^{β}, q_{jk}^{β}, q_{kj}^{β}, q_{ij}^{γ}, q_{ji}^{γ}, q_{jk}^{γ}, q_{kj}^{γ}.

Money flows to the drain $\tilde{q}_i^{\alpha}$, $\tilde{q}_i^{\beta}$, $\tilde{q}_i^{\gamma}$, $\tilde{q}_j^{\alpha}$, $\tilde{q}_j^{\beta}$, $\tilde{q}_j^{\gamma}$, $\tilde{q}_k^{\alpha}$, $\tilde{q}_k^{\beta}$, $\tilde{q}_k^{\gamma}$ denote the total investments in particular vehicles considering the attraction effect.

The money flow unit is connected with two parameters:

h – amount of transported freight,
c – gained income.

This parameters are calculated considering vehicles costs, their carrying capacity, turnover and average income for a month.

The region j has the following freight flows h_j^{α}, h_j^{β}, h_j^{γ}, h_{ij}^{α}, h_{ij}^{β}, h_{ij}^{γ}, h_{kj}^{α}, h_{kj}^{β}, h_{kj}^{γ}. Income from own vehicles – $(q_j^{\alpha} \cdot c_j^{\alpha})$, $(q_j^{\beta} \cdot c_j^{\beta})$, $(q_j^{\gamma} \cdot c_j^{\gamma})$, income gained with the use of vehicles from neighbour regions (for α region) – $(q_{ij}^{\alpha} \cdot c_{ij}^{\alpha})$, $(q_{kj}^{\alpha} \cdot c_{kj}^{\alpha})$.

Max and min restrictions can be assigned to all arcs:

$$\underline{q_i} \le q_i \le \overline{q_i},\ \underline{q_i^{\alpha}} \le q_i^{\alpha} \le \overline{q_i^{\alpha}},\ \underline{q_{ij}^{\alpha}} \le q_{ij}^{\alpha} \le \overline{q_{ij}^{\alpha}} \tag{1}$$

Substantial meaning of the restrictions:

$\overline{q_i}$ – restriction on maximum amount of funds in region i,
$\underline{q_i}$ – restriction on minimum amount of funds in region i,
$\tilde{q}_i^{\alpha} \ge \underline{q_i^{\alpha}}$ – amount of freight that can be transported only in trucks (for example, perishable freight),
$q_i^{\alpha} \le \overline{q_i^{\alpha}}$ – restriction on quantity of trucks for region i. It means that it is impossible to use more trucks.

Similar restrictions can be written for other vehicles and regions.

3.1 Income from Executed Transportations

To calculate income it is necessary to introduce several variables:

– income from transportations in region j with the use of α vehicles

$$C_j^{\alpha} = c_j^{\alpha} q_j^{\alpha} + c_{ij}^{\alpha} q_{ij}^{\alpha} + c_{kj}^{\alpha} q_{kj}^{\alpha} \tag{2}$$

– income from transportations in region j with the use of β vehicles

$$C_j^\beta = c_j^\beta q_j^\beta + c_{ij}^\beta q_{ij}^\beta + c_{kj}^\beta q_{kj}^\beta \tag{3}$$

– from transportations in region j with the use of γ vehicles

$$C_j^\gamma = c_j^\gamma q_j^\gamma + c_{ij}^\gamma q_{ij}^\gamma + c_{kj}^\gamma q_{kj}^\gamma \tag{4}$$

For other regions notations are similar.

Using mentioned above variables total income from transportations can be calculated according to the following formula

$$\sum C = C_i^\alpha + C_i^\beta + C_i^\gamma + C_j^\alpha + C_j^\beta + C_j^\gamma + C_k^\alpha + C_k^\beta + C_k^\gamma \tag{5}$$

To make the formula 5 easier enlarged variables are introduced:

– income from transportations in region i

$$C_i = C_i^\alpha + C_i^\beta + C_i^\gamma \tag{6}$$

– income from transportations in region j

$$C_j = C_j^\alpha + C_j^\beta + C_j^\gamma \tag{7}$$

– income from transportations in region k

$$C_k = C_k^\alpha + C_k^\beta + C_k^\gamma \tag{8}$$

Considering enlarged variables formula to calculate the total income is the following

$$\sum C = C_i + C_j + C_k \tag{9}$$

3.2 Penalties from Unexecuted Transportations

Variables that are necessary to calculate penalties from unexecuted transportations are shown below:

H – given volume of transportation,
$\tilde{H}$ – volume of executed transportations,
d – penalty for unexecuted transportations per the unit of freight flow,
Δd – additional penalty for unexecuted obligatory transportations with the use of given vehicles (per the unit of freight flow).

Volume of transported freight using α vehicles in region i

$$\tilde{H}_i^\alpha = h_{\mathrm{i}}^\alpha q_{\mathrm{i}}^\alpha \tag{10}$$

A penalty for unexecuted transportations in region i

$$D_i = d_{\mathrm{i}}(H_i - (h_i^\alpha q_i^\alpha + h_i^\beta q_i^\beta + h_i^\gamma q_i^\gamma + h_{ji}^\alpha q_{ji}^\alpha + h_{ji}^\beta q_{ji}^\beta + h_{ji}^\gamma q_{ji}^\gamma)) \tag{11}$$

An additional penalty for unexecuted obligatory transportations using given vehicles

$$\Delta D_i^\alpha = (d_i^\alpha - d_i)(H_i^\alpha - h_i^\alpha q_i^\alpha) \tag{12}$$

For the convenience we introduce enlarged variables (by example of region j):

- volume of transportation using all of the vehicles in region j

$$\tilde{H}_j = h_j^\alpha q_j^\alpha + h_j^\beta q_j^\beta + h_j^\gamma q_j^\gamma + h_{ij}^\alpha q_{ij}^\alpha + h_{ij}^\beta q_{ij}^\beta + h_{ij}^\gamma q_{ij}^\gamma + h_{kj}^\alpha q_{kj}^\alpha + h_{kj}^\beta q_{kj}^\beta + h_{kj}^\gamma q_{kj}^\gamma \tag{13}$$

- volume of transportation in region j using own α vehicles

$$\tilde{H}_j^\alpha = h_j^\alpha q_j^\alpha \tag{14}$$

- volume of transportation in region j using α vehicles from neighbour region i

$$\tilde{H}_{ij}^\alpha = h_{ij}^\alpha q_{ij}^\alpha \tag{15}$$

- volume of transportation in region j using α vehicles from neighbour region k

$$\tilde{H}_{kj}^\alpha = h_{kj}^\alpha q_{kj}^\alpha \tag{16}$$

Additional penalties are calculated using the following formulas:

- for region j and own α vehicles

$$\Delta d_j^\alpha = d_j^\alpha - d_j \tag{17}$$

- for region j and α vehicles from neighbour region i

$$\Delta d_{ij}^\alpha = d_{ij}^\alpha - d_{ij} \tag{18}$$

- for region j and α vehicles from neighbour region k

$$\Delta d_{kj}^\alpha = d_{kj}^\alpha - d_{kj} \tag{19}$$

An additional penalty for unexecuted obligatory transportations in region j

$$\Delta D_j^{\alpha} = \Delta d_j^{\alpha}(H_j^{\alpha} - \tilde{H}_j^{\alpha}) + \Delta d_{ij}^{\alpha}(H_{ij}^{\alpha} - \tilde{H}_{ij}^{\alpha}) + \Delta d_{kj}^{\alpha}(H_{kj}^{\alpha} - \tilde{H}_{kj}^{\alpha}) \tag{20}$$

A total penalty for unexecuted transportations for all regions

$$\begin{aligned}\sum D = {} & d_{\mathrm{i}}(H_i - \tilde{H}_i) + d_{\mathrm{j}}(H_j - \tilde{H}_j) + d_{\mathrm{k}}(H_k - \tilde{H}_k) \\ & + \Delta D_i^{\alpha} + \Delta D_i^{\beta} + \Delta D_i^{\gamma} + \Delta D_j^{\alpha} + \Delta D_j^{\beta} + \Delta D_j^{\gamma} + \Delta D_k^{\alpha} + \Delta D_k^{\beta} + \Delta D_k^{\gamma}\end{aligned} \tag{21}$$

To make the calculation more convenient enlarged variables are introduced:

- penalty for unexecuted transportations in region i

$$D_i = d_{\mathrm{i}}(H_i - \tilde{H}_i) \tag{22}$$

- penalty for unexecuted transportations in region j

$$D_j = d_{\mathrm{j}}(H_j - \tilde{H}_j) \tag{23}$$

- penalty for unexecuted transportations in region k

$$D_k = d_{\mathrm{k}}(H_k - \tilde{H}_k) \tag{24}$$

The total penalty for unexecuted transportations written using enlarged variables

$$\sum D = D_i + D_j + D_k + \Delta D_i^{\alpha} + \Delta D_i^{\beta} + \Delta D_i^{\gamma} + \Delta D_j^{\alpha} + \Delta D_j^{\beta} + \Delta D_j^{\gamma} + \Delta D_k^{\alpha} + \Delta D_k^{\beta} + \Delta D_k^{\gamma} \tag{25}$$

The use of vehicles is restricted by availability of freight and is denoted using the following equation

$$h_i^{\alpha} q_i^{\alpha} + h_i^{\beta} q_i^{\beta} + h_i^{\gamma} q_i^{\gamma} + h_{ji}^{\alpha} q_{ji}^{\alpha} + h_{ji}^{\beta} q_{ji}^{\beta} + h_{ji}^{\gamma} q_{ji}^{\gamma} \le H_i \tag{26}$$

Restrictions can be applied to a particular vehicle

$$h_i^{\alpha} \cdot q_i^{\alpha} + h_{ji}^{\alpha} \cdot q_{ji}^{\alpha} \le H_i^{\alpha} \text{ or } \tilde{H}_i^{\alpha} \le H_i^{\alpha} \tag{27}$$

An optimization criterion is the maximum difference between income and penalties

$$\begin{aligned}& C_i^{\alpha} + C_i^{\beta} + C_i^{\gamma} + C_j^{\alpha} + C_j^{\beta} + C_j^{\gamma} + C_k^{\alpha} + C_k^{\beta} + C_k^{\gamma} \\ & -(d_{\mathrm{i}}(H_i - \tilde{H}_i) + d_{\mathrm{j}}(H_j - \tilde{H}_j) + d_{\mathrm{k}}(H_k - \tilde{H}_k) \\ & + \Delta D_i^{\alpha} + \Delta D_i^{\beta} + \Delta D_i^{\gamma} + \Delta D_j^{\alpha} + \Delta D_j^{\beta} + \Delta D_j^{\gamma} + \Delta D_k^{\alpha} + \Delta D_k^{\beta} + \Delta D_k^{\gamma}) \to \max\end{aligned} \tag{28}$$

4 Results Obtained Using the Optimization Program

A set of calculations was carried out using the optimization program and results from one of the calculations are shown below.

4.1 Investments

A distribution of investments in vehicles is shown in Fig. 2:

Vehicle type	Quantity (units)	Cost (thousand of rubles)
Trucks	10	580.0
Containers	170	185.6
Covered wagons	240	1 234.4

Fig. 2. Vehicles structure

Investments in vehicles used inside home region are shown in Fig. 3, investments in vehicles used in neighbour regions – Fig. 4.

Vehicle type	Quantity (units)	Cost (thousand of rubles)
	i	
Trucks	0	0.0
Containers	21	22.9
Covered wagons	89	458.6
	j	
Trucks	10	580.0
Containers	15	15.7
Covered wagons	3	11.5
	k	
Trucks	0	0.0
Containers	8	8.6
Covered wagons	87	452.3

Fig. 3. Vehicles used inside home region

Vehicle type	Quantity (units)	Cost (thousand of rubles)
i - j		
Trucks	0	0.0
Containers	11	11.4
Covered wagons	29	147.1
j - i		
Trucks	0	0.0
Containers	111	122.7
Covered wagons	0	0.0
k - j		
Trucks	0	0.0
Containers	4	4.3
Covered wagons	32	164.8

Fig. 4. Vehicles used in neighbour regions

4.2 Transportations

The optimization program gives out volume of executed transportations using own vehicles and vehicles from neighbour regions (Fig. 5), including division by vehicle types (Fig. 6).

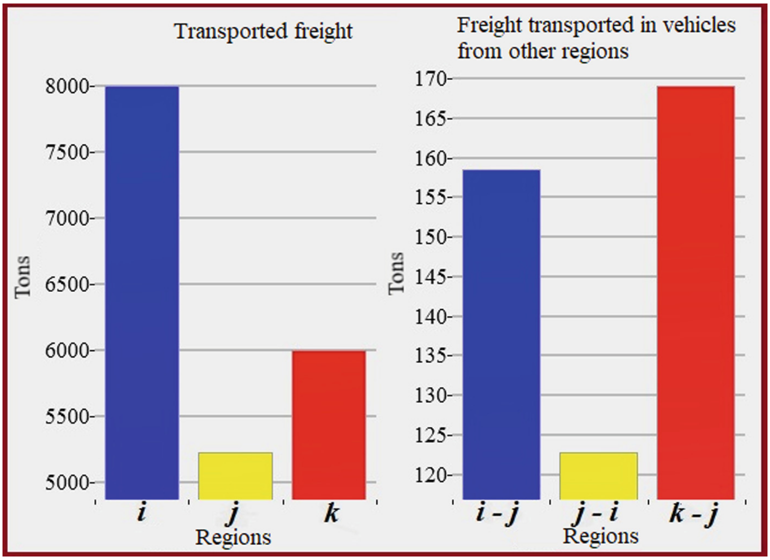

Fig. 5. Volume of transportation in regions

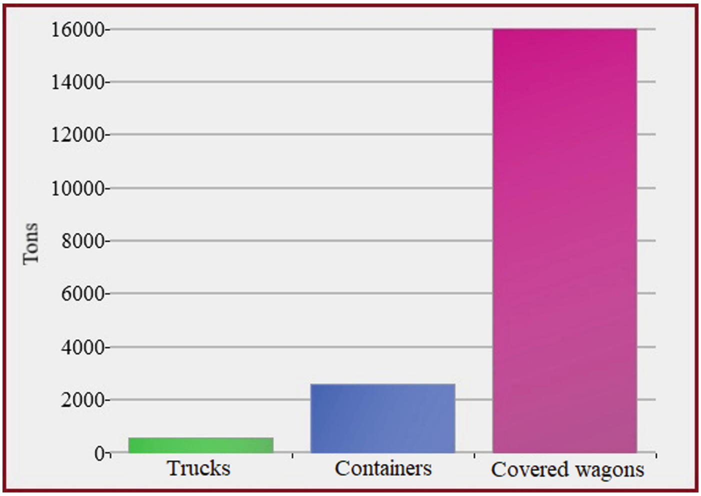

Fig. 6. Transportations executed using different types of vehicles

4.3 Income and Penalties

The optimization program calculates both total income and income divided by regions and vehicle types (Fig. 7).

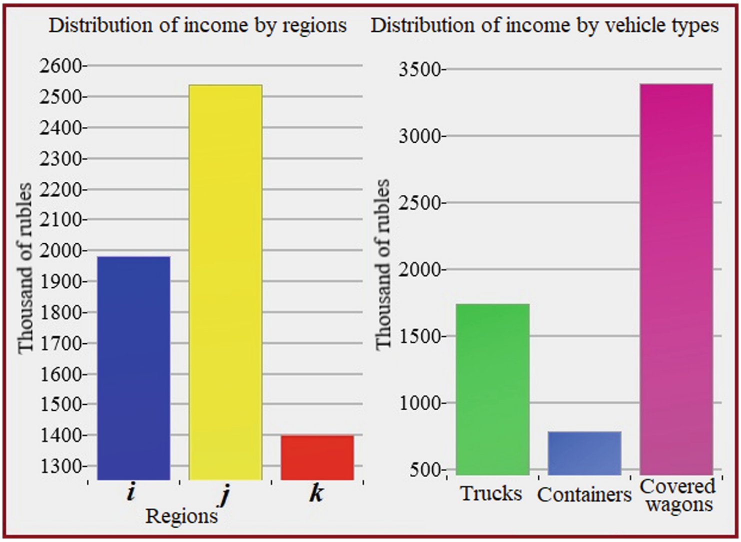

Fig. 7. Distribution of income by regions and vehicle types

Results of penalties calculation can be shown in different forms: the total penalty for all regions and penalties divided by vehicle types (Fig. 8). Moreover, the program gives out additional penalties for unexecuted obligatory transportations using specific vehicles.

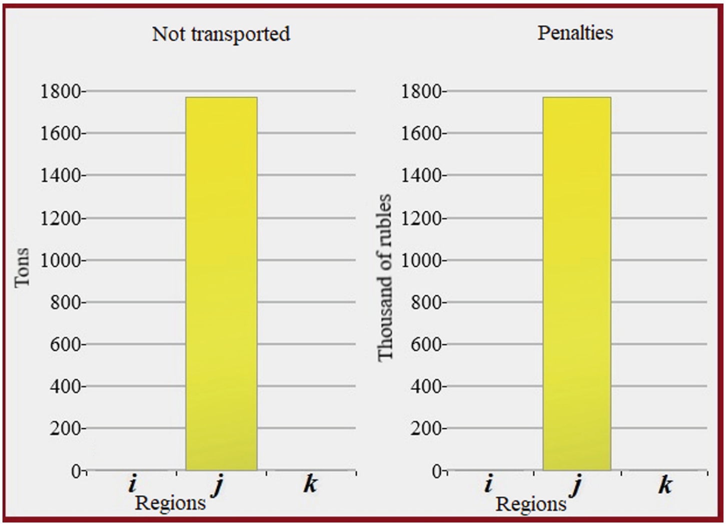

Fig. 8. Penalties for unexecuted transportations

5 Conclusion

Because of the impossibility of existing models to consider different types of transport in one model it was proposed to use money flows instead of freight flows. The optimization model allows to determine the optimal fleet size and structure of relatively interchangeable types of transport. The computer program based on proposed optimization model allows carrying out different experiments applying different initial data and helps to determine the most effective solutions in a dynamic market environment.

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Elaboration of a Model of Integrated Transport Service in the Segment of Freight Transportation

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Abstract. The transportation system is an independent industry implying carriage of goods from a producer to a consumer using various types of transport. Requirements of owners of business production processes to transportation of freights and goods can be covered by both single and several types of transport, depending on market conditions, technological features of production and level of infrastructure development. In the Russian Federation, a large part of cargo traffic accounts for railway transport, which determines the concept of the development of railway industry based on the principles of consolidation with other subjects of the unitary transportation process and its integration into the international transportation system. The paper is aimed at searching for an alternative way of development and implementation of transport potential of railway industry, both in the country's freight segment and in the international freight transportation area. The authors developed and proposed a model of integrated transport services in all categories of freight traffic based on self-organization. Self-organization coordinates and interconnects investments, profits, potential and target function of Divisions of the integrated transport services. This model allows determining the value of optimal expenditure of funds and investments that are necessary for upgrading an integrated transport service being provided or purchased to the preferred state. The results of using the proposed model bring to the conclusion that solving strategic tasks of Russian economy on ensuring the reliability of unitary transportation and production process, on increase in competitiveness, can be accomplished by using integrated transport service model.

Keywords: Model, integrated transport service · Transportation categories · Self-organization · Adaptation mechanism

1 Introduction

Forecasting and planning correspondence of freight traffic in the interaction space of various types of transport is a scientific and applied task aimed at developing the potential of the transport industry, taking into account the dependence of the production

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of goods, their consumption and the actual need for transport services. Studies show that the transport and economic potential [1] ensures the stable functioning of the transport system, but does not ensure its effective development in the interaction space of various means of transport.

The transport system is characterized by disunity of production processes [2], isolation of digital technologies, fragmentation of technological processes in the categories of transportation, when several types of transport are interacting. These features decrease the production volumes, increase the growth rate of the added value of end products, reduce the turnover of investments, which is unacceptable for a consumer of transport services, who is interested in the flow of end products to a consumer on time and in affordable price of goods and freight [3].

Freight services in the domestic transport system are classified by the following categories [4]:

1. Domestic transportation of industrial and manufacturing enterprises. Included in the process of production and affect the period of production (Pp) [4, 5]. Performed by various modes of transport. The costs of these shipments (Zit) are included in the calculation of the cost of production (Cend pr).
2. Industrial transportation. Included in the process [5, 6] commodity - cargo movements. Combine the activities of enterprises of inter-industry transport. The cost of industrial transportation (Zind.tr), are included in the calculation of value added products (Dend pr).
3. Regional transportation. Included in the process of transportation within the region. The tariff for regional transportation (Treg. tr), is an indicator of transport processes within the region, affects the calculation of the value added of the finished product. Profit from this transportation (Preg.tr), is the end result for the subject of the service.
4. Interregional transportation. Included in the process of transportation between regions. Tariff for inter-regional transportation (Tint.reg.tr) - an indicator of transport processes between regions and affects the calculation of value added products. Profit (Pint.reg.tr), the result for the subject of the service.
5. International transportation. Included in the process of transportation between states and countries. The international transportation tariff (Tint.tr) is an indicator of foreign trade processes in the import and export of transport services and affects the calculation of the value added of products. The result of international carriage for the subject of the service is the profit (Pint.tr).
6. Transit transportation. Included in the transit process for the domestic transport industry. The tariff of this transportation (Ttr) shows the ability of the country's transport industry to provide transit of goods and goods and the ability to compete in the international market of transport services. Profit from this transportation (Ptr), is the end result for the subject of the service.

Thus, the transport industry arranges engineering and manufacturing transportations, as well as economic ones [7] in the space of domestic and international transport.

Figure 1 shows the integrated transport service model in the freight transportation segment, where the leading role is determined by rail transport, and the mechanism for its adaptation.

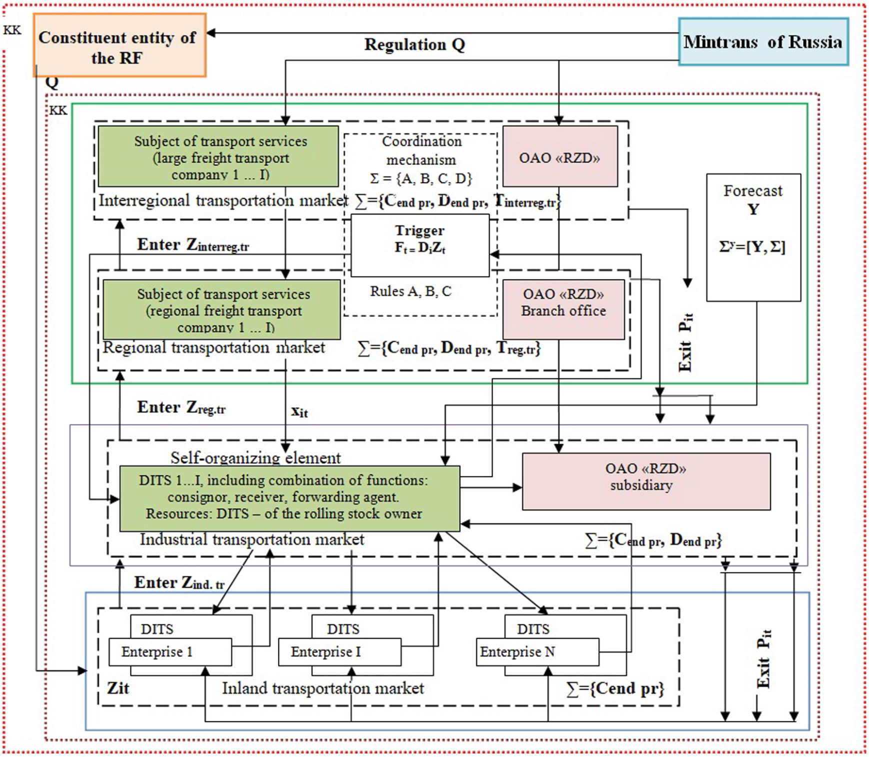

Fig. 1. Model of integrated transport services in the segment of freight traffic and the mechanism of its adaptation

Figure 2 shows the model of an integrated transport service in the international freight transportation space and the mechanism for its adaptation.

This model was developed based on characteristics of the transport service market and state regulation.

Figures 1 and 2 show how transport business processes enable forming the space unity of goods and freight movement, ensuring the transition to a new level of management that unites the processes [8] of transport services. This allows reducing the growth rate of value added of products, increasing investment in guaranteed performance of the main criteria for the quality of integrated transport services and provides the increase in productivity growth rate in a single transport system.

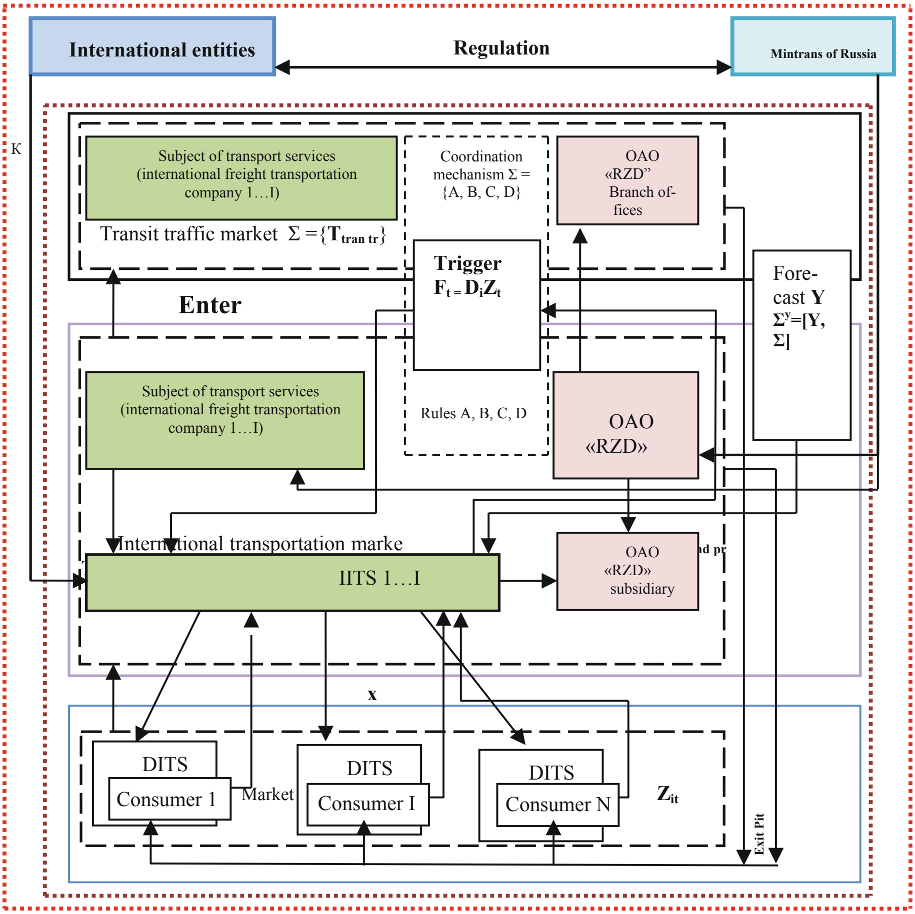

Fig. 2. Model of integrated transport services within international freight traffic and its adaptation mechanism

2 Model Structure and Methods of Its Developing

In the model of integrated transport services in the segment of freight transportation, the main criteria for consumers of the transport industry are considered not according to the principle of their increase, but according to the principle of improving the quality of the integrated provision of services [4, 9]. In other words, the model is a system of integrated transport services, characterized by the consolidated activities of transport services entities that provide transportation on the infrastructure of a unified transport system. The management system [10] of this model is a process for the targeted impact of business processes of transport services entities on the resources of the transport system of the model, which ensures its functioning and the achievement of the main criteria for the quality of integrated transport services [11].

To implement the principle of improving the quality of integrated services, it is proposed to develop the processes of interaction between the subjects of these services and provide integrated transport services in transportation categories by organizing their own resources of the Divisions of integrated transport services in the transport and production process based on self-organization. Self-organization coordinates [12] and interconnects investments, profits, potential and the objective function of the Divisions of the integrated transport services. The self-organization procedure allows determining the value of the optimal expenditure of funds and investments necessary for the transfer of an integrated transport service when it is provided or acquired in a preferred state.

The adaptation mechanism in the model of integrated transport services [1, 5] is characterized as a multi-level system. Figures 1 and 2 show that at the top level there is the administration unit of the coordination department of the Ministry of Transport and the unit of the constituent entity of the Russian Federation for the transportation categories domestic, industrial, regional and interregional. The fourth, third and second level form a self-organizing element, which is formed into a coordinating body. A large-scale freight transport company and the head office of Russian Railways in the interregional transportation category. The Managing Center is the Regional Freight Transport Company and branches of Russian Railways in the regional transportation category, the Integrated Transport Service Divisions and the railway station in the industrial transportation category. At the lower level are the consumers of the integrated transport services - industrial and industrial enterprises and performers - structural Divisions of the integrated transport services in the category of internal transport.

The Ministry of Transport and the constituent entities of the Russian Federation regulate the relationship between the owners and consumers in the integrated transport service model in the freight segment.

For the categories of international and transit traffic, at the top level is located the office of coordination of an international subject and the office of the Ministry of Transport of Russia. The self-organizing element is formed [7, 13] at the third and second levels and consists of the coordinating body International Freight Transport Company and the main department of JSC Russian Railways in the categories of international and transit traffic. The managing center is the International Center for Integrated Transport Services and the railway station in the international transport category. At the lower level are the consumers of the integrated transport services - industrial and industrial enterprises and performers - structural Divisions of the integrated transport services.

In the area of international freight transportation, the international entity and the Ministry of Transport carry out the regulation of relations between owners and consumers in the Integrated Transport Service Model.

The options of the possible states of the model of an integrated transport service depend on such parameters [7] as: $A = (A_1, \ldots, A_N)$, $B = (B_1, \ldots, B_N)$, $C = (C_1, \ldots, C_N)$, $D = (D_1, \ldots, D_N)$. The set of parameters forms the mechanism of coordination and regulation of the integrated transport service $\sum = \{A, B, C, D\}$ and consists of the following: each parameter determines the position of the transport and production processes of the subjects of the self-organizing element represented by key indicators of the main criteria for the quality of integrated transport services.

Using the methodological basis for the formation of adaptive mechanisms, the profitability of the i-th division of the integrated transport service A_i is determined:

$$A_i = (Z_i - C_i)(1 - gn_i)N_i, \tag{1}$$

where Z_i – cost of transport–production process;

C_i – prime cost of transport–production process;
gn_i – income tax rate;
N_i – amount of transport services or products.
B_i indicator determines the efficiency of investments in the development of integrated transport services:

$$B_i = r_i(1 + S_i), \tag{2}$$

where r_i – investment efficiency;
S_i – investment support by a coordinating body.
The indicator C_i determines the wear rate of transport-production assets:

$$C_i = 1 - a_i R_i \tag{3}$$

where a_i – standard value for depreciation;
R_i – depreciation coefficient
D_i indicator shows what percentage of profit left by the i-th Division of the integrated transport services depends on the depreciation allowance and the profit tax rate:

$$D_i = 1 - gn_i - ſ_i, \tag{4}$$

where $ſ_i$ – depreciation allowances.

In the process of regulation and coordination of the i-th Division of the integrated transport service, adaptation ensures [5, 14] a change in the growth of its potential, ft, depending on the investment xt by the control center. The potential is determined by the significance of the transport and production process of the Integrated Transport Service Division and depends on investments in previous periods:

$$f_{it+1} = C_{it}f_{it} + B_{it}x_{it},\ C_{it} > 0,\ B_{it} > 0,\ f_{i0} = f_i^0,\ f_i^1 > 0, i = 1, \ldots, N, \tag{5}$$

where t – period number, t = 0, 1, 2, 3, … .

The income of the *i*-th P_{it} enterprise is characterized by the following potential:

$$P_{it} = A_{it}f_{it},\ A_{it} > 0, i = 1, \ldots, N, \tag{6}$$

Self-organization implies that the coordinating body invests the share of the profit received within period t to the Division of Integrated Transport Service (DITS) and has the following form:

$$\sum\nolimits_{i=1}^{N} \mathrm{x}_{it} = \mathrm{F}_t \mathrm{E}, \tag{7}$$

where F_t – total profit remaining at the disposal of the Integrated Transport Service Division;

E – the profit share that is used for investing.

Investments of the Divisions of integrated transport service, as a self-organizing element, create [5, 7, 14] the structure of investment vectors in intervals t, …, and determine the vectors of criteria $\overline{x}_t$, $\tau =$ t, .., t $+ T - 1$ so that the task of synthesizing the mechanism of self-organization coincided with the forecast of preferred criteria $\sum\nolimits^{y} = \{Y, A, B, C, D\}$, as well as in the optimal definition of vectors A, B, C, D, providing the preferred solution:

$$\overline{Y}_i(\Sigma) = \bigcup_{\tau=t}^{t+T-1} \overline{Y}_{\tau t}(\Sigma) \tag{8}$$

It is assumed that the main task of the unity function of the adaptation mechanism of an integrated transport service in transport categories is to forecast the model of the mechanism Σ^y, that provides the maximum of target function, or in other words the investment of a self-organizing element that is preferable for transport service entities. Thus, the solution for a given forecast *Y*, on the set of mechanisms G_y is determined:

$$G^y = \{\Sigma^y = [Y, A, B, C, D,] | A_i \geq 0, |B_i \geq 0, |C_i \geq 0, |D_i \geq 0, |\} \tag{9}$$

Preferred criteria are a set of criteria vectors in period *t*, … , *t* + *T* − *1*: $y_t = (\bar{y}_t, \ldots, \bar{y}_{t+T-1})$ that belong to a set of possible criteria.

The set of self-organization states optimal for transport services entities of this model is defined as:

$$Y = \{y | \overline{y} = [\overline{y_0}, \ldots, \overline{y_n}]\} = \arg\max \Lambda(\overline{x}_0, \ldots, \overline{x}_n) \tag{10}$$

where $\overline{y} = [\overline{y_0}, \ldots, \overline{y_n}]$ – forecast of the vector of optimal investments in the period $t = 0, \ldots, T$;

$\Lambda(\overline{x}_0, \ldots, \overline{x}_n)$ – the target function of the subjects of transport services in the categories of traffic increasing on X_{it}.

Thus, the problem of optimal synthesis of the self-organization mechanism of integrated transport service in the developed model consists in fulfilling the development of each entity of a transport service [14] which is a part of the structure of the self-organizing element, as well as in building the transport and production process ensuring the maximum of the objective function of the integrated transport service on many preferred criteria.

3 Results

The results of using the integrated transport service model in the area of railroad service that were obtained by using the example of manufacturing enterprises and a freight company that owns rolling stock as an alternative owner of integrated transport service are presented in Figs. 3 and 4.

The characteristics of the calculations show that the process of providing integrated transport services is quite effective. Thus, Fig. 3 shows (dependence curve I) that the minimum total transportation costs (E) are achieved with rational transportation regulation ($R^{comp}_{trans.serv}$), at a distance of 630 km with a turnover of not more than 3 days, the model uses a combined mode of transportation, namely: two types of transport, rail and road. The implementation of this transportation allowed reducing the total transportation costs by 16%, and the total turnover by 23%.

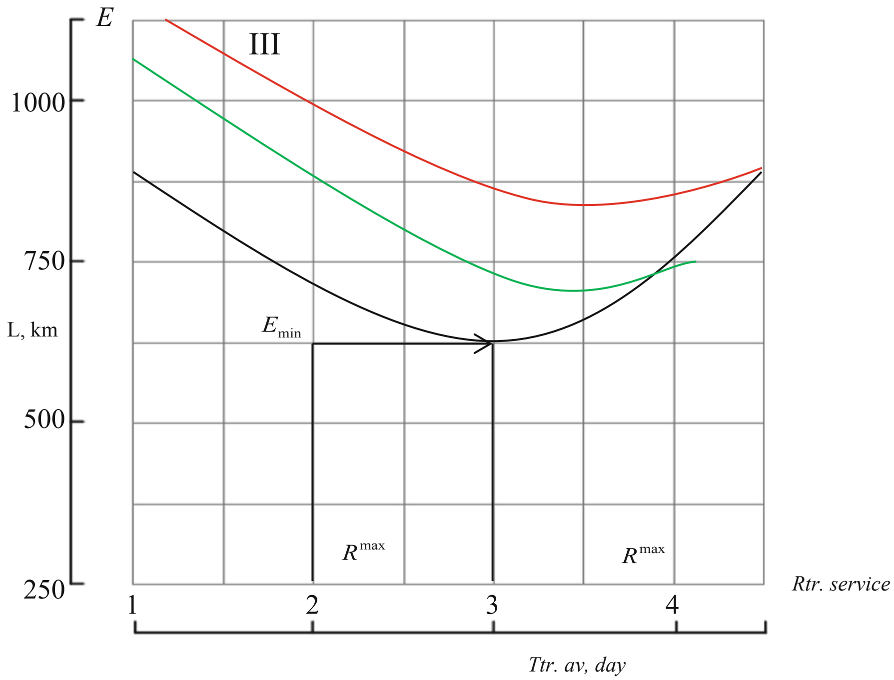

Fig. 3. Nature of dependence of transport costs on the regulation ratio of integrated transport services (on the example of two types of transport: rail and road)

The data presented in Fig. 4 suggests that if the invested periods of the proposed model are maintained, a 3.5-time increase in production is ensured (dependence curves II, III). A steady reduction in the unit cost of production up to 18%, the added value of the finished product up to 23% is provided, as a result, the price of production changes down to 19% (dependence curve III).

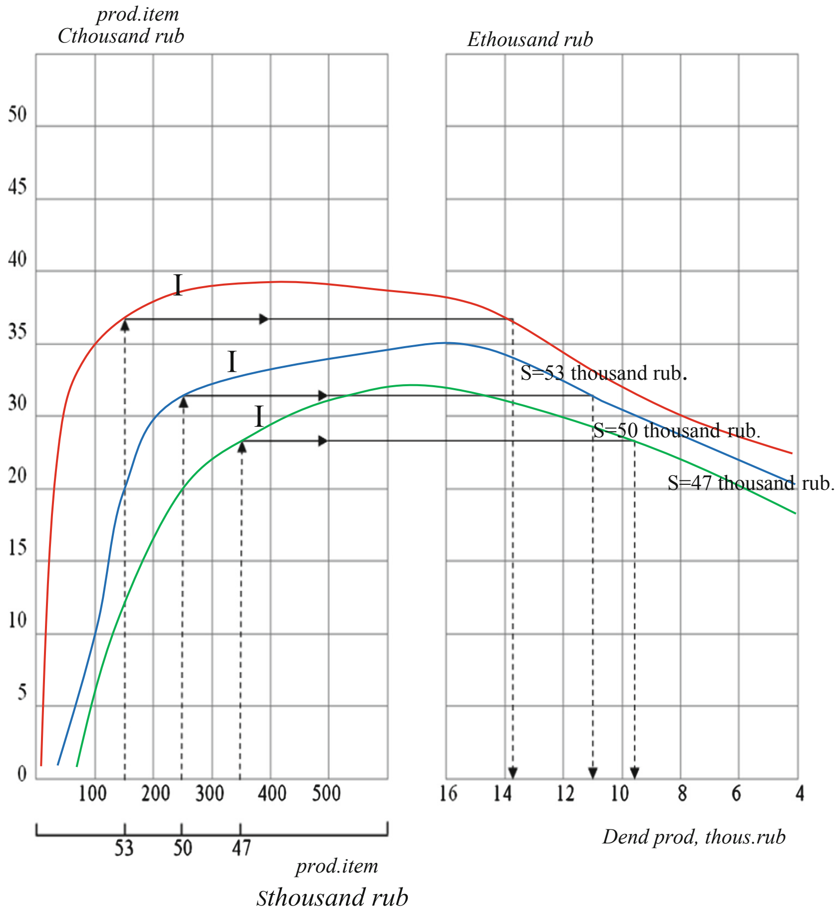

Fig. 4. The dependence of the price of products on total reduced costs and initial production volume of finished products (on the example of products of concrete)

Therefore, the obtained results lead to the conclusion that the solution of strategic tasks of the country's economy on ensuring the reliability of the unified transportation-production process, increasing the growth of competitiveness and affordability of transport services, is possible using the integrated transport service model.

The solution of the problem of synthesizing the mechanism of self-organization of the integrated transport service in the developed model enables the subjects of transport services to forecast and plan efficiently the transport and production process in the areas of interaction between different types of transport. The efficiency of interaction between industrial and mainline transport is increased. The qualitative analysis of sales and production based on the formation of transport and logistics flows in a unitary transport system is provided.

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Analysis of the Error in Determining the Location Inside the Logistics Warehouse Complexes

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Abstract. This paper presents the results of analyzing the error in calculating the mobile subscriber coordinates using three Wi-Fi access points, where the calculation is based on measuring the received signal power. The purpose of the study was to develop a geopositioning system for large storage facilities and to evaluate the accuracy of the calculations. The principles of local and global positioning, based on the measurement of various signal propagation physical characteristics, were considered, the method for the geopositioning system implementation was selected. The authors have developed a test bench layout of the IEEE 802.11 mobile network geolocation and a software product for solving this problem using the trilateration mechanism. A parameter for the imitation of the additive white Gaussian noise was added to the calculation formulas to emulate a real electromagnetic environment. Graphical relationships between the object coordinates measurement error, the channel's signal-to-noise ratio and the distance from the reference access point were obtained in the course of the work. The results showed that, even in the worst operating conditions, the developed system is superior to most systems on the market in terms of measurement accuracy.

Keywords: IEEE 802.11 · Geopositioning · Trilateration · Signal-to-noise ratio

1 Introduction

The task of determining the object's location in premises based on Location-based service (LBS) is of great interest for the implementation of logistics operations, traffic management and process automation inside large warehouse complexes.

Traditionally, the LBS uses Global Positioning System (GPS), Global Navigation Satellite System (GLONASS), and other satellite-based positioning and navigation systems [1–3]. The mentioned systems make it possible to ensure the measurement accuracy of three to five meters and require a direct line of sight for the satellites. The disadvantages of satellite navigation systems include high power consumption and the inability to receive a satellite signal indoors. Therefore, the local positioning services

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based on the use of Wi-Fi access points (AP) are now widely used [4, 5]. It should be noted that in Wi-Fi networks without centralized control the possibilities of geopositioning are either completely absent or very limited.

The existing LBS services, such as Skyhook, AlterGeo, Google and Yandex maps, provide information about the location of the subscriber in the urban environment, including indoor locations. These services are based on the triangulation method and provide the maximum location determining accuracy of about 15 m under the condition of a high Wi-Fi access points concentration on the ground.

The authors are faced with the following task: to develop a local geolocation system based on the known power of the signal received by the mobile subscriber from each of the Wi-Fi access points using the trilateration method and to evaluate the measurement error in reception conditions close to the real ones.

The principle of the positioning system operation in a centralized Wi-Fi network is based on the calculation of the Wi-Fi client coordinates in the coordinate system tied to access points and the indoors maps of facilities where GLONASS/GPS signals are not available and the mobile network signal location determination accuracy is very rough (300 to 500 m).

2 Geopositioning Methods in Mobile Systems

Let's review the existing mobile subscriber's location determination methods, used in various infocommunication systems [6, 7].

The principles of geopositioning are based on the following radio signal physical characteristics:

- Received Signal Strength (RSS). The electromagnetic wave power density in the free space is directly proportional to the power of the transmitter emitted signal emitted and inversely proportional to the square of the distance from the source (inverse-square law) [8].
- Time Of Flight (TOF). The distance between the transmitter and the receiver is equal to the signal propagation time and the propagation velocity (speed of light) composition. Here the distance can be determined both by the Time of Arrival (ToA) of the signal to the receiver, when the transmission start time is known, and by the Phase of Arrival (PoA) of the received signal, which is related to the propagation delay and the distance through the wavelength and the speed of light [9, 10].
- Angle Of Arrival (AOA) or Direction Of Arrival (DOA). The angle or direction of the wave arrival can be estimated by the antenna pattern. However, at least two AOA measurements (from different points) or a several parameters measurement (AOA and TOF or RSS) are required to determine a location [11, 12].
- Phase difference between electric and magnetic field. This value depends on the distance to the source and allows this distance to be calculated.

The following positioning mechanisms are based on the above characteristics measurement [6, 7]:

- The nearest access point mechanism. The subscriber is assigned the coordinates of the access point from which the signal of the highest power was received. The main advantage of the method lies in its implementation ease, the main disadvantage is the very low positioning accuracy.

The triangulation method is based on the geometric relationships. To determine the object's location, there must be at least two stationary access points with directional antennas and known coordinates. One of the access points is located at the origin of coordinate system (let's call it the reference point). The object's coordinates in this case depend on the angles AOA θ_1 and θ_2, which are measured relative to the north direction, and are calculated as follows:

$$
\begin{aligned}
y &= \frac{y_2 \cdot \tan(\theta_2) - x_2}{\tan(\theta_2) - \tan(\theta_1)} \\
x &= y \cdot \tan(\theta_1)
\end{aligned}
\tag{1}
$$

Positioning accuracy is determined by the antennas directivity.

- The spatial samples differentiation method is based on measuring the power of the signal received from all access points and comparing the obtained values with the measurement samples taken in advance at certain points of the room, which are stored in the database. This mechanism provides high measurement accuracy, but requires a great deal of preliminary measurements, which will be subsequently updated depending on the environmental conditions changes.
- The trilateration method is studied in detail in the next section. This method determines the object's position on the ground by constructing the adjacent triangles and measuring their sides.

3 Trilateration

The trilateration method is used for geopositioning in this work. It consists of determining the object's location as the coordinates of three spheres intersection point, with the centers of spheres being access points AP1, AP2 and AP3, the coordinates of which are known, so the method boils down to solving a system of linear equations [13, 14].

The basic principle of trilateration is illustrated in Fig. 1.

To simplify the calculations the coordinate system is transformed in such way that the center of the first (reference) sphere is at the origin $(0,\ 0,\ 0)$, the center of the second sphere is located on the abscissa axis $(x_2,\ 0,\ 0)$, and the center of the third sphere has the coordinates $(x_3,\ y_3,\ 0)$. Thus, the centers of all spheres lie in a plane $z = 0$.

The radii of the spheres $r_1,\ r_2$ and r_3 are the distances from the access points to the object and can be determined from RSS measurement or TOA delay.

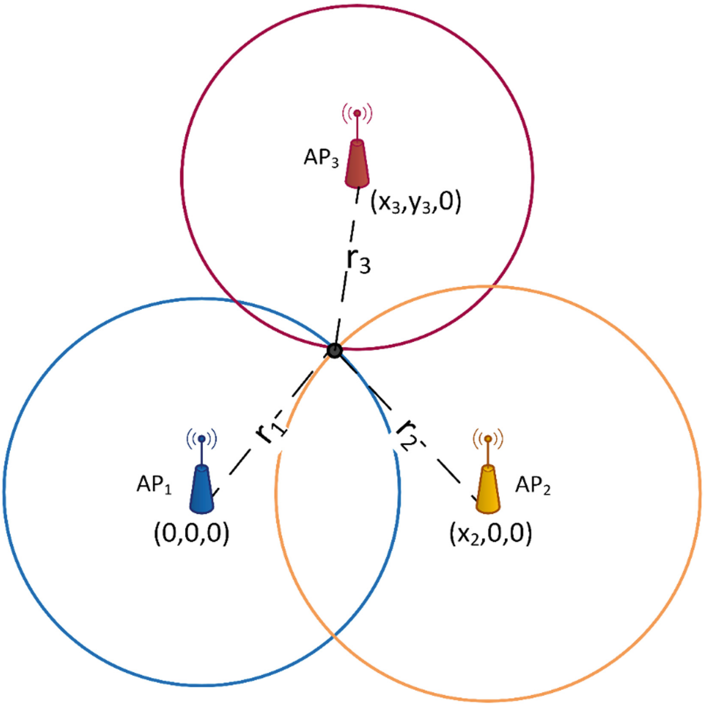

Fig. 1. The principle of positioning using three access points.

The object's coordinates can be calculated by solving the equations system of the three spheres equations, taking into account the reduced coordinate system:

$$\begin{array}{l} r_1^2 = x^2 + y^2 + z^2 \\ r_2^2 = (x - x_2)^2 + y^2 + z^2 \\ r_3^2 = (x - x_3)^2 + (y - y_3)^2 + z^2 \end{array}. \tag{2}$$

Let's express the object's coordinates:

$$x = \frac{r_2^2 - r_1^2 + x_2^2}{2 \cdot x_2}; \tag{3}$$

$$y = \frac{r_1^2 - r_3^2 + x_3^2 + y_3^2}{2 \cdot y_3} - \frac{x_3}{y_3}x; \tag{4}$$

$$z = \pm\sqrt{r_1^2 - x^2 - y^2} \tag{5}$$

Note that in the reduced coordinate system $z = 0$.

The system described here determines the distance by the power of the signal at the mobile equipment receiving device input. The Friis formula [15], which determines the radio waves propagation in free space, is used for that:

$$\frac{P_R}{P_T} = \frac{G_T G_R \lambda^2}{(4\pi)^2 R^2} \tag{6}$$

where P_R and P_T are the reception and transmission powers, respectively; G_T and G_R are the gain of the transmitting and receiving antennas, respectively; $\lambda = \frac{c}{f}$ is the wavelength of the radio signal, c is the speed of light, f is the transmission frequency; R is the distance between the transmitter and the receiver.

The disadvantage of this geopositioning method is that while determining the distance the real conditions of signal propagation are not taken into account: multipath, fading, absorption by obstacles, etc.

4 The Test Bench for the Local Positioning System

To implement the bench, the following equipment from Eltex, a Russian developer and manufacturer of telecommunication equipment, was used:

- Access points WEP-12ac;
- MES3108F and MES2208P switches;
- SoftWLC software for organizing DHCP, RADIUS, SNMP, HTTP and other servers.
- The test bench layout is shown in Fig. 2.

WEP-12ac access points operate in the 2.4 GHz and 5 GHz frequency ranges, with built-in antenna amplification factors of 5 dBi and 6 dBi, respectively, and transmitter output power up to 19 dBm.

Two VLANs are set up on the test bench:

- **VLAN 10** is used to transfer the control traffic between the controller and access points;
- **VLAN 20** is used to transfer the user traffic.

Each Wi-Fi access point is controlled by VLAN 10 and transfers user traffic to the network through VLAN 20. The DHCP server on the controller carries out the distribution of IP addresses to access points and network. The controller itself acts as a router between VLAN 10, VLAN 20 and Research and Education Center (REC). All the packets routed by the controller to the REC network (via the enp0s3 interface) go through Network Address Translation (NAT).

Authentication of users of each Wi-Fi network is carried out centrally through a web portal.

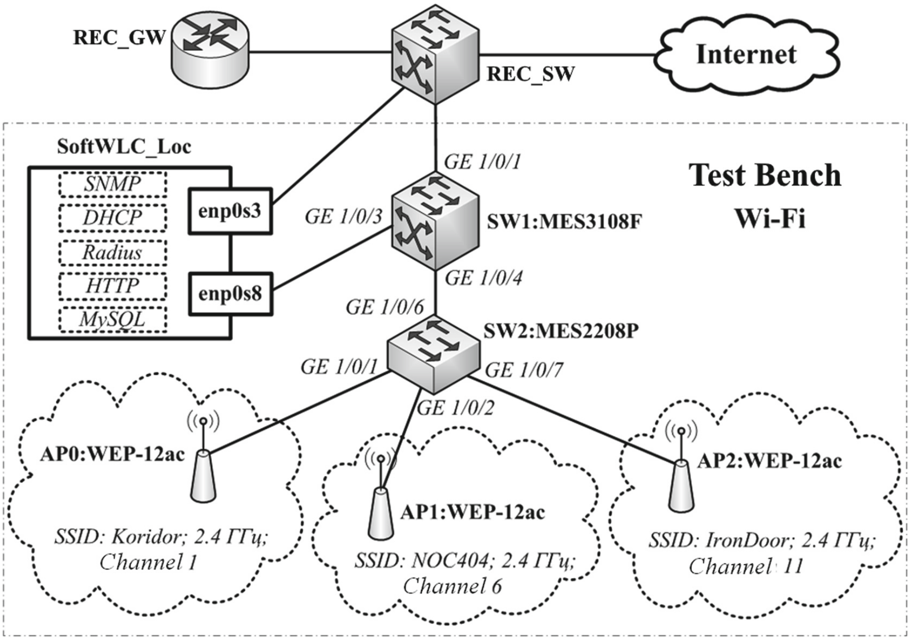

Fig. 2. The geopositioning in Wi-Fi network test bench layout.

5 The Results

To take into account the real conditions of signal propagation, an additional parameter was brought into the calculations for determining the mobile subscriber's location, which defines the signal-to-noise ratio (SNR) and corresponds to the Additive White Gaussian Noise (AWGN). Then the AWGN impact on the accuracy of determining the subscriber's location was evaluated.

Since the WEP-12ac access points used in the geopositioning system tests are dual-band, the calculations were carried out for the transmission in the 2.4 GHz and 5 GHz frequency ranges. As a result, the graphs showing the relationships between the measurement error, signal-to-noise ratio and the distance to the reference access point, were obtained and are presented in Figs. 3 and 4. The calculations were performed in the system of mathematical and engineering calculations Mathcad.

Figure 3 illustrates the relationship between the positioning error and signal-to-noise ratio. It can be seen in the figure how exactly AWGN affects measurement accuracy. Despite the result deterioration with an increase in the noise power compared to the useful signal power, the error value continues to remain within the acceptable range for use.

With the increase in the distance between access points and, correspondingly, the decrease in the signal power at the receiving antenna input, a slight measurement results deviation from the real values is observed, but likewise does not exceed the permissible values.

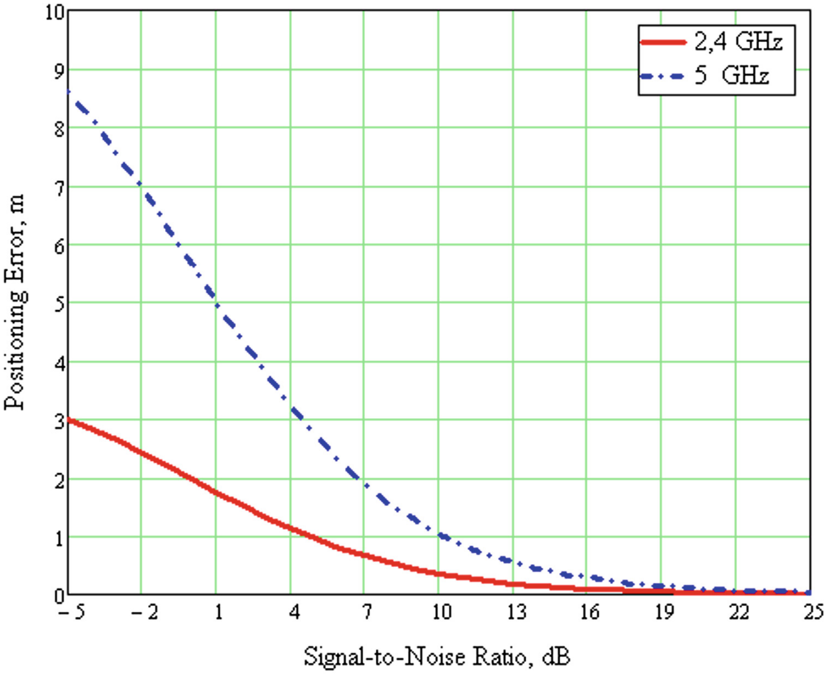

Fig. 3. The relationship between the measurement error and signal-to-noise ratio.

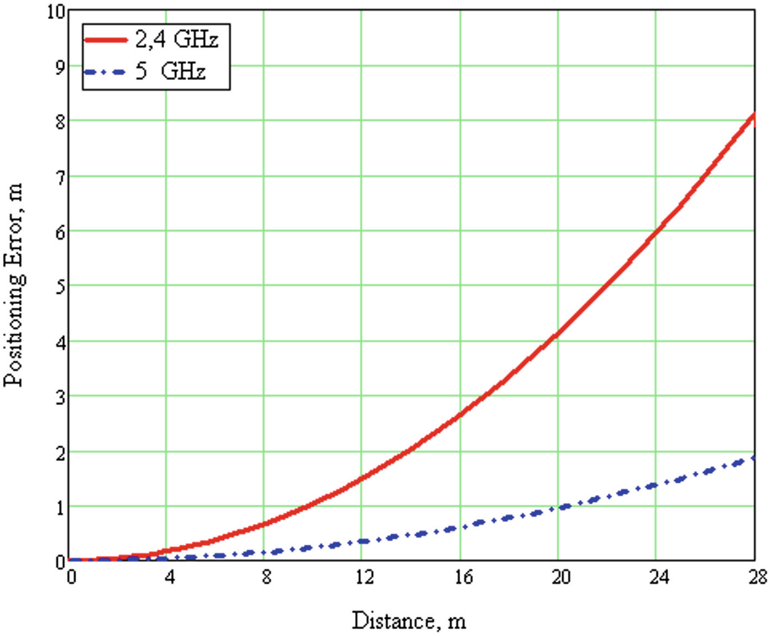

Fig. 4. The relationship between the measurement error and the distance.

The relationships presented in Figs. 3 and 4 show that, even in the worst conditions, the positioning error does not exceed 8.5 m for a transmission at 5 GHz frequency and 3 m for transmission at 2.4 GHz frequency, which is an acceptable result within the same room. It can be claimed that in terms of measurement accuracy this system is superior to many LBS solutions available on the market.

6 Conclusion

To determine the coordinates of the object inside the logistics warehouse complexes the local positioning methods based on the various physical characteristics measurements of the radio signal were considered in this paper. The trilateration method using the RSS parameter was selected to implement the geopositioning system in Wi-Fi networks. The authors developed the scheme for constructing a test bench for the system and the software for determining the mobile subscriber's coordinates in the room. Then the measurement error was estimated and showed the developed system efficiency in the real conditions of the radio signal propagation.

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Research of the Incoming Traffic Flow at City Intersections on the Suitability of the Use of Adapted Traffic Light Control

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Abstract. When choosing methods for traffic organization at intersections and introducing automated traffic control systems, the problem arises of assigning a method of regulating traffic flow. The choice is affected by the degree of isolation of one intersection from neighboring ones. Different sources and regulatory documents give different recommendations for determining this parameter. In particular, in "Highway capacity manual" it is defined that an intersection that does not have a signal-controlled intersection in the vicinity of more than 1.6 km in isolation is defined. This situation makes all city intersections uninsulated, a priori working in conjunction with neighboring intersections. The article checks the incoming traffic flow for compliance with the basic statistical laws of the distribution of intervals between vehicles in it. In the future, the goal is to identify significant differences in the behavior of the traffic flow, which would affect the effectiveness of adaptive traffic control.

Keywords: Traffic control systems · Traffic flow · Traffic organization · Isolated intersections · Adaptive control · Transport infrastructure

1 Introduction

In recent decades, the development of the road network in the largest cities in the world has moved away from broadening the roadway and building interchanges at different levels towards better traffic management and the use of automated traffic control systems [1–3]. It can also be called a transition from extensive to intensive development. As a result of this, hidden opportunities are used to increase the capacity of city intersections and the area occupied by the transport infrastructure is freed. This happens both with a decrease in the overall level of motorization in megacities and without a decrease (in cities with a population of more than 500 thousand inhabitants) [4].

General strategies for improving traffic management using automated traffic control systems such as Spectrum 2.0, SCOOT and UTOPIA [1]. These strategies can be formed in three forms:

- Rigid traffic light regulation;
- Coordinated management of interconnected intersections;
- Adaptive control of the incoming transport stream.

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The choice of the type of traffic control is assigned based on several criteria. One of them is the total traffic intensity, then a load of intersections and the distance between adjacent intersections is checked [1–3]. It is proposed to apply fixed regulation at isolated intersections with relatively low traffic intensity. At intersections with a high load level, it is recommended to use adaptive traffic control to increase throughput and reduce overall delays by 15–30% [2, 3]. At nearby intersections, it will be more convenient and efficient to use coordinated regulation (the so-called "green wave").

At first glance, with seemingly reasonable justification, one can notice here the presence of a heuristic approach, which ultimately gives little guidance and freedom in interpreting the data. Although with a similar intersection configuration, clear technical and economic substantiated recommendations are given for choosing the type of intersection (intersection at one level, roundabout, interchange). The difficulty is that the term "isolated intersection" is understood as an intersection located far enough from neighboring ones that a priori do not affect it [3], so working out of conjunction with neighboring nodes [2], which means "fixed" regulation. In norms [3], the distance of 1.6 km, which is equal to 1 land mile, is taken as the isolation criterion. When this criterion is applied to the road network of cities, all urban signal-controlled intersections automatically become uninsulated.

All of the above allows us to formulate the purpose of the study - to clarify the wording of the concept of "isolated intersection" [4] and to consider the possibility of effective adaptive control of traffic lights at signal-controlled intersections located relatively close to each other at distances of 200–1300 m.

2 Materials and Methods

In this research, it is proposed to analyze the incoming traffic flow, to verify compliance with the basic statistical laws used in the theory of traffic flows. Pearson's criterion is taken as a basis. It is assumed that with the proximity of signal-controlled intersections to each other, the general nature of the distribution of intervals will change significantly, this will make adjustments to the effectiveness of using adaptive traffic light control and to the correct application of models of such intersections.

The paper checks for the frequency of occurrence of intervals lasting more than 5 s. Since the article created an intersection model with adaptive regulation, which works on the principle of searching for a break in the stream (lasting more than 5 s), into which traffic signals are switched.

Next, a search is made for statistically significant differences in the input stream from the position of the distance of the previously signal-controlled intersections.

3 Experiment

Recently, in Tyumen on the main thoroughfares, the Spectrum 2.0 automated traffic control system has been introduced, which includes an adaptive traffic light control unit. The primary information received from the "TrafiCam" cameras is processed in the management center. The basic principle of the system's work is to search for a "gap in the stream" when the end of a parting line is caught and the interval between passing cars increases sharply (more than 5 s). This is the best time to change traffic signals and to ultimately increase the crossing capacity [1, 2].

In the course of the study, based on monitoring the traffic flow on the main streets of the city of Tyumen, webcams were used to compile a sample of the distribution of a suitable car flow in lanes for intervals of five seconds. In the process of assessing the representativeness of the sample, it turned out that for a reliability of 90%, within the framework of an acceptable error of the results of 10% of the average, 12–105 measurements of data for each lane are required. In the study, for simplicity, the total number of measurements for all lanes at intersections was taken as 100. An analysis was made of the correspondence of the distribution of intervals between vehicles in the stream to the correspondence to the Poisson stream and the normal distribution according to the Pearson chi-square test.

Later in the study, an attempt was made to establish a correlation between the distance from one to another signal-controlled intersections and the accuracy of the description of the distribution of intervals between vehicles with various statistical laws. The obtained value is compared with the critical value "tcr" for the significance level $\alpha = (0.05; 0.1)$ and the number of degrees of freedom $f = n - 2$. If the value obtained is "t > tcr", then the null hypothesis of the absence of any connection was rejected and the data should be checked for the presence of such a connection.

4 Result and Discussion

As a result of the analysis of the observational data, histograms were constructed (examples are shown in Fig. 1) of the frequency polygon for each band of the approach to the intersections under consideration and summary tables (Tables 1, 2, 3 and 4).

According to the results of Table 1, a rather high degree of correspondence of the flow suitable for traffic lanes to the Poisson flow is shown, which indicates the admissibility of using models of single adaptive intersections to simulate the entire traffic along a street with several nodes with obtaining the final data on the delays of cars.

As can be seen from Table 2, compared with the Student criterion, the relationship between traffic intensity and the degree of compliance with the Poisson flow is statistically confirmed, which does not represent comparative scientific value and is one of the postulates of the classical theory of traffic flows, because high-intensity flows are poorly described by the Poisson distribution. The relationship between the distance from the previously controlled intersection and the degree of fulfillment of statistical laws is not confirmed.

Next, a similar analysis is carried out for groups of lanes suitable for flow intersections.

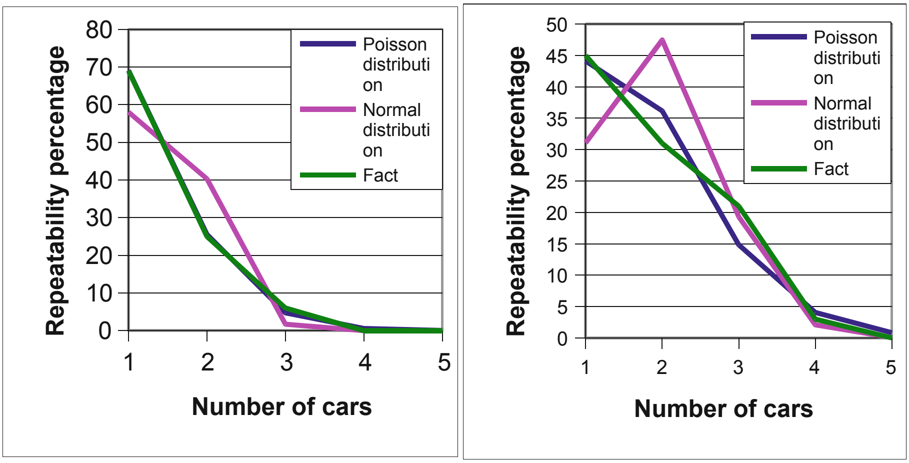

Fig. 1. Example of histograms of a frequency test range of actual and theoretical values (Herzen St. 1, 1 Shirotnaya St., in the city of Tyumen of the Russian Federation)

According to the data from Tables 3 and 4, we can conclude that there is a weak correlation between the number of bands on the approach to the intersection and the degree of correspondence to the Poisson flow. It looks logical enough, because, with a large number of lanes, packs of cars remain much longer, which contributes to the unevenness and non-stationary of the traffic flow. Other correlation dependencies are not confirmed. One of the reasons for not revealing clear correlation dependencies may be an insufficient number of observed objects, which reduces the number of degrees of freedom during statistical calculations. when driving in separate lanes.

In the course of the study, in addition to confirming the correctness of using the Poisson distribution in the adaptive controlled intersection model [1, 2] for both single (isolated) intersections and non-isolated intersections, it is necessary to raise the question of further research. The Pearson Chi-square test does not allow a sufficiently clear boundary to be found between an isolated and non-isolated type of intersection [1]. In addition to increasing the number of objects under consideration, it is necessary to use a more powerful statistical criterion, such as, for example, the Dickey-Fuller test, with which you can check the traffic flow for stationarity and autocorrelation. Using this criterion, it is possible to fix the cyclical nature of the change in the basic statistical parameters of the traffic flow, corresponding approximately to the time of the traffic control cycle. The null hypothesis during such a statistical analysis will look like this: the intersection is considered isolated if the stationary flow does not go beyond the confidence intervals [3, 4]. Based on this, it can be preliminarily formulated that an intersection is considered to be an intersection that has not been significantly affected by previous nodes by the criterion of maintaining the stationary traffic flow at short time intervals (60–180 s).

Table 1. The results of the analysis of suitable for intersections of the flow along the lanes for compliance with statistical distributions (in the city of Tyumen of the Russian Federation)

Direction	N, car/h	L to the previous intersection	Pearson Chi-square test value		Probability of law enforcement	
			Poisson distribution	Normal distribution	Poisson distribution	Normal distribution
Parhomenko 1	173	1280	1.4500745	19.7	69%	0%
Parhomenko 2	353	1280	7.5346499	2.86	6%	24%
Moskovsky trakt 1	284	287	3.1013238	102.8891	38%	0%
Moskovsky trakt 2	287	287	10.505022	32.67	1%	0%
Moskovsky trakt 3	349	287	3.7677094	18.63	29%	0%
Moskovsky trakt 4	247	287	1.5195801	10.56653	68%	1%
Herzen 1	266	213	0.991418	18.82	80%	0%
Herzen 2	374	213	5.4582264	20.05	14%	0%
Herzen 3	288	263	4.00	5.13	26%	8%
Herzen 4	194	263	0.7876838	21.65	85%	0%
Pervomaiskaya 1	281	210	1.8986046	9.02	59%	1%
Pervomaiskaya 2	202	210	1.0222432	17.71	80%	0%
Shirotnaya 1	590	807	4.4287351	12.57	22%	0%
Shirotnaya 2	677	807	6.4742667	13.44	9%	0%
Shirotnaya 3	553	807	11.085917	29.22	1%	0%
Melnikayte 1	108	416	1.3699811	13.35	71%	0%
Melnikayte 2	569	416	2.3549367	7.67	50%	2%
Melnikayte 3	180	416	0.358763	46.58	95%	0%
Melnikayte 4	223	870	1.2460587	635.9	74%	0%
Melnikayte 5	346	870	1.6186237	11.18	66%	0%
Melnikayte 6	576	870	2.919344	5.94	40%	5%
Zapadnosibirskaya 1	281	800	8.8092461	0.56	3%	76%
Zapadnosibirskaya 2	187	600	0.3003194	38.51	96%	0%
Zapadnosibirskaya 3	266	600	6.30294	30.69	10%	0%

Table 2. The results of the analysis suitable for intersections of the flow for the correlation between the main parameters

Indicator	N/X2 Poisson distribution	N/X2 Normal distribution	L/X2 Poisson distribution	L/X2 Normal distribution
Correlation coefficient	**0.440923**	−0.178	0.2398451	0.088177
t	**2.30419**	−0.848	1.158797	0.415202
$t_{0.05}$	**2.073875**	2.0739	2.0738753	2.073875

Table 3. The results of the analysis suitable for intersections in a group of flow bands for compliance with statistical distributions (in the city of Tyumen of the Russian Federation)

Direction	L to the previous intersection	Number of lanes, n	Pearson Chi-square test value	
			Poisson distribution	Normal distribution
Parhomenko 1-2	1280	1	6.74	11.7
Moskovsky trakt 1-6	287	4	74.1624	39.21878
Herzen 1-2	216	2	14.65284	33.06384
Herzen 3-4	263	2	6.644	49.07724
Pervomaiskaya 1-2	210	2	11.65759	32.28151
Shirotnaya 1-3	807	3	97.10248	42.43874
Melnikayte 1-3	416	3	4.342282	6.869902
Melnikayte 4-6	1500	3	6.37555	7.878168
Zapadnosibirskaya 1-2	800	2	5.934584	3.405849
Zapadnosibirskaya 3	600	1	6.30	21.75

Table 4. The results of the analysis suitable for intersections in a group of flow bands for the correlation between the main parameters

Indicator	L/X2 Poisson distribution	L/X2 Normal distribution	n/X2 Poisson distribution	n/X2 Normal distribution
Correlation coefficient	−0.09947	**−0.5885**	**0.606637**	0.196697
t	−0.28273	**−2.0588**	**2.158334**	0.567428
$t_{0.1}$	1.859548	**1.85955**	**1.859548**	1.859548
$t_{0.05}$	2.306006	2.30601	2.306006	2.306006

Conducting further research is advisable in connection with the creation of a convenient tool for engineers for the organization and management of road traffic and urban planners [4], which allows one to find reasonable boundaries for the use of both planning types of intersections and traffic control methods.

The obtained results can be compared for optimal with other options for organizing traffic or crossing intersection (arrangement of additional lanes, interchanges), especially in those conditions where construction and reconstruction work are difficult (dense urban development).

5 Conclusions

According to the results of the presented study, the nature of the Poisson distribution is confirmed, the interval between vehicles in the stream on the approach to the intersections of city highways along lanes [4]. The representativeness of the data sample is confirmed using Student's test for 90% probability. It turned out that the degree of confirmation of this law does not depend significantly on the distance from previous signal-controlled intersections. This circumstance allows us to simulate the work of an adaptive intersection and evaluate its effectiveness without building a sequentially located chain of nodes for closely located intersections. It is also proposed to call an isolated intersection such a signal-controlled intersection that would not have been influenced by previous controlled intersections and when approached, the traffic flow would meet the stationarity criterion.

In the future, it is necessary to study the emerging traffic flow on city highways for autocorrelation and stationary using the Dickey-Fuller test to find a reasonable border between the isolated and non-isolated types of intersections. The ultimate goal will be to better organize traffic with increased efficiency of the urban transport system.

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Analytical Model of Commercial Activity of a Transport-Logistics Enterprise

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Abstract. The main task of any commercial activity is to achieve objectives of an enterprise. The vast majority of Russian scientists and companies' Chief Executive Officers treat commercial activity as an operational component for gaining profit. This approach unveils only one side of commercial activity, i.e. to obtain the results today. Commercial activity has an ambivalent essence in itself. On the one hand, it is necessary to deliver results – make a profit. On the other hand, commercial activity should be reviewed from the aspect of collaborative nature of parties' relations, which aim at a continuous growth rate of satisfaction of the economic interests of the buyers as well as sellers. Thus, the commercial work is focused on reproduction of economic and industrial relations. The strategic objective of commercial activity is reproduction of commodity exchange relations. However, in order to organize operational work for target-setting of each specific department and employee it is necessary to supplement the strategic benchmark with a certain analytical model. Realization of the ambivalent essence of commerce should be reflected in work-planning. An analytical model of commercial work based on the market contacts and the results of its practical application are given in the article. The model for commercial activity of transport-logistics enterprises allows correlating the indicators of increase in the value of business with a production schedule and, simultaneously, achieving the balance of demand and supply.

Keywords: Transport-logistics company · Commercial activity · Analytical model · Business planning · Balanced scorecard

1 Introduction

The main task of any commercial activity is to achieve the company objectives. It is impossible to structure the work and evaluate it unless we clearly define an objective. Sustainable growth of business value is considered to be the key strategic benchmark [1–3]. Business management should be focused on company value. Russian companies often do not clarify their objectives. The attention of top managers of Russian companies is primarily drawn to the financial parameters, which are more suitable for operational objectives. Although, these specific objectives define a business strategy [4]. Not only practitioners but also the majority of Russian scientists treat commercial

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activity as an operational component for gaining profit. This approach unveils only one of the sides of commercial activity, namely, the necessity to obtain the results today.

2 Literature Review

Increasing complexity of technological, economic and competitive conditions has led to the emergence of a market-oriented concept of management in the advanced economies. The market-oriented theory proceeds from the premise that market-oriented intensity and economic results are interrelated [5, 6]. Commercial activity is of ambivalent essence. On the one hand, it is essential to ensure result, gain a profit. Therefore, it is necessary to develop a certain set of tools. On the other hand, commercial activity should be reviewed from parties' interrelations aspect, aimed at continuous growth of satisfaction level of economic interests of the buyers as well as sellers [7–9]. Consequently, sustainable development of enterprises requires improvement of economic links. Therefore, commercial activity is focused on reproduction of economic links and industrial relations (Fig. 1).

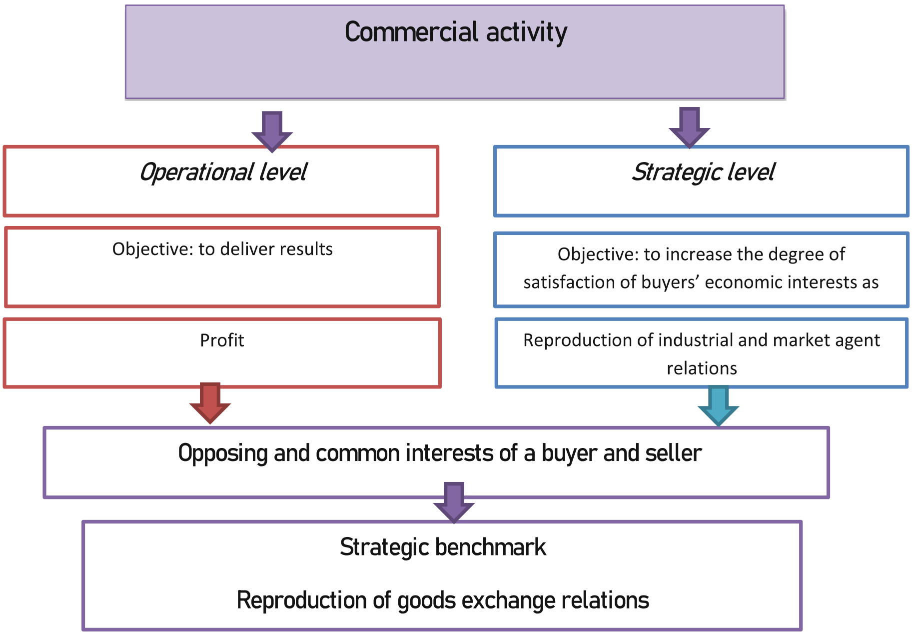

Fig. 1. Ambivalent essence of commercial activity

The individual nature of rendering transport-forwarding services, the necessity of prompt response to the market needs contributes to a vast range in formation of service assortment and type at a particular enterprise. The necessity for meeting various needs in a range of services as well as geographical coverage has led to emergence of a great number of small-scale enterprises. Commercial activity at such enterprises is conducted with consideration of common sense, without being formalized, due to the lack of professional competence and financial resources. A great number of small-scale enterprises in the transport-forwarding service industry is not a peculiar feature of the domestic market of Russia only. Large-scale enterprises are not common for advanced economies as well. The strategic objective of commercial activity is reproduction of commodity exchange relations. In order to organize operational work, set targets for the departments and employers the strategic benchmark should be supplemented by a certain analytical model. Manifestation of the ambivalent essence of commerce should be reflected in work planning.

3 The Correlation Between Strategy and Financial Result

In financial accounting, when addressing the issue of financial results planning, we imply profit. Gross profit value is estimated in the income and expense statement of an enterprise. The definition of company's financial objectives includes more than that. In order to reach the key strategic value (business value growth) the following value indicators are used: investment return rate, invested capital return rate, economic value added, total sales volume, free monetary flow.

At the end of the twentieth century the criticism of traditional system of management control has substantially intensified due to its narrow orientation towards financial indicators [10]. In the changing market conditions monitoring the financial indicators only is not enough. The traditional system of management control evolved under conditions of mature markets and slow advances in technology. The basic tools of traditional control are still used nowadays such as the allocation of funds, cost accounting based on a "standard-cost" method, transfer price formation. The role of management control was confined to budget indicators maintenance. As a result, responsible executives focused on the cost reduction and the significance of sales volume growth was underestimated. The financial indicators reflected the results of the decisions previously made, but increasing complexity of economic life requires the assessment of long-term development of a company. As a consequence, the new concepts and tools of management control emerged.

Integration of financial, commercial and production activities with a focus on strategy is not an easy task. The concept of strategy maps by Robert Kaplan and David Norton became a well-known method [11]. Significant correlations between various activity indicators are identified in the concept. If a company aims to become profitable, it should strive for its consumers' loyalty. It is essential to improve the quality of service in order to maintain loyalty. To ensure a better quality of service it is necessary to elaborate and implement operations throughout the entire chain of value creation and it requires strengthening of employers' knowledge and skills. The strategic map indicators characterize not only the results achieved, but precondition their main factors as well [12].

Receiving the financial result such as an influx of revenue volume will depend on customer capital. Building-up customer capital depends on quantity and quality of commercial contacts, customizing the service for a customer. The important element is the commercial staff qualification and training. The analytical model of commercial activity is framed in the logic of commercial maps.

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4 Analytical Model

The influx of revenue volume depends on increase of the number of customers or increase in sales to the current customers. Potential earnings from a single client depend on the specific nature of a customer. Customers can be classified on the bases of ABC, XYZ – analysis [13]. For each group of customers the potential earnings – "average purchase amount" can be estimated. Earnings will also depend on a particular commercial strategy. Not every commercial contact has a successful result. To assess the successful number of contacts an efficiency ratio can be introduced, which will illustrate proportion of the total number of contacts to the successful ones. This coefficient as well as the average purchase amount should be estimated on the basis of practical work analysis of the enterprise.

An exemplary view of analytical model of commercial activity:

$$F = \sum\nolimits_{i=1}^{n} \sum\nolimits_{j=1}^{m} k_{eij} \cdot C_{ij} X_{ij} \tag{1}$$

F - planned financial results;
X_{ij} - number of commercial contacts;
i - index of groups of customers in ABC, XYZ – analysis classification;
j - index of strategy;
C_{ij}- average purchase amount by group of customers and strategy,
k_{eij} - proportion of successful contacts to the total number of contacts.

The financial result can be specified in an absolute value as well as an increment to the obtained value. The resultant analytical model can be used for planning of commercial activity. The number of groups of customers, strategy of obtaining financial results, number of required contacts are estimated for each specific enterprise. Application of the proposed analytical model of commercial activity is inherently a large-scale planning of sales and commercial operations [14]. On the one hand, it is planning of production activity of commercial service (operational level). On the other hand, in commercial activity planning an assessment of strategic alternatives is made, efforts to reduce risks [15]. Thus, application of the analytical model relates strategic and financial business-plans of a company to operational planning of work schedule of commercial departments. Financial, marketing and production activities are integrated by commercial planning. A map of balanced scorecard (BSC) can serve as a planning tool [16, 17]. This method can be applied to railway transport companies, seaport management companies, and air transport service providers [18–20].

5 Commercial Activity Planning

Implementation of the analytical model concept of commercial activity for a strategic map was verified on practical data of “UTS” company’s consolidated cargo transportation department. The strategic objective was business growth.

Increase of the revenue per month $\Delta F = 2000000$ *roubles* by the end of the planning year was fixed by the financial measuring instrument. The limitation of a financial indicator was set – expenses in the expenditure line “others” are not to exceed the planned ones $(-\Delta F = 0)$.

The expenditure line “others” includes the expenses resulting from loss-making commercial operations such as write-off of uncollectible receivables, punitive damages, litigation costs, etc.

Sales growth strategy is chosen as the main market strategy, both through attracting new customers, and through profit from active clients. Increase of an average purchase amount $\left(\Delta C_{ij}\right)$ from a single customer was planned through either increase of orders handed over to the company, or through providing additional services. To such services we refer:

- receipt of cargo at the warehouse;
- additional transport package;
- transportation of sub-size heavy and bulky cargo;
- financial services, insurance;
- delivery of consignments to various shipment destinations.

A specific feature of consolidated transportation is availability of a large number of ordering customers with a small volume of proceeds, this explaining availability of a considerable number of group C - $К_с$ customers.

The amount of new clients (ΔK_i) was planned on the basis of market situation analysis and on the condition of continuing average earnings from a customer in group $\left(C_{ij}\right)$.

The amount of essential commercial contacts $\left(X_{ij}\right)$ was estimated in order to achieve the target by customers and the evaluation coefficient of contacts $\left(k_{eij}\right)$. A commercial contact is meant as a commercial department technological chain:

- market analysis, making a list of potential customers;
- “cold” calls, preliminary contacts;
- identification of persons in charge related to potential customers, identification of interests;
- making up a commercial proposal;
- presentation, negotiations;
- dealing with objections;
- “squeezing”, entering into a contract.

Efficiency coefficient is derived empirically through the experience accumulated in the company. For a starting business coefficients $k_e = 0.1 \div 0.2$ may be recommended. The recommendations are related to transport-forwarding industry. In mechanical engineering the coefficient may be $k_e = 0.01$

A strategy map is worked out as the outcome of planning. A simplified variant is shown in Fig. 2.

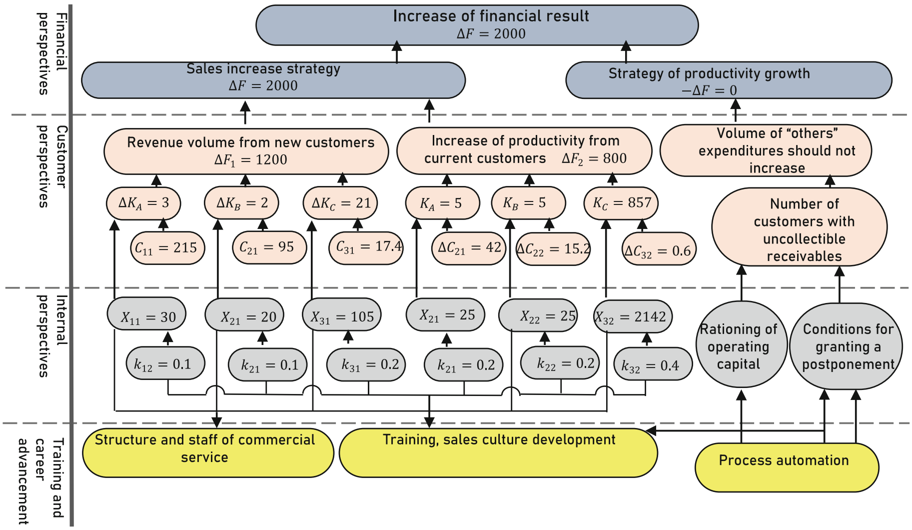

Fig. 2. BSC example for a transport and forwarding company

Stage-by-stage organization of sales and their quantitative norm setting is described in a number of papers [21–23]. Plotting a map stipulates balancing of commercial activity. Demand and commercial service possibilities are balanced in the first turn. If the demand exceeds some throughput capacity of commercial service, the customer is not served properly. The order execution time is extended. Queues appear. Customers quit, business is lost. In addition, overtime costs and attending additional warehousing areas expenses may also rise. Attracting temporary subcontractors may lead to a loss of service quality.

In another case, when the demand is small and commercial service possibilities are higher, incremental costs emerge. In the example with the consolidated transportation company, decrease of orders does not bring to proportional reduction of costs. The warehouse and its staff must still be supported. Reduction of vehicle trip regularity deteriorates, qualitative characteristics of service worsen. Moreover, moral environment is worsening, there appears a danger of dismissals. The staff is working less efficiently. As a result, marginal profit falls down. In order to attract customers, promotional events and special offers are held. The company is having a tough time.

In the example under consideration in order to obtain financial results it is necessary to realize 100 commercial contacts with Group A and B customers and 2247 with

Group C customers. Commercial service at the enterprise is headed by a Sales Director, The work is performed by a Contract Department Chief and 9 regional executives of self-standing businesses, who are functionally Sales Director Deputies. Order receiving and finalization is provided by Contract Department Managers. There are 16 specialists with such job responsibilities. Moreover, they work with orders, not with attracting customers. Practically, a Contract Department is a Marketing subdivision and does not deal with sales. 11 executive officers are involved in sales, having the right to sign contracts. In order to attain profit growth, each specialist dealing with sales is to have 4–5 contact per week. It is a very high load, considering availability of ongoing and operative work. Executive officers should concentrate mainly on Group A and B customers and Group C key clients. In order to work with Group C, it is necessary to involve Contract Department specialists after appropriate training and teaching. The identified problem of imbalance of commercial work and staff volumes made the executive officers to think over automation of routine marketing functions and switching the workers to sales.

Another planning task of commercial work lies in supporting balance between demand from customers' part and volume level of provided services. The volume of services is planned at business-planning stage and annual budgeting. At this stage necessary infrastructure (warehousing areas, own account transport, loading sections) and required personnel with pay-roll budget are estimated. Budget planning is made by a Financial Director once a year. Commercial department deals with operative planning of specific services required by customers. By definition, it is planning of nomenclature of services. And this issue is very important and urgent. Imbalance between the volume and nomenclature may result in either added complexity of execution of the accepted order or quality worsening and negative attitude to the company image. Probably, the best decision in such cases will be refusal from realization of orders.

6 Conclusion

Analytical model of commercial work is applicable in practice. Realization of the model for planning makes it possible to peg business value growth indicators to production schedules. In addition to the above, to achieve balance between offer and demand, a better vision of problems with resources, better interaction among executives. Pegging of the analytical model to the strategy map allows to build technological process of commercial planning for specific enterprises.

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Improvement of Cargo Transportation Technology in Rail and Sea Traffic

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Abstract. The purpose of this work is to find a new way to improve and develop the potential of the transport system, both in the segment of export cargo transportation, and in the space of interaction between different types of transport in the organization of mixed rail - sea transport. The experience of managing the process of export transportation of fuel and energy resources in the Russian Federation is presented and analyzed. Scientifically grounded variants of decisions on the organization of export transportations in the mixed railway - sea communication creating conditions for decrease in a rate of growth of the added value of finished goods are offered. A new alternative way of development and improvement of export cargo transportation is proposed. The model of complex transport service in the area of interaction of several types of transport in the implementation of railway - sea communication is presented. Further improvement of the technology of interaction between the subjects of complex transport service is considered. Transition to integrated transport service by the method of construction and functioning in the model of integrated transport service of virtual enterprises is chosen. The methods of construction of this model are currently used in the management of transport services in the organization of inert cargo carriage flows and in determining the forecast of their supply. The obtained results confirm the effectiveness of the proposed innovative technological solutions.

Keywords: Model · Integrated transport service · Self-organization · Railway - sea communication · Information space · Business-system · Virtual enterprises

1 Introduction

In the Russian Federation, rail transport accounts for a large share of the transportation services market in the export cargo segment. In the conditions of globalization of the external market of transport and production business processes, the most important and urgent are the tasks to determine the further development and improvement of the technology of export cargo transportation and to maintain competitiveness in the world market of domestic manufacturers of finished products and subjects of transport services [1].

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Increase in the potential of the railway industry, its productivity, directly depends on the methods, methods of organization and management of the transportation process, which is a complex of transport services to perform cargo operations in the places of origin and repayment of cargo transportation, cargo transportation and maintenance of rolling stock.

Highly efficient organization and rational management of the transportation process is possible only in case of qualitative interaction of several types of transport as participants of the single process of export cargo delivery. Interaction of different types of transport in the space of interbranch transportation at a high level creates conditions for reducing the share of transport component in the cost of transported cargo, improving the quality of transport services and competitiveness of both the transport system and the manufacturer of finished products. In this regard, the railway industry, as well as the transport system as a whole, needs innovative technological products that will ensure the development of increasing volumes of export cargo correspondence and improve the quality of integrated transport services to all its consumers [2].

At present, the authors are choosing a rational solution in the field of compromises in the field of management and organization of delivery of export cargoes in the mixed railway - sea traffic, provided that there are limiting restrictions in processing and throughput capacity of the transport system infrastructure.

The object of the study is mixed railway - sea traffic, as this message serves more than 90% of the export of solid - fuel products. In the Russian Federation, as well as in many foreign countries, the extraction of solid fuel raw materials (coal of various grades) performs an important function in satisfying the needs of the population with fuel and energy resources and participates in the formation of the country's budget from its export, ensuring the development of international foreign economic relations. In 2018, the work carried out in Russia to raise funds to improve the process of mining solid combustibles, allowed to ensure the extraction of coal by 10.6% more than in 2017. In the future, it is planned to increase coal production, which predicts an increase in the volume of deliveries of these cargoes to external market consumers. Thus, this year the growth of coal products exports is forecasted to be up to 3.5% by the level of 2018. Achievement of the planned values is achieved by improving the quality of raw materials and the efficiency of mining technologies, as well as expanding the supply zones. As a consequence, the growth of export cargo volumes leads to the filling of the coal market and the creation of prerequisites for the reduction of procurement prices for this category of goods. In such conditions, ensuring the competitiveness of domestic goods and cargoes is a priority state task. Preservation of the ability to compete in the external market to domestic producers is possible by reducing the added value of finished products, namely, reducing the share of transport component in the price of export cargo, which is possible due to the optimization of the management of the transportation process of interacting modes of transport and optimization of the interaction of subjects of transport services.

Under the existing conditions, the qualitative realization of the coal products export potential in the category of international cargo transportation and with the use of railroad and sea transportation has significant technical and technological difficulties, such as:

– difference in volume values between the accumulation (storage) infrastructure, transshipment (port) infrastructure and terminal and logistics infrastructure [3];
– significant differences between the production capacities of origination sites and repayment sites of coal products export correspondences;
– difference in productivity of loading and unloading resources of shippers and consignees of coal products;
– share of wagonload shipments not covered by routing;
– necessity of additional formation of ship consignments by coal raw material grades with many owners and owners of rolling stock;
– loss of free-flowing properties of cargoes in the process of their delivery to the destination station in conditions of low temperatures;
– lack of common resources and information space.

In order to avoid these drawbacks, it is necessary to effectively attract investment funds and innovative technologies, which will provide an opportunity to master the growth of freight correspondence with the provision of integrated transport services at the required level [4].

Scientists from different countries are studying ways to solve important problems of transformation and improvement of transport and production processes, optimization of costs and expenses aimed at strengthening the transport system as a whole. This paper presents an alternative way to improve the technology of delivery of export solid fuel raw materials in rail and sea transport, subject to limiting the limits of throughput and processing capacity on the infrastructure of the transport system [5].

2 Structure and Methods of Model Construction

For qualitative performance of criteria of transport services, creation of conditions on qualitative forecasting and planning of origin and repayment of correspondences of export cargoes, increase in processing and carrying capacities of subjects of transport services, the authors developed model of complex transport service (KTU) in the railway - sea communication. The BE model is built on the basis of the theory of decision-making in conditions of certainty, the method of analysis of hierarchies and methods of construction and operation of virtual enterprises [6].

For the qualitative fulfillment of the transport services criteria, the creation of conditions for the qualitative forecasting and planning of the origin and completion of export freight transportations, the increase in the processing and throughput capacities of transport services entities, the authors have developed a model of complex transport service (CTS) in railway and marine traffic. The CTS model is based on the theory of decision making under certainty, a method for hierarchies analyzing, and methods for virtual enterprises constructing and operating [7].

Figure 1 presents the conceptual model of CTS in the railway - marine traffic as a single business system.

The goal management system in the CTS model is as follows. The CTS model is considered as a single business system. In order to implement the principle of improving the quality of complex service delivery in mixed railway and marine traffic,

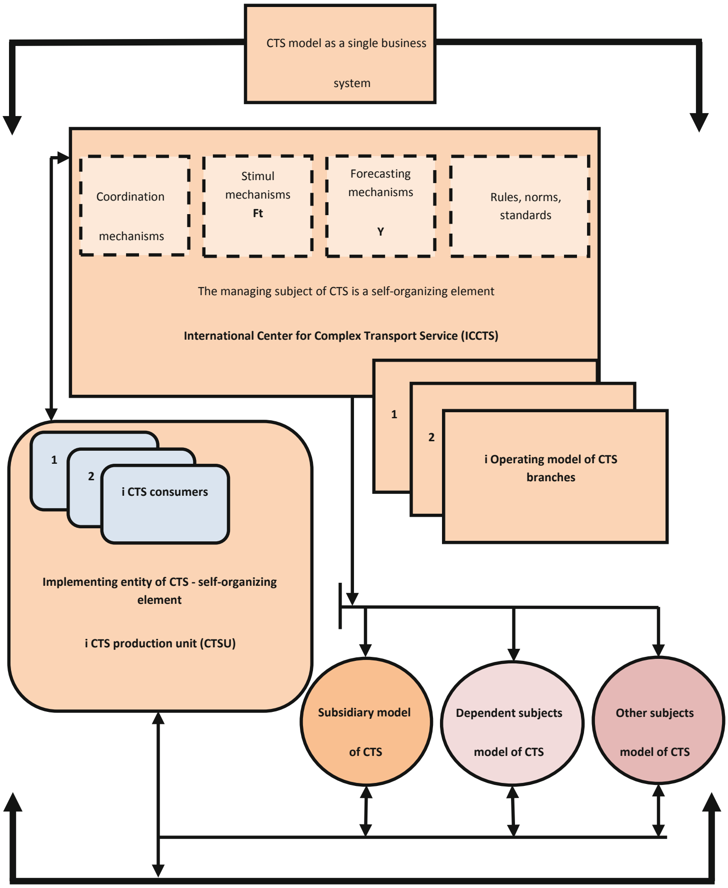

Fig. 1. The conceptual model of CTS in the railway - marine traffic as a single business system.

it is proposed the processes of developing the interactions of entities of these services and providing complex transport services in the international transportation category to be organized by investing our own resources of the complex transport service units (CTSU) in the transport and production process based on self-organization [7]. Self-organization coordinates and interconnects investments, profit, potential and target function of CTSU. The self-organization procedure allows to determine the optimal expenditures and investments which are necessary to transfer a complex transport service when it is provided or acquired in a preferred state.

Figure 2 shows that the quality criteria of a complex transport service and their set are determined on the basis of the conditions arising for a particular transportation in a certain period of time and taking into account the influence of external and internal impact factors.

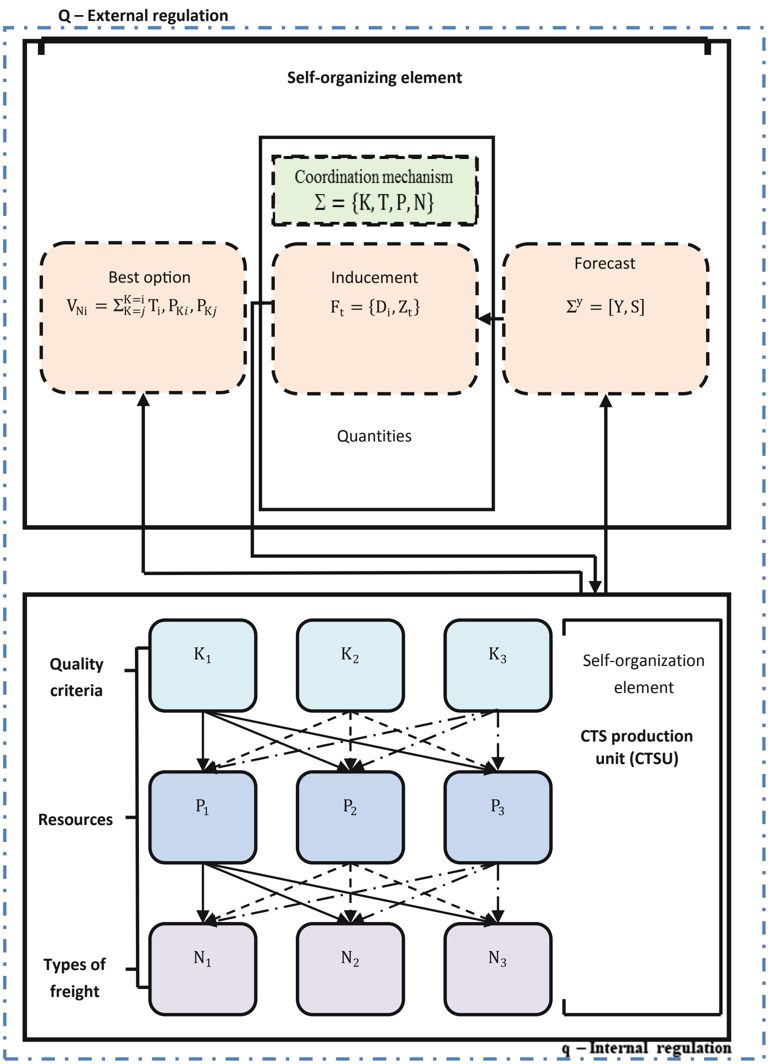

Fig. 2. The structure of causal actions of the control goals of the CTS model

Results variation of the CTS model and its purpose, depend on the quality criteria and their set (Fig. 2):

$$\sum K = \{K_1, K_2, K_3, \ldots ..K_i\}, \tag{1}$$

self-maintenance period:

$$\sum T = \{T_1, T_2, T_3, \ldots ...T_i\}, \tag{2}$$

self-maintenance resources:

$$\sum P = \{P_1, P_2, P_3, \ldots ...P_i\}, \tag{3}$$

number of freight nomenclatures:

$$\sum N = \{N_1, N_2, N_3, \ldots ...N_i\}, \tag{4}$$

To determine the preferred option V_{Ni}, we accept that the purpose of the integrity of the adaptive mechanism in the railway-marine traffic is the predicted formation of the mechanism model $\sum^{y}$ itself, which creates the maximum destination, that is, prior variants of the self-organization element for export entities (Fig. 2):

$$\sum^{y} = \left[Y, \sum\right]. \tag{5}$$

The methodological foundations of adaptation mechanisms construction confirm the need to stimulate F_t when choosing the best option, the value of which is the share of profit D_i belonging to the Complex Transport Service Unit (CTSU) and the share of reducing the transport component in the cost of the freight Z_t belonging to the consumer of the complex transportation service:

$$F_t = \{D_i, Z_t\}. \tag{6}$$

As a result, using the fundamentals of the hierarchy analysis method, the function of the best option VNi in the forecast Y, on the set of quantities Σ, with the compelling stimulus Ft, and the profit share Di, looks as follows:

$$V_{Ni} = \left\{\Sigma^{y} = [Y, K, T, P, N, F_t, D_i] \middle| \sum\nolimits_{K=1}^{K=i} T_1, P_{K1}, P_{Ki} \middle| \ldots \middle| \sum\nolimits_{K=j}^{K=i} T_i, P_{Ki}, P_{Kj} \middle| \right\}. \tag{7}$$

Thus, the function of best replication of the self-organizing mechanism in the proposed CTS model for the transportation of export goods in the international transportation category and when using several modes of transport is to ensure the development of all participants of the complex transport service included into the structure of the element of self-support and self-organization as well as the formation of such a technology for the transportation process of export freights, which will provide the maximum intended purpose of the CTS model under many preferred qualitative criteria [8].

World practice shows that the most difficult task in managing freight flows is the organization of the goods transfer between two or more modes of transport. The model of complex transport service improves and transforms the organization of work in the space of interaction of two or more modes of transport. It makes it more effective, subject to the coordination of coal industry freight delivers from the place of origin to the place of completion: the owner (proprietor) of the freight - the consignor - the owner (proprietor) of the railway rolling stock - the consignment - the port (storage, transshipment) of freight - the sea vessel. At the same time, one of the important aspects of its improvement is the introduction and maximum implementation of contact schedules for supplying rolling stock and vessels. The implementation of these policies is possible. So, the next aspect in improving the interaction technology is the transition to a complete complex transport service with the construction and operation of virtual enterprises in the CTS model (Fig. 3).

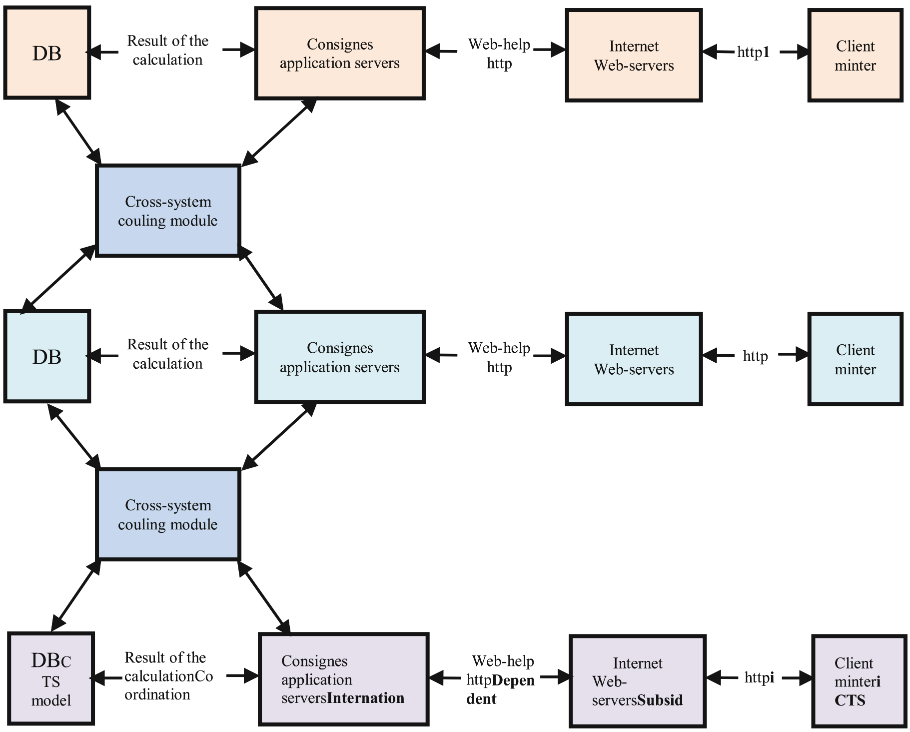

Fig. 3. An example of information architecture based on the CTS model in mixed railway and marine traffic

The CTS goals management system in the CTS model by the method of virtual enterprises construction is proposed to consider as a single business system, and the interaction of CTS entities as end-to-end business processes through their organization and management goals [9]. This is based on the following principles:

– the presence of a flexible structure ensuring the efficient distribution of common resources and rebuilding its design [10];
– the decentralized hierarchy, united to achieve the common goal of the of the CTS entities in the interests of acquiring a competitive service and finished products [11];

– ensuring the transformation and integration of transport - production processes in a single virtual space [12];
– the presence of a single information infrastructure and a single information space [13];
– functioning on common databases (DB) and unified software products [14].

Virtual space in the CTS model includes:

1. functional "core", the basis of which is ICCTS (Figs. 1 and 2) providing coordination and management of the transport and production process, planning and management of common resources;
2. "validator" (minter) (Fig. 3), its basis is CTSU (Figs. 1 and 2), which performs the functions of maintaining the continuous operation of the virtual information space;
3. a single information space based on a common architecture, common databases and software products (Fig. 3).

It is difficult to evaluate the effect of the implementation and compatibility of information systems in a single information space. The authors have proposed the following methodology, which is based on achieving the final result, that is, realizing the number of transport services performed [15]. It looks as follows: compatibility and adaptation of users information systems and integrators of export freight transportations I_V, is estimated by the period spent on the organization of collaborative technological operations of the participants of the mixed railway - marine traffic T_{TO}, the number of provided transport services N_{RT}, to the total normative (under the complex transport service agreement) amount of collaborative technological operations N_{NT}, and is determined by the formula:

$$I_V = T_{TO} \frac{N_{RT}}{N_{NT}} \tag{8}$$

3 Results

The research presents and analyzes the experience of managing the process of export fuel and energy resources transportations in the Russian Federation.

To create market conditions for reducing the growth rate of added value of finished products, scientifically substantiated solutions for the organization of export transportations in mixed railway and marine traffic are proposed.

Existing technologies of export freight transportations are considered under existing restrictions in throughput and processing capabilities.

A new alternative way of developing and improving the transportation of export goods using the model of complex transport services in the space of interaction of several modes of transport in the implementation of railway - marine traffic is proposed. The methods for constructing this model are currently used in the management of transport services in organizing the car traffic volume of inert cargoes and in determining the forecast for their supply.

Further improvement in the technology of entities interaction of CTS is presented, transition to a full complex transport service by the construction and operation of virtual enterprises in the CTS model is selected.

4 Discussion

In the Complex Transport Service Model, the objectives of perfect technology in mixed railway and marine traffic are:

4. adaptive self-organization with self-maintenance of the process of high-quality and comprehensive transport service from its entity to its consumer;
5. determination of best options for the implementation of transport service by the hierarchy analysis method;
6. organization and coordination of the functions of transport services in the space of interaction of various modes of transport;
7. forecasting, planning of transportation of export goods;
8. analysis, control over the quality of transport services at various stages;
9. formation of corrective or self-sustaining decisions based on performance analysis;
10. search and expansion of the consumers' geography of complex transport service;
11. efficient distribution of common resources;
12. ensuring the transformation and integration of transport and production processes in a single virtual space;
13. the presence of a single information infrastructure and a single information space.

5 Conclusions

The high-quality functioning of two types of transport, railway and marine ones, in the management of export transportations of goods in a single technological process is expressed in the presence of adaptive and self-supporting information and technological ties arising in the process of collaborative organization of freight transportation. In the process of organizing a mixed railway - marine traffic, each type of transport assumes the share of transport services of their total number to ensure and achieve the proper quality level of transportation.

The comprehensive implementation of the presented innovative developments will allow us to create a qualitatively new product - a complex transport service that meets the requirements of consumers, improve the quality of service in the transport industry and maintain competitiveness of transport on the international market by reducing the share of the transport component in the cost of goods and freight.

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Main Parameters and Placement of the "Warehouse on Wheels" Terminals of Seaports for Transshipment Coal

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Abstract. The article substantiates the relevance and develops a method for solving the problem of calculating the required capacity of station tracks to waiting for wagon to ensure direct transshipment of rational volume of export coal from rail to sea transport. The developed method takes into account the intensity of the arrival of cargo to the port by rail and the productivity of the mechanization facilities of the berthing complex. The criterion for optimizing the share of transshipment of cargo in the direct variant and the capacity of the "warehouse on wheels" (station tracks for waiting wagon) is the value of the total cost of accumulation, storage and transshipment of one consignment, and also on Parking of wagons. Recommendations on placement of "warehouse on wheels" in the port railway junction are given.

Keywords: Berth complex · Direct transshipment of coal · Coal warehouse · Capacity of "warehouse on wheels"

1 Introduction

As a result of a steady trend of increasing coal consumption by the Pacific Rim [1–3] and stable volumes of imports by European countries, over the past two decades, the world coal market increase 2 times. Currently, the annual global coal trade exceeds 1.33 billion tons, compared with 640 million tons in 2001 [4]. According to customs statistics, the volume of coal exports from Russia in 2018 increased by 10.6%, to 210.3 million tons, in value terms, the increase was 26.1% [5]. In Russia since 2017 coal export volumes exceed supplies to the domestic market.

By 2035, Russian coal companies plan to increase production to 670 million tons per year. These volumes will be realized only if the competitiveness of Russian coal in the world market and with a steady increase in its exports.

About 60% of the total coal in Russia is mined in the Kuznetsk region far from its consumption markets and transshipment points on the maritime transport. Range of transportation distances from coal mining sites in Russia to land borders and seaports averages 3–4 thousand km. This significantly reduces the competitiveness of Russian coal in the world market. In this regard, the most important, for the coal mining and

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transport enterprises of Russia, is the task of reducing the transport component in the value of export coal.

About 70% of coal exported by Russia is transported through seaports. At the same time, coal is transported to seaports by rail. The most important article to reduce costs in the transportation of goods of mixed railway-sea communication is to save costs through the use of transshipment of goods in the direct option. The most important moment to reduce costs in the transportation of goods of mixed railway-sea communication is the cost savings through the use of transshipment of goods in the direct option.

The technology of transportation of goods in the direct variant in the seaport involves the use of the necessary technical means including railway devices. In transshipment from railway to sea, these are station railway tracks to waiting for wagon, used as a “warehouse on wheels”.

For various options for the technical equipment of transshipment terminals of seaports and the capacity of cargo flows, the time parameters of the transshipment process differ: the duration of the accumulation of cargo on the vessel, and the duration of the full loading of the vessel.

As a result, transshipment of cargoes directly from the railroad to maritime transport does not have a distinct advantage, therefore, in practice, the amount of cargo per ship is accumulated at storage sites and almost all export coal in seaports is reloaded two times: from a wagon to a warehouse, from warehouse in the ship.

Various aspects of the organization of cargo transshipment in the direct version between rail and water transport were studied in the works of Zvonkov V.V., Komarov A.V., Persianov V.A., Skalov K.Yu., Pravdin N.V., Povorozhenko V. P., Sologub N.K., Bolotny V.Ya., Slutsky S.S., Zin E.A., Buchin E.D., Kurenkov P.V. and etc. In these works, the problem of optimizing the operational work of the transshipment point without suggestions for determining the permanent devices needed for this was solved. At the same time, the authors do not take into account: the difference in the cost of overloading by various means of mechanization; the intensity of the receipt of goods; productivity of means of mechanization of moorings. The economic feasibility of the transshipment methods includes two options: 100% transshipment in the direct variant, including using a “warehouse on wheels” and “a warehouse on the water”, as well as a combined method of transshipment of goods with the technological possibility of transshipment in the direct variant. Some tasks of formalizing the processes of using the “warehouse on wheels” were solved in [6], but the problem of determining the capacity and placement of railway waiting tracks for wagons was not solved. The issues of optimizing the interaction of rail and sea transport and the formation of the corresponding infrastructure of seaports were considered in [7, 8], while the technology for transshipment of cargo to the direct version was not taken into account.

2 Problem Statement

Taking into account the noted shortcomings of the methods developed earlier for justifying the transshipment of cargoes of mixed rail and sea traffic according to the direct version, the method for solving the problem of determining the optimal ratio of the volume of accumulated export coal in a stationary warehouse for subsequent transshipment to the vessel and the volume of accumulation is proposed below in the "warehouse on wheels" for reloading into the vessel in the direct variant. As an optimality criterion, the total costs for storage and reloading of cargo in vessel were taken into account, taking into account: the cost and operating costs of open warehouses and station tracks to waiting for wagons with cargo; transshipment cost; berth transshipment complex productivity; capacity of cargo flow entering the port by rail.

3 Technological Features and Technical Parameters of the Studied Objects

When creating systems for the transportation of goods of mixed railway-sea communication, preference is given to technical devices of maritime transport. This is due to the fact that the cost of infrastructure and ships of the sea transport exceeds the cost of the railway subsystems of the ports and railway rolling stock. Consequently, the technical means of the port and the organization of cargo transshipment should ensure the minimum expectation of vessels when realizing the processing capacity of the berth complex. This is possible with the continuous operation of reloading devices for loading the vessel after setting it to the berth. The use of the direct option and through the warehouse should ensure the minimum cost of accumulating, storing and reloading the entire volume of goods, as well as the cost of waiting for the wagons, that is, the implementation of the work of the berthing complex according to this criterion in the optimal mode.

The capacity of the cargo flow and, accordingly, the intensity of coal arrival at the port station depends on the capacity of the coal mining enterprise, on the velocity of coal loading onto the railway transport and the degree of routing of the corresponding cargo flow, etc. Therefore, when determining the rational option for transshipment of coal and the method of its storage in the seaport, it is important to take into account the ratio of the intensity of cargo arrival at the port and the intensity of its loading onto the ship.

Transshipment of cargo in the direct variant is achieved when the productivity of quay cargo complex, M_1 (tonns/day), average intensity of receipt of the goods to the port by railway transport M_2 (tonns/day) and timely submission of vessel for loading will be equal (Fig. 1). In this case, the pre-accumulation and storage of cargo in the port is excluded and, therefore, the railway tracks to waiting for wagons used as a "warehouse on wheels" are not required. In practice, such conditions of interaction between rail and sea transport do not occur, because the processing capacity of berthing complexes, as a rule, several times exceeds the intensity of receipt of a particular kind of cargo or cargo destination on a particular vessel. This necessitates the accumulation of cargo in the warehouse or in the "warehouse on wheels" to ensure continuous loading of the vessel and the implementation of transshipment options: wagon-warehouse-ship (Fig. 2) or wagon-ship with delayed cars for transshipment according to the direct option (Fig. 3). In this regard, it is necessary that the warehouse or "warehouse on wheels", as the buffer capacity of the mooring complex between rail and sea transport,

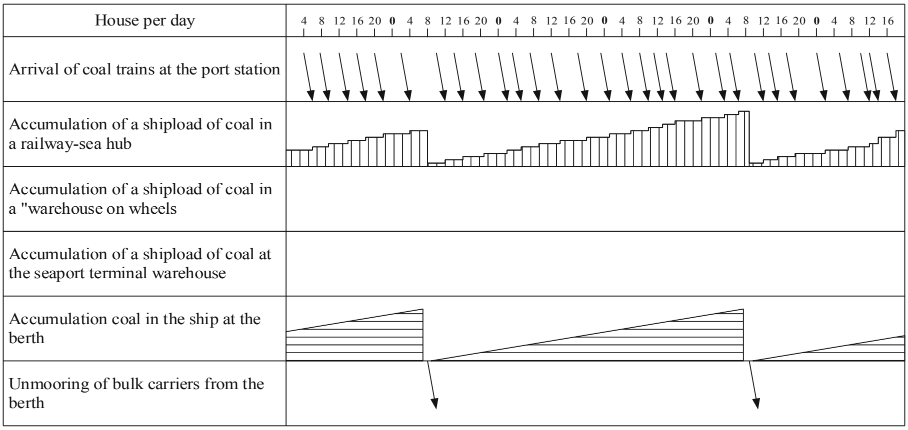

Fig. 1. Fragment of the contact graph work of the mooring complex, where $M_1 = M_2$, with 100% processing of cargo according to the direct option

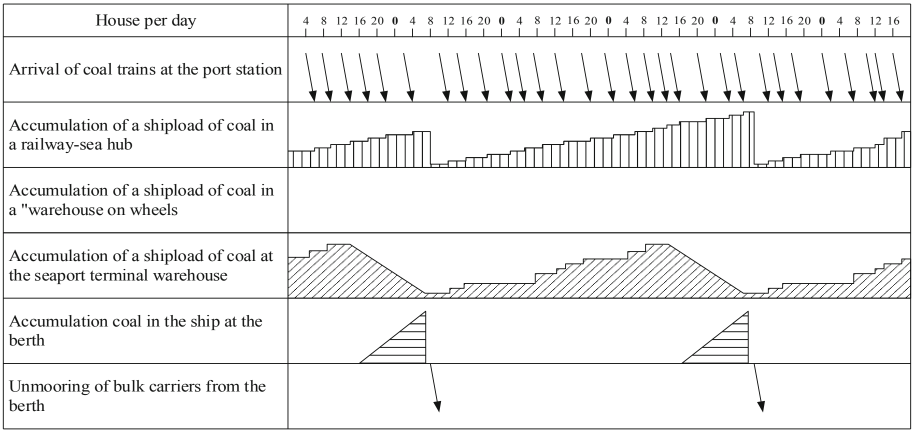

Fig. 2. A fragment of the contact graph work of the mooring complex, where $M_1 > M_2$, at 100% transshipment of cargo through the warehouse

have a capacity sufficient to accumulate cargo on a vessel of maximum carrying capacity.

The buffer capacity of the mooring complex V (tonns) for the preliminary accumulation and storage of cargo in the port is calculated by the formula:

$$V = Q_c - V_0 \tag{1}$$

where:

Q_c – cargo capacity of the vessel, tons

V_0 – quantity of specific cargo arriving at the port during loading of the vessel, tons

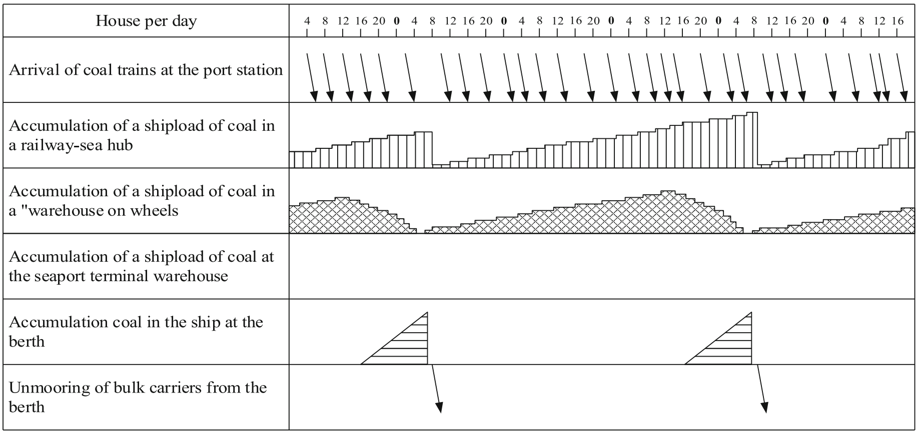

Fig. 3. A fragment of the contact graph work of the mooring complex, where $M_1 > M_2$, with a 100% transshipment of cargo according to the direct option

$$V_0 = Q_c \cdot \frac{M_2}{24 \cdot M_3} \tag{2}$$

where:

M_3 - the productivity of quay cargo complex, tons/hour

The required time of accumulation of cargo to ensure continuous loading of the vessel t_1 (hour) is equal to:

$$t_1 = \frac{24 \cdot V}{M_2} \tag{3}$$

The duration of loading of the vessel t2 (hour) is equal to:

$$t_2 = \frac{Q_c}{M_3} \tag{4}$$

The cargo handling of the vessel in the direct variant is carried out by the same transshipment machines of the berth complex as in the warehouse variant, therefore, the productivity of the berth complex in the wagon-ship variant with some assumption can be considered equal to the productivity of the berthing complex in the warehouse-ship variant.

The economic feasibility of preliminary accumulation of cargo in a warehouse or "warehouse on wheels," and, consequently, the construction of station tracks to waiting for wagons, is established for each type of cargo, since there are significant differences in: the following cost characteristics the cost of transshipment of cargo in the direct variant E_1 (rub/tons); the cost of transshipment of cargo through the warehouse,

E_2 (rubles/tons); the cost of storing the goods in a “warehouse on wheels”, E_3 (rubles/tons-hour); the cost of storing cargo in a warehouse, E_4 (rubles/ton-hour).

Transshipment of the total volume of cargo from the vessel according to the direct option with preliminary accumulation of volume V (tons) in wagons is economically beneficial if the following condition is met:

$$\frac{E_3 \cdot V \cdot (t_1 + t_2) - E_4 \cdot V \cdot (t_1 + t_2)}{2} \leq E_2 \cdot V - E_1 \cdot V \tag{5}$$

In the case when the costs of accumulating and storing the required volume of cargo V in the “warehouse on wheels” exceed the savings from transshipment in the direct variant, that is, inequality (5) is not fulfilled, it is necessary to accumulate some of the cargo V_1 in the warehouse, and some to hold up part V_2 of the wagons for subsequent transshipment according to the direct option, that is, to implement a combined version of the mooring complex (see Fig. 4).

4 A New Method of Optimizing the Capacity of the “Warehouse on Wheels”

Solving the task of determining the volume V_1 and V_2, where: $V_1 + V_2 = V$, comes down to building a geometric model of the processes of accumulation, storage and transshipment of cargo in the form of a triangle ABC (Fig. 5).

A triangle ABO is a geometric model of the processes of accumulation and storage, and a triangle OBC - of processes of storage of cargo in warehouse, as well as unloading of the “warehouse on wheels” and the warehouse, during the loading of the vessel with this cargo.

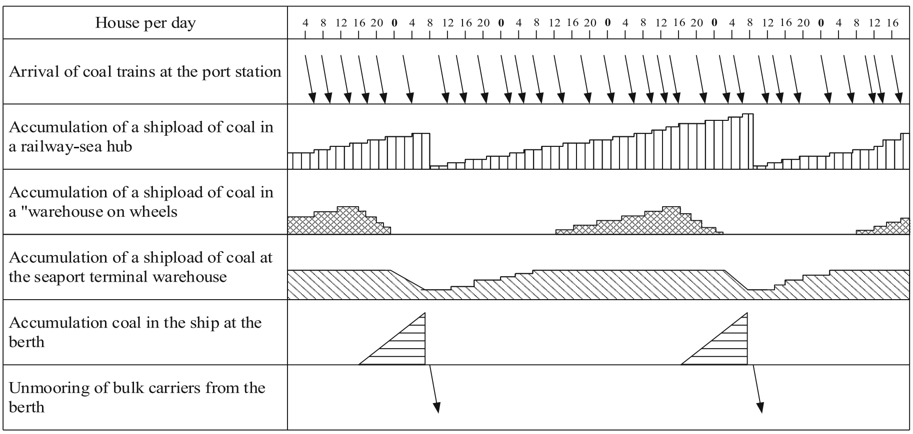

Fig. 4. A fragment of the contact graph work of the mooring complex, where M1 > M2, during combined transshipment of cargo for the wagon-ship and wagon-warehouse-ship options

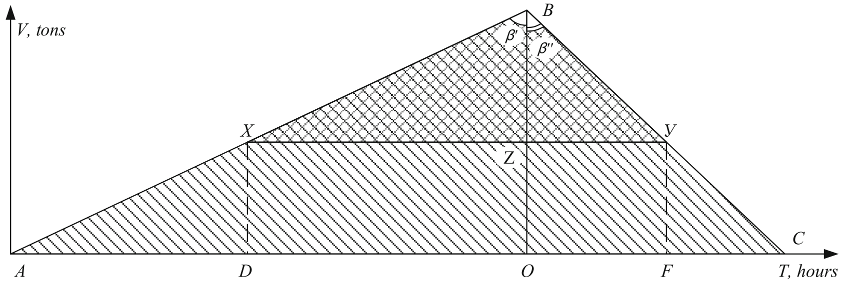

Fig. 5. The geometric model of the mooring complex of the combined method: triangle (XBY) – model of cargo transshipment as per direct scheme; trapeze (AXYC) model of transshipment cargo through a warehouse

Accordingly, the trapezoid *AXYC* is a model of work of the warehouse, where the segment *AX* is the accumulation and storage of cargo; segment *XY* - storage; segment *YC* - storage and unloading of cargo from the warehouse, and triangle *XBY* - model of work of the "warehouse on wheels", where segment *XB* - accumulation and storage of cargo in wagons; segment *BY* - waiting and unloading wagons. Thus, solving the task, it is necessary to find the optimal ratio of volumes V_1 and V_2 (respectively, segments *OZ* and *ZB* see Fig. 5), while ensuring minimal costs for storage and transshipment of cargo. At the same time, V_2 is the calculated optimal capacity of the "warehouse on wheels".

A triangle *ABO* is a geometric model of the processes of accumulation and storage, and a triangle *OBC* - of processes of storage of cargo in warehouse, as well as unloading of the "warehouse on wheels" and the warehouse, during the loading of the vessel with this cargo.

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The total costs of storage and reloading of cargo (rub.) are determined by the ratio:

$$C = \frac{E_4 \cdot V_1 \cdot (t_3 + t_6)}{2} + E_4 \cdot V_1 \cdot (t_1 + t_5) + \frac{E_3 \cdot V_2 \cdot (t_4 + t_5)}{2} + E_2 \cdot V_1 + E_1 \cdot (V_2 + V_0), \tag{6}$$

where

t_3, t_4 – the required duration of accumulation of cargo in the warehouse and in the “warehouse on wheels” (accordingly, the segment *AD* and the segment *DO* see Fig. 5), hour

t_5 – time of transshipment from the “warehouse on wheels” to the ship (segment *OF* see Fig. 5), hour, $t_5 = \frac{V_2 \cdot Q_c}{V \cdot M_3}$

t_6 – time of transshipment from warehouse to ship (segment *FC* see Fig. 5), hour, $t_6 = \frac{V_1 \cdot Q_c}{V \cdot M_3}$

According to Fig. 5 the first and second terms in formula (6) are $(E_2 \cdot S_{AXYC})$, where S_{AXYC} – trapeze area *AXYC*, that is part of a triangle *ABC*. The third term in formula (6) is $(E_2 \cdot S_{XBY})$, where S_{XBY} – the area of a triangle *XBY*, that is part of a triangle *ABC*.

In this regard, the formula (6) is converted into the following form:

$$C = E_4 \cdot S_{AXYC} + E_3 \cdot S_{XBY} + E_2 \cdot (V - V_2) + E_1 \cdot \left(V_2 + V_0\right) \tag{7}$$

From the condition of similarity of triangles *ABC* and *XBY*, and also considering that *ABC* and $tg\beta'' = \frac{t_2}{V}$ are determining:

$$S_{XBY} = \frac{1}{2} \cdot \frac{t_1}{V} \cdot V_2^2 + \frac{1}{2} \cdot \frac{t_2}{V} \cdot V_2^2 = \frac{V_2^2}{2} \cdot \left(\frac{t_1 + t_2}{V}\right) \tag{8}$$

Then:

$$S_{AXYC} = \frac{1}{2} \cdot V \cdot (t_1 + t_2) - \frac{1}{2} \cdot V_2^2 \cdot \left(\frac{t_1 + t_2}{V}\right) \tag{9}$$

According to Fig. 5 $t_1 + t_2 = T$, therefore, substituting in the formula (7) values S_{XBY}, S_{AXYC} and T instead of $(t_1 + t_2)$ we obtain:

$$C = \frac{E_3 \cdot T}{2 \cdot V} \cdot V_2^2 + \frac{E_4 \cdot T \cdot V}{V} - \frac{E_4 \cdot T}{2 \cdot V} \cdot V_2^2 + E_1 \cdot \left(V_2 + V_0\right) + E_2 \cdot (V - V_2) \tag{10}$$

Converting to the standard form of the power function, we obtain:

$$C = \frac{E_3 \cdot T - E_4 \cdot T}{2 \cdot V} \cdot V_2^2 + (E_1 - E_2) \cdot V_2 + \frac{E_4 \cdot T \cdot V}{2} + E_1 \cdot V_0 + E_2 \cdot V. \tag{11}$$

To find the minimum we investigate this function on the extremum:

$$\frac{dC}{dV_2} = 2\frac{E_3 \cdot T - E_4 \cdot T}{2 \cdot V} \cdot V_2 + E_1 - E_2$$

$$\frac{(E_3 - E_4) \cdot T \cdot V_2}{V} + E_1 - E_2 = 0$$

$$V_2 = \frac{(E_2 - E_4) \cdot V}{(E_3 - E_4) \cdot T} \tag{12}$$

In the case $E_3 > E4$, the function of the total cost of storage and processing of cargo has a minimum at (12), since the second derivative:

$$\frac{d^2C}{dV_2^2} = \frac{(E_3 - E_4) \cdot T}{V} > 0$$

Thus, the dependence of the share of freight traffic, which is advisable to leave in the cars, using them as a "warehouse on wheels," for subsequent direct transshipment to the ship, was found. In accordance with this, the optimal mode of operation of the berthing complex, specialized for a particular cargo flow, is provided by the presence of a "warehouse on wheels" with a capacity of V_2, as well as the sequence of performing these operations according to Fig. 5. Cargo arriving in the process of loading the vessel in the volume of V_0 (see formula (2)) is reloaded from the wagons to the vessel simultaneously with transshipment of previously accumulated cargo according to the wagon-ship option, and then simultaneously with transshipment according to the warehouse-ship option.

Additional time of cargo delay in the volume V_2 due to untimely submission of the vessel for loading or berth occupancy does not affect the capacity the railway tracks to waiting for wagons. This task relates to the operational management of the transport hub, which are not considered in this article.

5 Parameters for Calculation to Implement the Developed Method

To use the above methodology, the following formulas are presented for determining the components of formula (12).

To determine the volume of pre-accumulated cargo $V(t)$ by formulas (1) and (2), the values of variables M_2 (tons/day) and M_3 (tons/hour) are required. The same variables are used to find the values t_1 (hour) and t_2 (hour) (see formulas (3) and (4)). The capacity of railway tracks to waiting for wagons for feeding to the quay complex should be sufficient for transshipment of coal in the optimal mode, taking into account the seasonal uneven flow of cargo.

Therefore, the volume of the average daily receipt of cargo M_2 is determined by:

$$M_2 = \frac{G \cdot \lambda_c}{365}$$

where:

G – the annual volume of receipt of the cargo on the mooring complex, tons
λ_c – seasonality index of receipt of the cargo in the port

To determine the productivity of the berth complex, M_2 (tons/hour) it is convenient to use the load rate of the vessel per hour for cargo operations at this berth, depending on the type of cargo and type of vessel.

The performance of the mooring complex can be determined through the performance of mooring reloading machines by the formula:

$$M_2 = \sum_{i=1}^{n} P_i \cdot \tau_i$$

where:

n – number of reloading machines simultaneously involved in the cargo handling of the vessel

P_i – capacity of the I-th berthing reloading machine (tons/hour)

τ_i – share of time of cargo operation of the i-th reloading machine during the shift

Components of the formula (12) E_1 and E_2 can be determined by the formulas:

$$E_1 = \frac{R_n}{M_3}; \quad E_2 = \frac{R_c}{M_3}$$

where: R_n and R_c – the cost of maintenance of the mooring complex, respectively, in the direct version and through the warehouse.

6 Results

According to the above methodology, the required capacity of railway tracks to waiting for wagons was calculated for different intensities of cargo arrival by rail at a berth complex productivity of 200 tons/hour, as well as for different berth complex productivity with a cargo arrival intensity of 2000 tons/day. Figures 6 and 7 show the dependence of the capacity of the "warehouse on wheels", respectively, on the change in the intensity of the receipt of cargo to the port and on the performance of the mooring complex.

The results of calculations indicate that the change in the required capacity of the "warehouse on wheels" is disproportionate to the increase in the intensity of the receipt of cargo to the port and the productivity of the mooring complex and depends mainly on the carrying capacity of ships.

Based on the formula (12), the number the railway tracks to waiting for wagons in anticipation of transshipment in the direct version is determined by the expression:

$$m_0 = \frac{V_2 \cdot l_w}{q \cdot l} \tag{13}$$

where:

V_2 - capacity of the warehouse on wheels, tons

l_w - wagon length, m

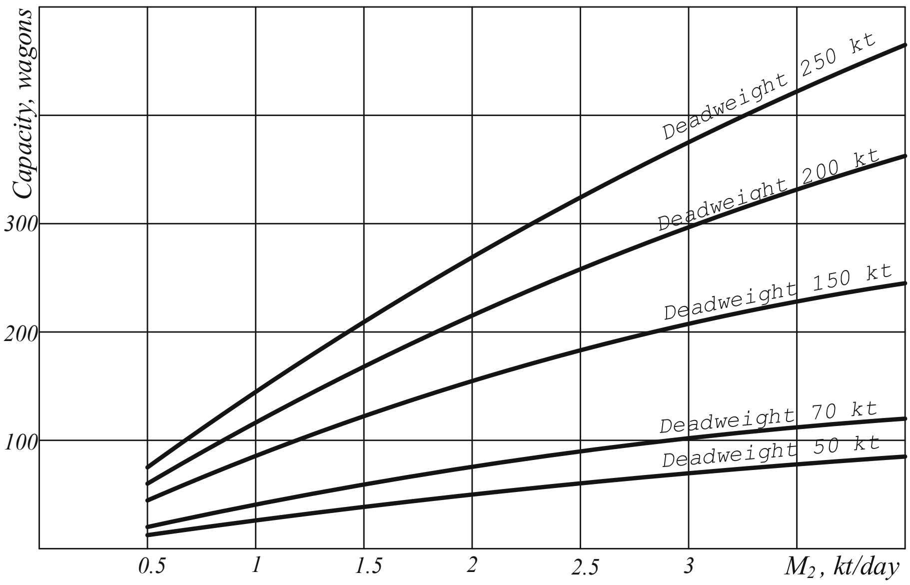

Fig. 6. Dependence of the capacity of the “warehouse on wheels” on the intensity of receipt of cargo, M_2

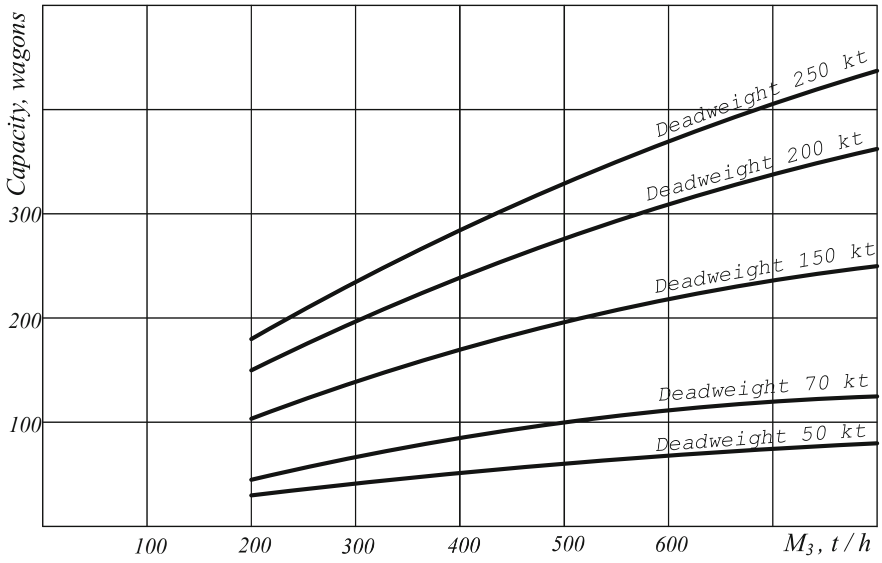

Fig. 7. Dependence of the capacity of the “warehouse on wheels” on the performance of the mooring complex, M_3

q - static load of wagons for a specific cargo, tons
l - useful length the railway tracks to waiting for wagons the, corresponding to the average useful path length of the device, where the "warehouse on wheels" is located, m

According to the scheme, it is advisable to construct the railway tracks to waiting for wagons with through tracks (a trapezoid scheme or a parallelogram). In order to minimize construction costs at the initial stage of construction, it is permissible to use dead-end railway tracks.

The expediency of the location the railway tracks to waiting for wagons depends on the layout of the port railway junction [9]. The railway tracks to waiting for wagons it is necessary to have so that the distance to mooring ways allowed to carry out giving-cleaning of cars on the mooring by one locomotive. This is a necessary requirement for the safety of shunting work in the area of the berth transshipment complex. Therefore, when servicing the mooring ways of the coal terminal at the pre-port sorting station, it is necessary to place tracks for waiting for cars in combination with the sorting fleet of this station. When organizing the transfer movement for the promotion of wagons flows with coal in the transport hub, it is advisable to place the railway tracks of waiting cars in parallel with the pre-port station. The most rational is the option of placing tracks for waiting for cars in the district park, specialized for servicing a coal terminal. Compliance with these requirements will ensure the compactness of railway devices in the port.

7 Conclusions

The application of the proposed method of determining the capacity of the "warehouse on wheels" will contribute to the implementation of the direct option of transshipment of export coal and correspondingly reduce its value on the world market. The proposed method for optimizing the share of coal transshipment in the direct version can be adapted to determine the rational parameters of the work of berthing complexes, specialized for other mass cargoes.

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Coordination of Parameters of Transport Elements System in the Conditions of Lack of Traffic and Estimated Capacity

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Abstract. The paper deals with the balanced development problem of the infrastructure of railway transport enterprises, aimed at improving the economic efficiency of their operation. In order to solve the problem, it is proposed to use an approach, according to which the interaction of its elements is taken into account for calculating the capacity of the transport system. In other words, the traffic and estimated capacities of the station devices ("channels") is determined considering the reserve capacity of the preceding elements ("bins"). Bins carry out an important task, they reduce flow irregularity, thereby increasing the load factor of subsequent servicing devices. Inefficient interaction of elements means economic losses in terms of excess or lack of capacity. Therefore, in order to achieve economic efficiency of railway enterprises, the elements in the structure have to interact efficiently, which implies the harmonization of the parameters of elements according to some criterion. In order to organize the effective interaction of elements at the "bin + channel" level, the balanced traffic capacity criterion was formulated. Speaking about the elements inside the "bin + channel" structures, the final decision on their coordination is made based on the minimum capital and operating costs criterion. As a result, based on the developed criteria, the methodology for coordinating the parameters of structural elements of railway stations is proposed in the paper. The methodology ensures minimization of capital and operating costs of the transport system as a whole.

1 Introduction

Nowadays, the problem of balanced development of railway transport infrastructure is becoming increasingly relevant. Thus, the Transport Strategy of the Russian Federation for the period up to 2030 [1] states that the country's transport system in its current state does not meet the requirements of the economy and the population, and therefore a balanced development of infrastructure is one of the strategy priority goals. And a lot will depend on the methodology for determining the parameters of station devices, since inaccuracies in the calculations can lead to large economic losses in terms of excess or lack of traffic and estimated capacities.

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In recent years, according to the technical literature, scientists are increasingly turning to the problem of calculating and evaluating the traffic and estimated capacities of railway stations [2–5], while offering different calculation approaches and software systems that improve the quality of its definition and use. All calculating methods for traffic and estimated capacities can be divided into 4 following groups: deterministic analytical, graphical, analytical probabilistic and simulation modeling.

Analytical models are based on formalized knowledge about the transport system, which involves calculations based on mathematical expressions. For example, Potthoff [6, 7] was developing a theory for calculating the traffic capacity of throats in tabular form.

Along with the analytical methods, graphic methods were developed and gained traction in [8, 9]. The most classic example of these methods is the daily scheduled plan.

The reaction to the excessive determinism of the previous methods was analytical probabilistic approaches, which are different queuing models. On the basis of the queuing theory Wakob [10] and De Kort [11] proposed an approach to the calculation of railway stations and junctions. The approach extends the Schwanhäusser [12] method consisting in applying the queuing model to predict delays that occur during simultaneous arrival and random change in maintenance time of two trains. In 1999, Wendler [13] proposed a number of improvements in relation to these models based on new approximating algorithms. One of the recent researches, the article Malavasi et al. [14] needs to be noted. In this article authors presented the initial stage of an extensive study, including the analysis of various analytical methods for the purpose of comparison and possible integration into a completely new approach to assess the traffic and estimated capacities of stations in the synthesis mode.

Simulation modeling is a research method in which a more accurate representation of reality is achieved by creating a model that describes the object of study in as much detail as possible. At the present stage there are a large number of simulation systems on the intellectual market allowing studying the railway stations and junctions. The most widely used software products are RailSys [15], OpenTrack [16], Villon [17], and ISTRA [18–20]. A more detailed analysis of simulation systems is presented in [21] and [4].

Analytical and graphical methods can be useful in simple cases and they often lead to useful results without complex simulation expertise [2]. However, the performance of large railway stations is strongly affected by the interaction of random processes and control, so they are difficult to study and calculate. The above mentioned methods cannot fully represent the features of structure and technology, as well as the adaptability and influence of random processes, so the results of calculations cannot be absolutely reliable. Simulation modeling can fully satisfy all the requirements for methods of studying transport systems, and can give reliable results for the evaluation of the object under study.

The purpose of the study is to develop a methodology for coordinating the parameters of the structural elements of railway stations, taking into account the influence of the nature of their interaction and ensuring minimization of capital and operating costs.

2 Materials and Methods

A large-scale theoretical study of railway transport systems was made by Kozlov [22]. The principle of dividing the system into bin and channel element categories, which he proposed, reflects the properties of the system more complete. This principle makes it possible to evaluate the conditions of interaction of the selected elements most accurately while maintaining a holistic view of the considered object. Therefore, it is advisable to use the abstract channel and bin elements within the framework of this study, in order to build a conceptual interaction scheme.

At the first stage of the study, the initial concepts of the selected elements are defined, as well as the conditions for their interaction with each other and with the transport flow.

Flow is a union of moving discrete units.

A channel is an element of the system with the following parameters (Fig. 1): input stream $w(t)$; output stream $f(t)$; travel time $\tau(t)$; traffic capacity C [22].

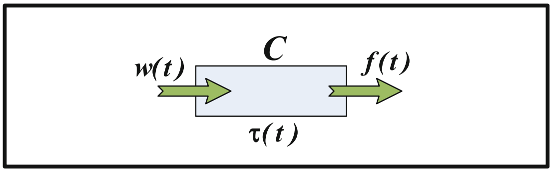

Fig. 1. Conceptual representation of the channel

It should be noted that the input and output flows cannot exceed the traffic capacity of the channel, change their value over time, and the output stream is equal to the input stream with a time difference $\tau(t)$. Thus, the following conditions must be met for the channel:

$$w(t) \leq C,\ f(t) \leq C,\ f(t) = w(t - \tau(t)). \tag{1}$$

Due to the inconstancy of transfer time when passing through the channel, the flow becomes more disorganized, and therefore, a traffic capacity reserve is required for the flow to pass:

$$\tilde{f} = f(1 + \rho) \leq C \tag{2}$$

Where $\tilde{f}$ is the calculated flow; ρ – indicator of flow disorganization.

At the output from the channel the flow disorganization increases:

$$\rho_f = \rho_w + \Delta\rho \tag{3}$$

Bin is an element of the system, which is characterized by the following parameters (Fig. 2): input stream $w(t)$; output stream $f(t)$; current capacity (state) $q(t)$; total capacity Q [22].

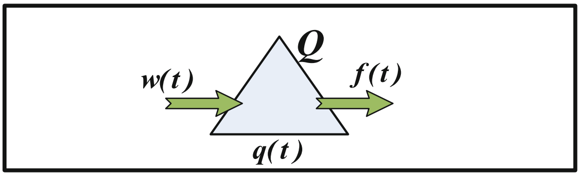

Fig. 2. Conceptual representation of the bin

The bin can be characterized by the following ratios:

$$q(t) \leq Q, \text{ for all } t, \tag{4}$$

$$q(t + 1) = q(t) + w(t) - f(t)$$

The bin, unlike the channel, is able to reduce the disorganization of the flow:

$$\rho_f = \rho_w + \Delta\rho \tag{5}$$

Thus, the output flow from the bin becomes more manageable. The value $\Delta\rho$ depends on the capacity of the bin and on its occupancy level [22].

Transport systems are various combinations of channels and bins. The scheme of their location in the structure defines various types of interaction: channel – channel, channel – branched channel, bin – channel.

In practice, the channel – channel and channel – branched channel interactions are quite rare in the structure of a transport object. The most common is the bin – channel interaction of elements. Therefore, in order to determine the capacity of the railway transport system more accurately, it is necessary to consider devices (so-called channels) together with the backup ways and warehouses located in front of them (so-called bins). The capacity of the channel depends on the level of its possible load, determined by the properties of the incoming flow. With a high irregularity of the incoming flow and maintenance time, the loading level of the channel will be low. If, however, the flow irregularity is reduced due to the use of a bin, then the load of the channel will be increased.

Thus, in order to take into account the influence of the previous bin on the channel capacity, it is proposed to use the load factor of the channel γ [5], depending on the capacity of the bin Q.

$$\tilde{C}_i = \gamma_i C_i \tag{6}$$

where C_i is the maximum traffic capacity of the i-th channel; $\tilde{C}_i$ – the traffic capacity of the i-th channel; γ_i – load factor of the channel with the given flow parameters.

More clearly, the effect of bins on the traffic capacity of channels is demonstrated by a conceptual model of their interaction (Fig. 3). Despite the fact that channel 1 has the biggest capacity, its actual capacity will be the smallest due to the smallest capacity of the previous bin and, accordingly, the smallest load factor.

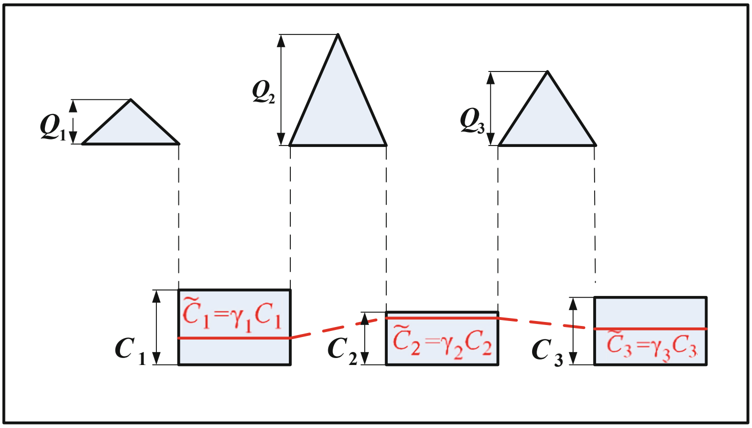

Fig. 3. Conceptual interaction model bin and channel elements

As a result, when determining the limiting element in the structure of a transport object, it is necessary to consider the bin + channel structure and adhere to the *min* $\gamma_i C_i$ criterion. This means that traffic capacity depends on the nature of the interaction between elements in the structure of the transport system. Moreover, it is necessary to consider the interaction of the transport object elements both at the bin + channel structures and at the bin and channel elements level within the bin + channel structure. Inefficient interaction between elements means economic losses in terms of excess or lack of traffic capacity. Therefore, it is very important to assess the effectiveness of interaction between elements in the structure at the stage of examining existing and designed stations.

3 Results of the Research

Effective interaction of elements in the structure means the coordination of parameters according to following criteria: flow rate, reduced costs, maximum traffic capacity, etc. However, in order to agree on the parameters, appropriate criteria are needed to determine the nature of the interaction at the bin + channel structure level, and within these structures at the level of bin and channel elements.

So, in order to avoid economic losses in terms of excess or lack of traffic capacity, it is necessary that all design elements have the same capacity. Therefore, effective interaction at the bin + channel level means that the capacity of all design elements in the structure of the transport object is equal, which will provide harmonization of the parameters of elements for a given work amount.

$$\forall_i | \gamma_i C_i = \tilde{C}_n = const \qquad (7)$$

where $\tilde{C}_n$ is the required traffic capacity of the station.

The interaction within the calculated elements also has to be considered. Since the parameters of the channel and bin are interrelated in the structure of the calculated pair, the traffic capacity of the calculated element can be affected both by changing the parameters of the channel and bin. The economic efficiency of these changes plays an important role. In order to achieve it, the Minimum capital and operating costs criterion is proposed, but it is necessary to take into account a number of additional criteria like ensuring the required level of delays and ensuring the required traffic capacity.

$$\gamma_i C_i = \tilde{C}_n, D_i < D_i^{max}, R_i + r_i \rightarrow min \qquad (8)$$

where D_i is the delay due to the i-th channel, h; D_i^{max} – the maximum allowable value of delays due to the i-th channel, h; R_i – capital expenditures on the development of the i-th channel and the i-th bin, Thous. RUB; r_i – operating costs for the maintenance of the i-th channel and the i-th bunker, Thous. RUB;

An algorithm has been developed for matching the parameters of elements according to the criteria (Fig. 4), which includes 2 stages of matching.

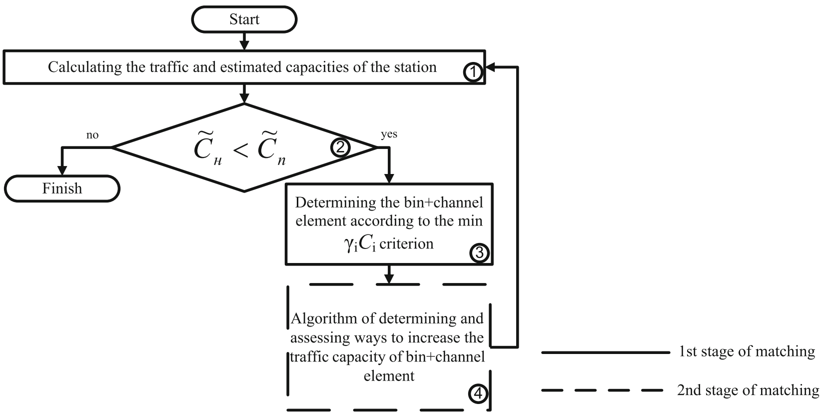

Fig. 4. Algorithm for the matching of parameters of the station structural elements

At the first stage, the interaction effectiveness at the level of bin + channel calculated elements is evaluated, in other words, couples with insufficient traffic capacity are determined, which, in turn, fall into the second matching stage. At the second matching stage, the interaction effectiveness between the bin and channel elements within calculated pair is assessed and cost-effective options for achieving the required traffic capacity are determined (Fig. 5).

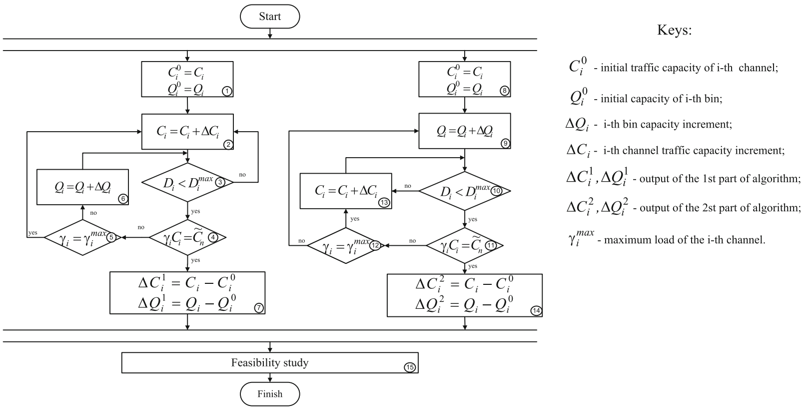

Fig. 5. Algorithm for determining and evaluating options for increasing the traffic capacity of the bin + channel element

In order to determine ways for increasing the traffic capacity of the bin + channel element, it is most rational to use such an indicator of comparative economic efficiency as Reduced construction and operating costs. The most cost-effective option is the one that has the lowest value of reduced construction and operating costs:

$$C_{re} = \sum_{t=0}^{T} \frac{K_t}{(1+E)^t} + (1-\gamma)\sum_{t=0}^{T} \frac{Э_t}{(1+E)^t} \tag{9}$$

where T is the time horizon; t – calculation step; K_t – investment costs of the period t; E – discount rate; γ – the share of tax deductions in the increase of the surplus product; $Э_t$ – operating costs of the period t.

In order to test the methodology for matching the parameters of the structural elements of railway stations and demonstrating the work of the algorithms, a large number of experiments was conducted in the simulation system on the Utes railway station model. The station serves the company adjacent not to the station itself, but to the Utes-Zagotovka section, and an exhaustive set of results was obtained. In order to achieve the goal of the study, the situation with a 40% increase in processing volumes was considered. Experiments have shown that the station does not cope with prospective volumes, but made it possible to identify the cargo front, an element with a minimum estimated capacity (Fig. 6).

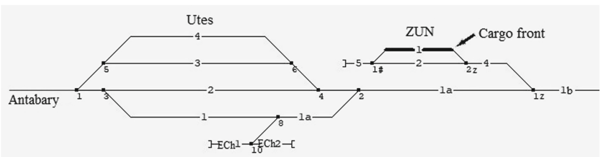

Fig. 6. Utes station layout and non-public ZapadUralNerud railway

At the second matching stage, the influence nature of the parameters of some elements on the parameters of others within the considered parameter pairs was assessed. As a result of using the developed algorithm, it was determined that it is possible to increase the estimated capacity by either increasing the maximum traffic of the channel itself, or through constructing the bin device before the channel. Thus, it is possible to increase the estimated capacity of the cargo front by introducing an additional front loader, or by constructing the dead end track (Table 1).

Table 1. Station performance indicators when calculating options to improve the estimated capacity of the cargo front.

Indicator	Integrating the second front loader $\left(\Delta C_i^1\right)$	Constructing the dead end track $\left(\Delta Q_i^2\right)$
Required estimated capacity $\tilde{C}_n$, cars/d	48	48
Cargo front load γ, %	63.6	94.6

In order to determine the most efficient way to increase the estimated capacity of devices, the proposed criterion Minimum of reduced construction and operating costs was used.

As a result, the most effective option is to increase the maximum traffic capacity of the channel by adding an additional loader (Fig. 7).

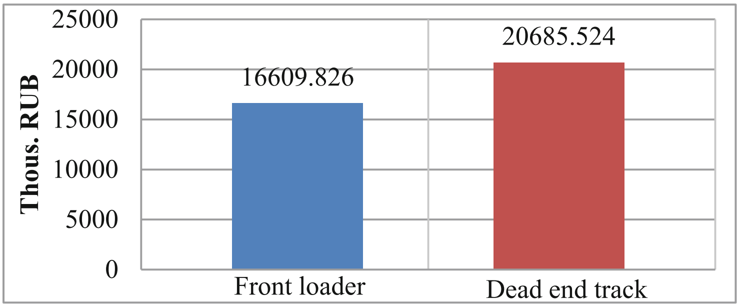

Fig. 7. Reduced construction and operating costs for options of improving the estimated capacity of the cargo front

4 Discussing the Results

In order to achieve the goal of the study and determine the traffic capacity of rail transport systems more accurately, a new approach is proposed in the paper. According to this approach, the traffic capacity of the channels is calculated considering the capacity of the previous bins, that is, it depends on the efficiency of their interaction in the structure. For the organization of effective interaction between elements at the bin + channel level, the Balanced traffic capacity criterion was proposed. In order to coordinate the parameters of elements within these structures, the final decision was made based on the Minimum capital and operating costs criterion. As a result, the methodology for coordinating the parameters of the structural elements of railway stations was proposed on the basis of the developed criteria, ensuring minimization of capital and operating costs of the transport system as a whole. Combining the possibilities of conceptualization and simulation allows studying the object in detail and at the same time not miss the holistic perception of its operation principles. This method provides a more accurate calculation of the traffic and estimated capacities of railway stations and allows you to determine the cost-effective parameters of their structural elements. Implementing the proposed methodology at Utes station will allow saving 4075.698 thousand RUB of investment funds, with an increase in estimated capacity of 40%. Subsequent studies are aimed at developing a methodology for matching the parameters of the railway stations structural elements by developing and implementing an algorithm for determining and evaluating options for eliminating or reducing the excess capacity of the bin + channel element.

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Construction of Efficient Railway Operating Domains Based on a Simulation Examination

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Abstract. A growing free market economy needs intensive development of the transportation infrastructure, including railway operating domains. Large amounts of investments require detailed substantiation. This is provided by simulation examination. This article proposes a technology for constructing efficient operating domains according to various criteria, including the maximum traffic capacity, the minimum flow passing time, and the minimum costs for ensuring the preset process parameters. A new concept of the minimum calculation element (a channel-bunker, i.e. a duplex instead of a commonly employed channel) is presented, while the "bottleneck" concept is replaced by the "bound element" term. This fact essentially changes the main provisions of the existing instructions on calculation of operating domains.

Keywords: Railway operating domains · Simulation examination · Traffic capacity · Railway transport · Simulation modeling

1 Introduction

The present-day and future operating conditions of railway transport require a substantial gain in the development and performance effectiveness of the railway network operating domains.

A part of the railway network is combined into an operating domain according to technological criteria (formation and cancellation of cargo flows, provision of traction services, logistical control of approach to sea ports and border points, etc.). Such operating domain is characterized by unifying the technological and infrastructure parameters of the transportation process and by providing integrated end-to-end management of field operation and performance of construction-and-installation and repair work.

As shown by studies, the operating domain's technical and process parameters are functions of each other. Therefore, simulation modeling computer systems hold a central position in a set of mathematical models ensuring calculation of operating domains.

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The purpose of this study is to develop methods for constructing operating domains with efficient technical and process characteristics according to various criteria including the maximum traffic capacity, the minimum flow passing time, and the minimum costs for ensuring the preset process parameters.

2 Objectives and Paths of Operating Domain Development

A long-term program of RZD OJSC development has been approved by the Government of the Russian Federation [1]. It is necessary to ensure transportation of goods by developing the integrated servicing of cargo shippers and improving the quality of freight transportation. The task of increasing the transportation mobility of the population both within and between agglomerations must be solved.

The accomplishment of these goals requires new methods for developing the infrastructure of operating domains and effective use of their resources. It is required to substantiate high-speed and speed routes for transportation of passengers and urgent-delivery goods, as well as traffic routes for heavy-tonnage trains carrying bulk cargoes. It is also required to ensure high reliability of performance of operating domains in case of changes in the passenger and cargo flows, repairs, and possible traffic accidents.

These tasks will have to be solved within extremely rigid constraints. The constraints include:

- available investment resources, capacities of the construction sector and design organizations;
- time intervals that can be provided for reconstruction work on active railway lines;
- investment project implementation deadlines.

For example, in compliance with the instructions of President of the Russian Federation, the carriage capacity of the Baikal-Amur Mainline and the Trans-Siberian Railway must be augmented up to 180 million tons by 2024. The time of container carriage by rail from the Russian Far East to the western border of the Russian Federation must be reduced to 7 days.

In general, it is envisaged that the traffic capacity of the Russian railways will be augmented for the volume of container transit traffic to increase 4-fold by 2024. Development of rail approaches to the ports of northwest Russia and Azov-Black Sea basin is also a challenging task.

3 Technology of Constructing Efficient Operating Domains

3.1 About Simulation Examination

The objectives of scientific support of the Transportation Strategy [2] include: "carrying out simulation examination of the transport infrastructure development investment projects…, and development of proposals for adjustment of the projects on the basis of simulation examination".

Simulation examination is a system research using a computer model-based experiments that allow obtaining a complete characteristic of a facility as a system (traffic capacity, time of transportation vehicles residence in the system with breakdown by operations, structure and technology "bottlenecks" [3]). Foreign scientists conduct active studies of rail transport facilities by using analytical models, the waiting-line theory, the theory of graphs as well as simulation systems [4–7]. Currently, IMETRA modeling system is the most advanced examination apparatus for operating domains [8–10]. IMETRA macro-modeling system employs a functional approach instead of a merely structural one. Only the ultimate functional capacity with which a yard preserves its functional properties, rather than the structure of tracks and their physical capacity, is specified for the yard. Instead of a detailed structure, the number of parallel movements is used as a parameter for the throat. The system generates the traffic capacity of stations and sections as well as their aggregated parameters including the load density/utilization of yards, throats, and sections, delays caused by them, and full or divided detention of cars.

3.2 About the Minimum Calculation Element

When calculating the traffic capacity of stations and sections in compliance with the existing instructions [11, 12], a certain channel (structural or functional) is commonly used as a calculation element. The channel is structural when a flow moves along an element (for example, a hump yard) and is functional when the flow is transformed on the element without movement (for example, train handling upon arrival). The channel is a device through which the flow passes without accumulation (either positive or negative). The situation in a bunker is different. The input can be greater than the output (positive accumulation) or, by contrast, the output can be greater than the input (negative accumulation).

A bunker in front of the channel transforms the flow from random to controllable one, thus increasing the possible level of useful utilization of the channel. Therefore, the minimum calculation unit in an operating domain is a bunker-channel combination ("duplex") (Fig. 1).

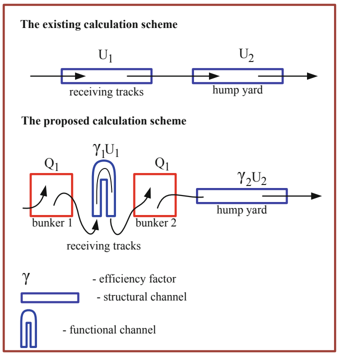


Fig. 1. 1. Hump yard calculation schemes.

So, the actual traffic capacity of a certain channel depends on the level of its possible useful load density

$$\tilde{U} = \gamma \cdot U,$$

where: U is the maximum possible traffic capacity;

$\tilde{U}$ is the real traffic capacity;
γ is the factor of possible load of the channel at given parameters of the flow and bunker capacity.

3.3 Operating Domain with Balanced Structure

A calculated operating domain should have a balanced structure. Or, in other words, parameters of stations and sections should be harmoniously reconciled throughout the operating domain.

Formally, it means the equality of traffic capacities of all duplexes describing the sections and stations (Fig. 2). This can be expressed by the ratio

$$\forall_i | \gamma_i \cdot U_i = const$$

where: U is the maximum traffic capacity of the channel,

γ is the channel useful load factor. It characterizes the capabilities of a bunker for transformation of a flow from a random (inconvenient for the channel) into a controllable one (convenient).

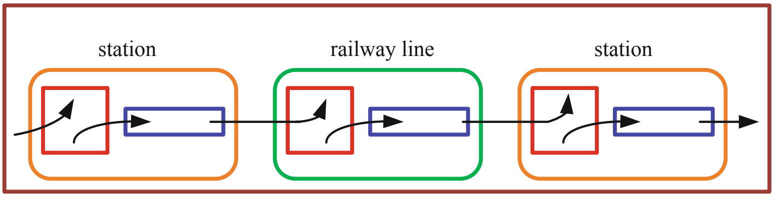


Fig. 2. Diagram of a calculated operating domain.

As this takes place, the useful load of channels should be less than the greatest possible one. In many industries, a load of approximately 70% is considered to be reasonable. The transportation industry should create reliable transport links for economical interaction. Meanwhile, economic ties in a free market economy can change dynamically. Therefore, the operating domains should have appropriate reserves.

This is confirmed by the experience of economically developed countries. The level of reasonable reserves is best calculated using simulation models.

3.4 Basic Optimization Strategies

The strategies differ in terms of the main task, criterion, and constraints. The "bottle-neck" concept is not suitable here any longer, so it should be replaced by the "bound element" term. In a general case, it will be an element that complicates to the greatest extent the execution of the assigned task.

(a) Provision of the maximum traffic capacity
If a transport network is undeveloped, the task definition that involves passing of the maximum flow with limited development resources appears out of necessity. The bound element will be a duplex with the minimum traffic capacity; it is precisely the duplex but not the channel.
An operating domain should correspond to the "with balanced structure" concept

$$\forall_i | \gamma_i \cdot U_i = const$$

But, at the same time, $\forall_i | \gamma_i \cdot U_i = \max$
The basic constraint is the limiting value of outlay costs (reduced costs where reduction is made by investments and current costs)

$$\sum_i (\alpha R_i + r_i) \leq R_{\max}$$

where: R_i are investments into development of the i-th duplex;

r_i are the current costs for operation of the i-th duplex over the calculation period;
α is the reduction factor.

(b) Provision of the maximum flow velocity
Criterion is the minimum total time of the flow movement through the operating domain

$$\sum_i \sum_j u_{ij} \tau_{ij} \rightarrow \min$$

where: u_{ij} is the j-th flow jet at the i-th duplex;
τ_{ij} is the passage time of the j-th flow jet along the i-th duplex.

Constraints:

- minimum traffic capacity;
- maximum reduced costs.
  The bound element will be a duplex with the greatest flow passing time.

(c) Development of an operating domain with minimum costs
Criterion is the minimum reduced costs (reduction by investments and current costs)

$$\sum_i (\alpha R_i + r_i) \rightarrow \min$$

Basic constraints:

- the minimum flow movement velocity (critical total time of the flow movement through the operating domain)

$$\sum_i \sum_j u_{ij} \tau_{ij} \leq (\sum_i \sum_j u_{ij})T$$

Where T is the average time of the flow movement through the operating domain;

- the minimum traffic capacity.

The bound element will be a duplex that causes the greatest cost of losses when passing the flow.
A Pareto set of potentially optimum alternatives appears for each strategy, because an objective can be achieved by different methods.
A sequence of simulation experiments allows constructing an operating domain with the required parameters. In order to decrease the number of experiments, it is expedient to use the so-called "simulation descent" [].

3.5 An Example of Constructing an Operating Domain upon the "Maximum Flow Passing Speed" Criterion

(a) Increasing the number of functional channels
The main functional channels at the operating domain stations are gangs for train handling upon arrival or before departure (naturally, the railway tracks in the yard where handling takes place are also occupied during the handling process).
At several stations, where delays caused by gangs were large, the number of gangs were increased for an experiment.

Lyangasovo Station
Up-train delays caused by gangs were considerable, and each train was delayed by 61 min (Fig. 3). Meanwhile, resultant up-train delays were 93.5 min per train.

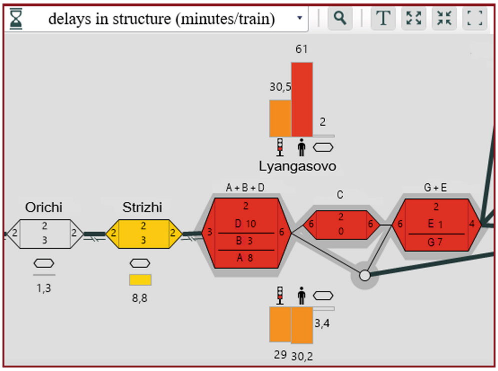


Fig. 3. Delays of trains at Lyangasovo station (original variant).

Upon involvement of new gangs, the delays have reduced substantially (Fig. 4). The total delays were only 36 min per train, and delays caused by gangs fully disappeared.

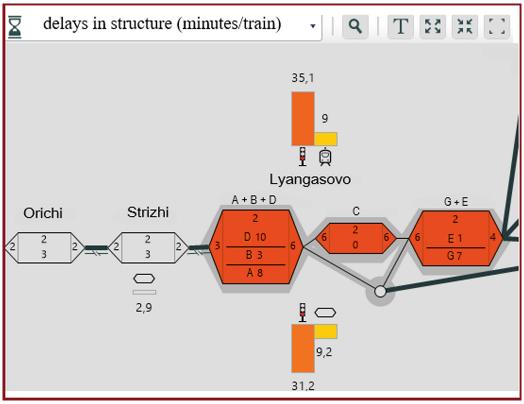


Fig. 4. Delays of trains at Lyangasovo station (experiment).

However, the model allows seeing how this will affect other operating parameters. The service speed at the adjacent section has increased from 43.82 km/h to 47.94 km/h (Fig. 5).

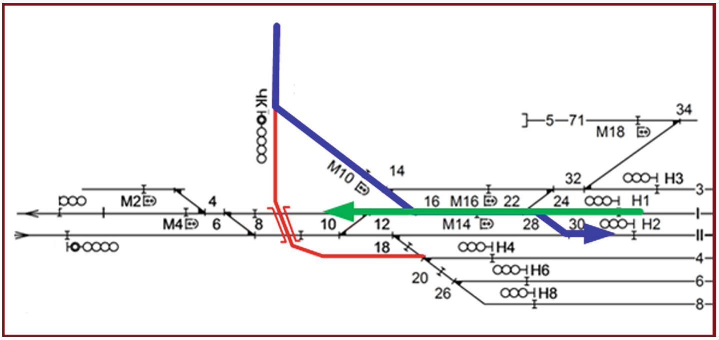
Speed, km/h

Line	Technical (uneven)	Technical (even)	Service (uneven)	Service (even)
Balezino-Lyangas	55,48	55,43	46,00	43,82
Balezino-Lyangas	55,66	56,12	47,66	47,94

Fig. 5. Increasing the service speed.

(b) Increasing the number of structural channels
Throats at several stations have been selected as structural channels.

Pozdino Station
Passenger and freight traffic at Kirovsky railway hub are divided here. However, the station lacks a flying junction, which causes hostility in the routes of down (odd) freight trains and up (even) passenger trains. These flows can be separated by means of a flying junction (Fig. 6):



Green is the route of down freight trains, blue is the route of passenger trains, red is the flying junction

Fig. 6. Junction at Pozdino station.

When adjusting the model, we change the number of channels in the throat and then specify new channels in the train routes. Comparison of the results of the original model variant (before) and of the experiment (after) is given in Table 1.

Table 1. Delays in Pozdino station throat

Channel	Utilization,%		Delays			
			Hour/Day		Min/Train	
	Before	After	Before	After	Before	After
1	19	9	0	0		
2	40	30	3.2	0.1		
3	42	32	10.8	2.3		
4	–	10	–	0		
Total	**–**	**–**	**14.0**	**2.4**	**6.3**	**1.1**

As can be seen, the throat-related delays have decreased six-fold. The down-train service speed in Balezino—Lyangasovo section has increased from 47.66 km/h to 48.39 km/h.

4 Conclusion

The specificity of large integrated investment projects for development of the railway network operating domains imposes high requirements on the quality of their substantiation at the pre-project stage. These requirements are matched by the methodology substantiated herein. Formalization of the process by means of duplex calculation elements allows interpreting the results of simulation calculations more completely and adequately than the known analysis methods. This makes it possible to determine the devices utilization rate and to construct a set of computational simulation experiments to search the parameters of the operating domain according to the preset criteria and constraints.

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Logistics Grading of Railroad Stations

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Abstract. The purpose of this study is to develop a method of assigning a logistics grade to freight stations according to the principles of customer focus, accessibility, and information comprehensiveness. The tools and methods of logistics theory, systems theory, systems analysis, marketing, linear and dynamic programming, morphologic synthesis, and terminalistics are used. The main results of the research include a unique grading system for railroad freight stations open for cargo operations that works by assigning a logistics grade based on the information about additional logistics services that is relevant for the clients. Another practical result of the study is the method of assigning the logistics grade that takes into account the specifics of the terminal and warehouse infrastructure and logistics service offered by the station. The classification of railroad logistics objects has been proposed with specified transport and logistics service comprehensiveness ratio obtained under real-life conditions. The direct objective of the method's application in the transport sector is the implementation of the customer-focused logistics principles to enable high-profit freight traffic and to divert cargo from motor transport to railroad terminal network objects.

Keywords: Customer focus · Logistics grade · Logistics objects · Logistics activity · Comprehensive transport and logistics service

1 Introduction

The employment of the customer-focused approach by the railroad sector as an anti-crisis management element in the context of competition for customers is driven by customers switching to another transportation method (motor transport) or to commercial logistics operators, which lowers the overall cargo traffic [1].

The foundation of a customer-focused service is its accessibility and convenience, as well as a sufficient level of information available to customers about services provided by a carrier, for instance RZD OJSC [2].

Nowadays, the need to implement a customer-focused approach to informing customers about terminal warehouse objects of RZD OJSC is obvious, especially in the context of competition for customers, which is indicated by the reported data from Russian sources [3, 4].

The study of transport and logistics literature that deals with setting up efficient transport and warehouse systems, in particular, research concerned with the rational design and operation of transportation hubs [5, 6], classification of terminal and

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warehouse infrastructure [7, 8], optimization of customer interaction on the transport and logistics market [9, 10], transport and logistics service quality [11, 12], transportation geography [13], warehouse and distribution logistics [14, 15], showed that the existing theoretical research on terminal and warehouse infrastructure is insufficient. The studied academic works address the subject in terms of transportation, logistics, and design but not in terms of customer focus. The emphasis on technical features of the terminal and warehouse infrastructure does not allow customers to adequately evaluate the service range, since the existing format of information presentation on logistics object operation complicates the decision making on whether a given object is appropriate for the customer's business specifics and does not provide information on which additional services are available at the station.

It can be concluded that there needs to be a new approach to logistics operations identification, which would integrate various aspects of designing and developing railroad transport and logistics systems.

The studies also showed some other "blind spots" in the research, development and operation of logistics objects, such as improvement of customer focus of the services they provide, offering a comprehensive range of transport and logistics services, and comprehensive evaluation of railroad network terminal and warehouse infrastructure performance in terms of logistics (this is expressed in the author's earlier works [16, 17]).

In terms of possible applications of the subject, the studies showed the following. The development strategy of Russian railroad transportation up to 2030 considers the company's transition from an infrastructure and carrier business to a transportation and logistics enterprise [1].

Russian experts established that in the last ten years at least 5% of cargo traffic had been transferred to motor transport [2]. With the lack of well-developed contemporary objects of terminal and logistics infrastructure, it is virtually impossible to implement a comprehensive ("end-to-end, seamless") transport and logistics service and to bring high-profit freight to railroad transportation, since added value services can only be implemented on such objects. These findings indicate high relevance of exploring new approaches to attracting customers to railroad transport, increasing logistics operations profitability, and increasing high-profit cargo traffic in the network.

High practical value of the new approach to grading freight stations is confirmed by accessibility, simplicity and comprehensiveness of information on "transport-related" service; it should be implemented in the grading approach itself.

The main customer requirement to logistics features of the terminal infrastructure is a grading system that reflects the features of the terminal and warehouse infrastructure available at a station, the range of transport, storage and comprehensive logistics services, i.e., the parameters important to the customer. Thus, a completely different classification of freight stations is required, which considers the specifics, typology, capabilities and equipment of the available terminal and warehouse infrastructure, and the range of transportation, storage and comprehensive logistics services.

On the one hand, the customer focus of the proposed logistics grading system involves displaying the parameters relevant to customer decision making in favor of a particular object. On the other hand, the customer focus should account for the specifics of railroad operations and contribute to the management, record keeping, monitoring and performance evaluation of terminal and warehouse infrastructure objects in public areas of the entire railroad network [18].

The purpose of this study is to propose a method of logistics grading of freight stations, that would consider customer focus, accessibility and comprehensiveness of information. To that end, a unique system has been developed. It assigns a logistics grade to railroad freight stations open for freight operation based on the information about additional logistics services relevant to the customer.

The specific goals of the study include: classifying the "logistics grade" concept as a new way of identifying logistics objects, developing a grading system for railroad logistics objects based on service parameters, introducing and examining various new indices for evaluation of a freight station's logistics object operation.

A railroad logistics object (LO) is an element of the terminal and warehouse infrastructure that functions as a transportation hub for the terminal and logistics system that provides technical support and carries out cargo loading, unloading, storage and distribution services, including cargo delivery to the consumer, along with other participants of the transportation process [19].

The logistics grade of a railroad station is a new customer-focused way of identifying railroad logistics services and objects. The logistics grade is defined as a particular classification category of freight stations in the context of logistics that helps to determine and identify complexity, performance and comprehensiveness of the terminal and warehouse and logistics service implemented at a station's logistics object.

2 Research Methods

To achieve the set goal, the study used tools and methods of the logistics theory, systems theory, system analysis, marketing, linear and dynamic programming, morphologic synthesis, and the author's terminalistics methodology.

To determine the logistics grade of a station the following initial data is required: railroad station class; the number of tracks; total area of the LO, ha; the ratio of operational and in-house logistic service, %; the portfolio of the services provided by the LO; classification of the warehouse buildings (according to the renowned international Knight Frank classification); the presence of a seaport, airport, federal highway or customs point in close vicinity to the station; whether or not the station is a transit, border, or port station; the size of increase in the added value of the cargo through handling at the LO, %; availability of logistics consultations and distribution chain management services; the number and types of transport interacting in the LO infrastructure; availability of multimodal transportation service at the LO.

Let us consider a method of logistics grade assignment.

Stepwise it can be represented as follows:

1. initial data collection, processing, and systematization in volume terms, including mean values of both planned and actual performance parameters of a railroad station and the logistics object it's housing;
2. expert analysis through a three-stage polling (by a business audit unit of the railroad carrier, independent experts or customers);
3. systematization and analysis of polling data;
4. evaluation of relevant parameters with a total score calculation;

5. preliminary identification of the logistics object type and logistics grade of the station;
6. calculation of the author's parameters (for carrier and customer purposes)
7. adjustment of the logistics grade of the station based on the determined values for the author's parameters (this study presents reasoning for making a decision based on the K_{log} parameter).

At the core of the logistics grading lies the classification of terminal and warehouse infrastructure objects, as well as the renowned classification of warehouse buildings, proposed by Knight Frank, a consulting company.

3 Results

The proposed logistics grading of a freight station open for freight operations is represented by numbers 1 through 9 and reflects (based on the author's Klog ratio) the range of additional transport and logistics services.

The logistics grade is determined for railroad freight stations open for freight operations and having an LO open for freight operations using a rating scale on every logistic function and operation provided by the station, taking their comprehensiveness into account [20].

According to the method described above, the logistics grade should be assigned by experts (business audit units, independent experts, customers) and made publicly available online to enhance capabilities for comprehensive evaluation and real-time monitoring of the traffic and development of the terminal and warehouse infrastructure and provide customers with public access to the information. That last point is a mandatory requirement for a railroad carrier transitioning to a new level of logistics

Table 1. Identification table, part 1

Station Class	Score	Railroad Tracks, Number	Score	Total LO Area, Ha	Score	Ratio of General Services to In-house Logistic Services, Inclusive	Score	Service Package	Score	Classification of Warehouse Buildings (Knight Frank Classification)	Score
Unclassified	6	Two		Up to 2	1	Up to 0.05	1	Standard	1	A	4
1	5	Three		Up to 5	2	Up to 0.1	2	Standard+	2	B	3
2	4	More than three		Up to 10	3	Up to 0.15	3	Extended	3	C	2
3	3			Up to 15–20	4	Up to 0.25	4	Extended+	4	D	1
4	2			Up to 25	5	Up to 0.3	5	Comprehensive	5		
5	1			Up to 30–40	6	Up to 0.4	6	Ultimate	6		
				Up to 60–80	7	Up to 0.5	7				
				Up to 100	8	Up to 0.7	8				
				Up to 150	9	Up to 0.8	9				

Table 2. Identification table, part 2

Transition Point, Border Station, Port Station, Customs Availability	Score	Significant Increase of Cargo Properties	Score	Customs Services	Score	Freight Shipment Management	Score	Consulting Services	Score	Interaction With Other Types of Transport	Score	Multimodal Transportation Services	Score
Yes	4	Yes	4	Yes	4	Yes	4	Yes	4	Yes	4	Yes	4
No	0	No	0	No	0	No	0	No	0	No	0	No	0

service provision—4PL—that supports a unified information field for customer-provider interaction. Using identification Tables 1 and 2, an LO can be given a score from 6 to 68 points.

Table 3 provides (according to Table 3) ranges of values for each of the nine classes (their score) on relevant parameters for three LO groups: A, B and C.

Table 3. LO grade

LO type	Grade designation	Range, points
Group A (4-point range)—top		
MTLC	9	64–68
TLN	8	59–63
TN	7	54–58
Group B (7-point range)—intermediate		
LC	6	46–53
DC	5	38–45
TT	4	30–37
Group C (10-, 9-, or 8-point range)—bottom		
TWC	3	21–29
C	2	11–20
SA	1	10 or less

The logistics grade is formed according to the identification Tables 1 and 2, with the $K_{\log}$ ratio factored in.

The grade is assigned with the author's comprehensiveness ratio for the transport and logistics services of the LO, $K_{\log}$, taken into account (the ratio of the extended logistics services volume to the total volume of freight and commercial operations at the station).

At the core of the proposed logistics grade is the comprehensiveness ratio of the transport and logistics services of the LO, $K_{\log}$, which is defined as

$$K_{\log} = \frac{Q_{\text{sim}}}{\text{Q}_{\text{compl}}} K_{\text{lc}} \tag{1}$$

or

$$K_{\log} = \frac{Q_{\log}}{\text{Q}_{\text{total}}} K_{\text{lc}} \tag{1}$$

where Q_{sim} is the volume of simple (elementary) logistic operations with the total value of no more than 15–20% of the total LO profit, c.u./year; Q_{comp} is the volume of compound complex logistic operations with the total value 70% of the total LO profit, c.u./year; K_{lc} is the coefficient of logistic operation combination, defined as the ratio of simultaneously performed operations to the total number of operations necessary for the given cargo; $Q_{\log}$ is the volume of logistics services provided by the LO, c.u./year; Q_{total} is the total volume of services (freight, commercial, logistics services) provided by the LO, c.u./year.

For the performance evaluation of the LO, according to the terminalistics theory (described in detail in the author's works [19–22]), the term "logistics activity" is proposed as the second index of the LO grade in addition to $K_{\log}$ described above.

Logistics activity is the number of logistic operations performed by the LO per ton of the i-th freight unit per unit of time, ton-operations/day:

$$Q_{\text{LP}} = \frac{Q_{\text{fr}\,i}^{\text{LO}} N_{\text{logop}}^{\text{fr}\,i}}{T} \tag{3}$$

Where $Q_{\text{fr}\,i}^{\text{LO}}$ is the volume of the i-th freight unit at the LO that needs logistics service, tons; $N_{\text{logop}}^{\text{fr}\,i}$ is the number of elementary logistic operations performed per ton of the i-th freight, operations; T is the duration of logistics operations (full cargo handling cycle) at the LO, days.

Compared to the known cargo transfer ratio, Q_{LP} does not just cover the operations per ton of freight during cargo transfer but during the entire time the freight stays at the logistics chain node (at the LO), including the added value operations.

It can be assumed that the new parameter will indicate to the railroad carrier the efficiency of the terminal capacities utilization, and for the customer it will provide a quick way of determining whether a particular LO is appropriate for their business.

Based on the proposed logistics grading system of railroad stations assessed under real-life conditions, we prepared a classification of railroad LOs by service parameters. Let us consider the service parameters of LOs.

Here are the service packages provided by LOs:

– the basic (standard) package includes the standard transport and storage services, loading-unloading, acceptance-release, documentation, storage, sorting out, rolling stock dispatching operations;
– the basic plus (standard+) package adds such transport features as "door-to-door", "last mile" (using motor transport), cargo transfer;

– the extended package adds, on top of the standard+ services, simple “transport-related” features, such as marking, sorting, packaging, sub-grouping, documentation, cargo and rolling stock tracking, shipment management;
– extended+ adds compound “transport-related” services: customs support, freight expedition, rolling stock operations, developing alternative cargo delivery chains tailored to customer’s needs;
– the comprehensive package adds services that significantly increase the added value of the cargo (goods): logistics consulting, multimodal transportation and “seamless” services, distribution chain development and management, stevedore, transshipment and surveying services in maritime transportation, distribution and sales, pre-sale preparation, assembly, enhancement, i.e., active transformation of consumer properties of the cargo (goods);
– the ultimate package involves, along with the implementation of the comprehensive service package, all-in-one service provision by one entity in one place spatially (directly at LO) with the logistics independence (self-sufficiency) ratio of the LO [21] close to 1 (according to the previously published author’s works [19–22]).

Services packages have been formed by analyzing real-world design and development of Russian logistics objects and using the works [7, 13, 14].

4 Results and Discussion

Consider how the logistics grade is different from the known station grading:

1. it reflects parameters relevant to the customer;
2. it is open and publicly available;
3. it allows to comprehensively evaluate the performance of railroad LOs;
4. it provides the foundation for the transition of RZD OJSC to 4PL;
5. it sets up LOs traffic and performance monitoring capabilities;
6. it reflects most of the logistics activity parameters of LOs;
7. it improves management of terminal and warehouse infrastructure;
8. it reflects technical capabilities of the logistics service, including available infrastructure objects.

Unlike the conventional station grading system, the logistics grade represents specifics of the available terminal and warehouse infrastructure, the range of transport, storage and comprehensive logistics services, i.e., parameters relevant to the customer.

Practical calculations and studies of a real-world transportation node (Novosibirsk, Russia) show that the values of $K_{\log}$ average upwards of 1.7 for Group A, 1.2–1.6 inclusive for Group B, and less than 1.2 for Group C. Calculations included 25 LOs that the node consists of.

According to the description of the service packages provided above, Table 4 presents the classification of railroad LOs with specific values of the $K_{\log}$ transport and logistics service comprehensiveness ratio.

Table 4. Classification of railroad LOs by service parameters

LO	Service Package	Transport and Logistics Service Comprehensiveness Ratio, K_{log}
Basic package: standard transportation and storage services		Minimum 0.1;...; 1.3
SA*	Up to 10% service comprehensiveness	
C	Up to 20%	
TWC	Up to 30%	Intermediate 1.4;...; 1.8
Extended package: basic + transport-related services		
TT	Up to 50% service comprehensiveness	
DC	Up to 60%	
LC	Up to 70 %	Maximum >1.8
Ultimate package: Extended + services that significantly add to the cargo value		
TN	Up to 80% service comprehensiveness	
TLN	80–90%	
MTLC	More than 90%	

* SA stands for storage area, W—warehouse. TWC—terminal and warehouse complex, TT—transport terminal, DC—distribution center, LC—logistics center, TN—transport node, TLN—transport and logistics node, MTLC—multimodal transport and logistics center.

The methodology is described in more detail in [16, 17]; the method itself is automated, which allows its immediate application and easy integration in the comprehensive "Digital Railroad" project. Obviously, a unified database of logistics grades of stations and logistics objects will be required at a later stage, as well as its integration into the railroad orders and transportation management system.

The main results of the research include a unique grading system for railroad freight stations open for cargo operations that works by assigning a logistics grade based on the information about additional logistics services that is relevant for the clients.

In addition, the study examines several original indices which enable comprehensive evaluation of the work of freight stations' logistics objects, in particular, "logistics activity" and "transport and logistics service comprehensiveness ratio". The classification of railroad logistics objects has been proposed with specified transport and logistics service comprehensiveness ratio.

The direct objective of the method's application in the transport sector is the implementation of the customer-focused logistics principles to enable high-profit freight traffic and to divert cargo from motor transport to railroad terminal network objects.

The proposed logistics grading meets the criteria stated in the introduction as a way of identifying logistics functionality of a particular LO, namely: on the one hand, the grade reflects parameters relevant to the customer; on the other hand, it suits the specifics of railroad operations and assists in monitoring and evaluation of terminal and warehouse infrastructure elements. Therefore, the purpose of this study can be considered fully achieved.

It should be noted that the methods suggested in this study (which are fully automated by the author) can be applied in practice with two conditions: (1) existence of a legislated method of LO classification and identification; (2) existence of an all-in-one "customer-railroad" information system.

Based on the conducted study, it can be concluded that the obtained results match the author's previous works. The results also:

- develop the concepts of spatially functional development of the logistics infrastructure, stated in the works of Rodrigue [13] and Notteboom [6];
- improve the functional specifics and classification of logistics business operations presented in [7, 14, 15];
- satisfy methodology, concepts and principles of modern logistics, transport geography, terminalistics, as well as management of supply chains, operational management of railroads and terminal technologies of freight transportation;
- are fully consistent with the main priorities of the currently implemented Transportation Strategy being implemented, railroad digitalization, as well as principles of customer focus and business culture of railroad carriers.

From a practical point of view, the results of the study fill in the gaps of marketing campaigns aimed at drawing high-profit cargo traffic to railroad transportation and provide practical tools for improving customer focus of logistics operations and for comprehensive evaluation of individual performance of railroad terminal and warehouse infrastructure elements.

Further studies can be focused on developing methodical tools into a project of a national standard in the area of terminal and logistics railroad operations, as well as solving the problems of integration of the proposed railroad logistic grading system into a public online database and services currently implemented by the railroad sector.

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Modeling of a System for Organization of Traffic via a Terminal Network

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Abstract. The research subject is a terminal network. The research purpose is development of a set-theoretical model of the terminal network. The research methods are based on the theory of sets, the theory of transport systems, the general system theory, and the authors' methodology of terminalistics. The research provides a parametric description of the terminal network and its key elements: logistical facilities; identifies factors that determine the composition and configuration of the terminal network; develops a model of the terminal network as a logistical chain and, on its basis, suggests an integrated set-theoretical model of a region's terminal network. A model for forming the composition of the terminal network is provided. The terminal network is considered as a logistical chain, since its configuration, purpose in a delivery system, and logistical functions performed in transportation sections reproduce the morphology of a classical logistical chain connecting a cargo sending customer with a cargo receiving customer while providing a transparent, integrated, and seamless service for cargo traffic. Using a complex of enlarged block modules of the terminal network, element-by-element study and optimization become possible. The task of finding the best option of the terminal network becomes a three-level and two-step task. The research results can be used as an economic and mathematical toolbox in design, development planning, and evaluation of facilities of the terminal and warehouse infrastructure of RZD OJSC.

Keywords: Set-theoretical model · Terminal network · Logistics facility

1 Introduction

The topicality of researching the formation of the railway transport terminal network, in particular, of modeling its composition for efficient design and subsequent operation, is corroborated by the Russian Federation Railway Transport Development Strategy for the Period up to 2030. Efficient formation of a modern terminal and warehouse infrastructure in the key regions of the country, to meet the requirements of the transportation and logistics market, is identified as one of the development priorities. Thus, one of the scenarios of development of the transportation and logistics business

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unit of RZD OJSC provides for stable growth of the share of transportation and logistics services implemented by enterprises of the Holding's logistics business unit.

Today's researchers point out that, at present, systemically important institutions, such as RZD OJSC, have important influence on development of the entire country [1].

Russia is among the countries with a high level of logistics costs. For example, the share of logistics costs in the gross domestic product of the RF reaches 19%, with 18% in China, 11–13% in Brasilia and India, 9.7% in Italy, 8.5% and 8.8% in Japan and Germany, respectively. In the USA, as of the end of 2017, the level of logistics costs was 7.7% [2]. The importance of reducing the logistical costs is noted by researchers all over the world. Reduction in the logistics costs creates conditions for development of inter-regional interaction [3] and improves international competitiveness of the country [4].

Due to the customers' new requirements to the integrity of the transportation and logistics service, the issues of integrated and comprehensive design and study of logistical facilities (LF) gain in importance. The problems of interaction between individual subjects of logistics services were considered in the work of Fedorenko [5]. The necessity of concurrent consideration of the cargo transportation and warehousing is discussed in the works by Bowersox [6], Prokofieva [7], Malikov [8], Baumann [9], Kondratowicz [10], and others. Researchers studying the problems of railway transport operation pay serious attention to evaluation of its role in logistics systems. The problems of efficient development of railway network are explored by both foreign authors, e.g., Marchetti [11], and Russian scientists, e.g., Karpova [12].

In general, most studies are illustrative of immaturity of the Russian market of transportation and logistics services as a whole and in railway transport in particular. The following facts are the main signs of that:

1. a major part of services in cargo transportation and storage, let alone stock and supply chain management, is provided by own departments of manufacturing enterprises, distributors or retailers (more than 60% of the total volume of logistics operations);
2. the market structure is dominated by the carriers' services, while the share of third party logistics providers' services does not exceed 6% (a similar indicator for EU countries and China is 20%);
3. a low level of development of the segment of integrated logistical services is directly related to the structure of demand from mineral companies that are usually willing to outsource only the basic services of cargo transportation and processing while retaining the management of logistical chains.

However, as the experience of RZD Logistics JSC shows, provision of integrated transportation and logistics services to customers can substantially reduce their logistics costs due to organization of an optimal delivery system. Apart from high quality of the provided services, an essential service prerequisite today is a customer-friendly system to offer and sell the provided services. The current situation calls for drastic measures aimed first of all at bringing the terminal and warehouse infrastructure of RZD OJSC into conformity with current requirements of the world market of transportation and logistics services. Implementation of infrastructure projects of this kind amid an unstable world economic situation seems rather a challenging task, the more so as the logistics infrastructure is a non-core business for RZD OJSC.

Despite its wide presence in the regions of the RF, the terminal and warehouse complex of RZD OJSC has a high degree of depreciation of fixed assets, outdated terminal, warehousing, and transportation technologies, a low level of processes automation, “unfriendly interface” for customer relations, and a limited portfolio of the provided services [13]. All this is a significant factor in deterioration of competitiveness of railway transportation in comparison with automobile transportation, and the distance of cargo transportation by rail increases.

Therefore, the company faces the task of creating a complex of multimodal terminal and logistics centers throughout the entire network of RZD in the major transport nodes to ensure interrelation of the transportation subsystem and the terminal and warehouse subsystem of the logistics chain. Formation of the terminal network will not only allow providing a full range of high-quality logistics services to customers but will also attract a wide variety of high-paying cargoes to the railway transport. Therefore, given high relevance of the issues of designing and developing the transportation and logistics infrastructure of the railway transport, the terminal network is the research subject.

The terminal network (TN) may be viewed as a system for organization of traffic by means of the logistics facilities (LF) deployed at the transportation network nodes where the cargoes are transferred from one mode of transport to another. The transportation links of traffic directions that connect them include various communication routes and transportation lines along which cargo flows move from their places of origin to the places of their destination or distribution.

The purpose of the research is building a set-theoretical model of the terminal network for the comprehensive study of its morphology and its efficient design in terms of composition and configuration. To achieve this purpose, several tasks had to be solved:

1. provide parametric description of the terminal network and its key elements, the logistics facilities;
2. identify factors that determine the composition and configuration of the terminal network;
3. develop a model of the terminal network as a logistical chain and, on its basis,
4. propose an integrated set-theoretical model of the region’s terminal network.

2 Research Methods

The research methods are based on the theory of sets, the theory of transport systems, the general system theory, and the authors’ methodology of terminalistics. The results of analysis of domestic and foreign classifications have formed a methodological basis for modeling the traffic organization system. In the course of the research preparation, methods of logistics, synergetics, transport geography, cluster and system analysis, classification, economic and mathematical modeling were used.

The authors relied on a previously developed system of classification and hierarchy of logistical facilities as nodal elements of terminal and warehouse infrastructure. The system was composed on the basis of a functional and logistical approach [14].

When working out the theoretical and practical foundations for the terminal network development, the authors rested upon the results of studies in the area of transportation and warehouse logistics [15], transport geography [16], regionalistics. The scientific application toolbox of the research was developed in the framework of terminalistics (“logistics” + “terminal” = logistics of terminal and terminal networks) [17] that have been descried in earlier works of the authors [18].

The research conforms to the priorities of the Transport Strategy of the Russian Federation, as well as the Roadmap for Development of Container Business in RZD OJSC, and the Roadmap for Creation of a Network of Terminal And Logistical Centers in the Russian Federation.

3 Research Results

3.1 Parametric Description of the Terminal Network and Its Nodes

Today, the country’s logistics market has no commonly accepted terminology in the area of transportation and warehouse logistics. This is largely due to relative immaturity of the domestic logistics. A universal conceptual framework reflecting the properties and logistics function of the facilities of terminal and warehouse transport infrastructure remains underdeveloped. Meanwhile, such facilities are actively involved in the cargo delivery system, converting traffic flows and implementing a wide range of services for the cargo storage, distribution, warehousing, and transportation. This indicates high relevance of theoretical and methodological insights in this area, since optimized development of new projects and operating technology of the existing facilities is not possible without necessary and sufficient theoretical research. The distinctive features of the suggested conceptual framework developed in the theory of terminalistics are:

1. designation of an entire group of facilities implementing a logistics service;
2. universality in definition of the main properties being characteristic for the logistics facilities as transportation and warehouse systems;
3. integrated approach unifying the terminology of railway and logistics theory and practice;
4. reflection of the logistical role of LF in the cargo delivery system;
5. focus on ability to provide the traffic process, along its entire length, with multi-functional logistics services.

Generally, a logistics facility is a nodal element of the terminal network as a system of transportation and warehouse infrastructure, implementing a complex of logistics functions in the system of cargo delivery from the original supplier to the end user. The role of LF can be played by infrastructure facilities of varying complexity (cargo areas, warehouses, terminals, distribution and logistics centers, etc.), which physically implement provision of integrated multifunctional logistics services to various customers and are concentrated according to a combination of characteristics in a spatially-defined region.

A railway logistics facility is an element of terminal and warehouse infrastructure of railway transport located in a transportation node and functioning as a nodal element of terminal and logistics system to provide engineering support and practical performance of services for cargo loading, unloading, storage, and distribution, including delivery of cargoes to the end user, while interacting with participants of the delivery system and other modes of transport. The novelty of this definition is in generalization, into a single universal term, of an entire group of enterprises, engineering structures, and facilities, which provide/are used to provide logistics functions in the railway transport. The function of “transportation and warehouse service” is mentioned as it is the principal and typical function for all logistics facilities as a buffer transportation and warehouse system implementing the interaction between transportation, warehouse, and customer.

In particular, the logistics facility as a nodal element of the terminal network can be parametrically described as follows:

$$\mathrm{LF} = \begin{cases} \mathrm{F}_{\mathrm{LF}}^{\mathrm{F}} = \sum\limits_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{C}\left\{\mathrm{T}_{\mathrm{efc}}; \mathrm{R}_{\mathrm{op}}; \mathrm{S}_{\mathrm{crg}}\right\} \to \min \\ \mathrm{F}_{\mathrm{LF}}^{\mathrm{T}} = \sum\limits_{i=1}^{n} C\{P; P'; Q_{usc}; A\} \to \max \\ \mathrm{F}_{\mathrm{LF}}^{\mathrm{Q}} = \sum\limits_{i=1}^{n} C\left\{K_{log}; Q_{log}; LOG\right\} \to \max \end{cases}$$

1st kind, financial, reflects cost efficiency of warehouse cargo handling, where R_{op} are operational costs for current maintenance of TN or its element, in thousand rubles/year; S_{crg} is the cost of warehouse handling of 1 ton of cargo, in rubles/ton; T_{efc} is payback period for investments in facility construction according to estimate and financial calculation, in years.

2nd kind, technical, reflects optimality of engineering solutions for LF, where P is productivity of warehouse load handling equipment, in tons/day; Q_{usc} is a usable storage capacity of the warehouse, in tons (usable warehouse capacity in quantity: tons, cargo units); A is the logistical operations automation level (automation coefficient is the ratio of completely automated warehouse processes to the total number of operations).

3rd kind, qualitative (logistics), suggested by authors, reflects the quality of the logistics services provided by LF, where K_{log} is the integration degree of the logistics services provided by the *i-th* warehouse (logistics integration coefficient is the ratio of the amount of “package” integrated logistics services to the total amount of the warehouse services); Q_{log} is the coefficient of logistical coverage of the added value of standard warehouse operations; LOG is the warehouse logistical usefulness. Such parameters, being indicators of the LF condition, have not been suggested before.

The terminal network is a complex of the logistics facilities (LF) of the ith type and transportation sections U of dimension L, serviced unimodally (j) or multimodally (j′), for efficient organization of handling in the process of cargo traffic and delivery from customer Ki (1) (sending customer) to customer Ki (2) (receiving customer).

TN can be parametrically described as follows:

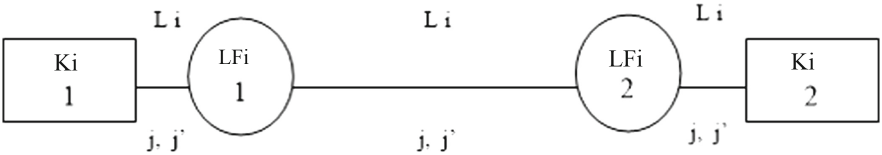
$$\mathrm{TN} = \begin{cases} \mathrm{F}_{\mathrm{TN}}^{\mathrm{F}} = \left[\sum\limits_{i,n} C_{log} \in \left\{\mathrm{R}_{\mathrm{op}}; I; T\right\}; \sum\limits_{k,m} C_{tran} \in \left\{\mathrm{S}_{\mathrm{tran}}; \mathrm{S}_{\mathrm{op}}\right\}\right] \rightarrow \min \\ \mathrm{F}_{\mathrm{TC}}^{\mathrm{T}} = \sum\limits_{i=1}^{n} C\{T_{deliv}; T_{TN}; C; L_{TN\ av.}; \mathrm{C}_{\mathrm{TN}}; \mathrm{I}_{TN}\} \rightarrow \min \\ \mathrm{F}_{\mathrm{TN}}^{\mathrm{Q}} = \sum\limits_{i=1}^{n} C\left\{\alpha_{log}; R_{op}; INF; K_{dens\ TN}; K_K; W_{TN}; V_{TN}; W; R_{integr}; R; \mathrm{E}_{\mathrm{crg}};\ ME_{TN}\right\} \rightarrow \max \end{cases}$$

1st kind, financial, consists of logistics C_{log} and transportation C_{tran} units; where R_{op} are operational costs for maintenance of LF, in c.u./year; I is the amount of investments in construction and commissioning of LF, in c.u.; T is payback period for investments in facility construction according to estimate and financial computation, in years; $\mathrm{S}_{\mathrm{tran}}$ are the customer's costs for cargo traffic by the k-th transport mode over the m-th section of TN, in c.u.; S_{op} are the operational costs for goods traffic by the carrier of the k-th transport mode, in c.u.

2nd kind, technical and operational, reflects optimality of technologies of cargo delivery and handling in TN, where $T_{del\,TOTAL}$ is time of cargo delivery through TN, in days; T_{TN} is the time of cargo residence in TN, in days; C is an average prime cost of services in TN, in c.u.; $L_{TN\ av}$ is average distance of delivery through TN, in km; C_{TN} are costs of railway transport related to formation of TN, in c.u.; I_{TN} are investments in formation of TN of a certain composition, in c.u.

3rd kind, qualitative (logistics), suggested by authors, reflects the quality of the provided logistics services, where α_{log} is coverage of regional traffic by the logistics infrastructure, in %; R_{op} is operational productivity of TN section, in car-km or ton-km; INF is provision with the logistics infrastructure; $K_{dens\ TN}$ is TN density coefficient; $K_{integr\ log}$ is coefficient of the logistics location; W_{TN} is TN productivity, in thousand tons/year; V_{TN} is rate of the logistics service to customers in TN, in c.u./day; is cargo handling capacity of TN, in tons/day; R_{integr} is coefficient of the service integration; R is capacity of the TN logistics services market, in customers/square meter; $\mathrm{E}_{\mathrm{crg\ TN}}$ is traffic density for TN, in thousand tons/year; ME_{TN} is multiplicative effect from the TN formation. Such parameters, being indicators of the LF condition, have not been suggested before.

Thus, for TN and LF, all the listed modules form blocks of parameters that are maximized or minimized in the design and operation of TN and LF. Using a complex of three enlarged block modules, most complete description of TN in terms of the grouped sets of parameters becomes possible as well as element-by-element study and optimization of TN, depending on which element of the network possesses certain parameters to be optimized. TN as a cargo conducting system providing the logistics service of handled cargoes, their terminal and warehouse processing, and increase in their added value, is considered as a logistics chain consisting of: nodal elements, i.e. initial and final customers (that send and receive cargoes) and LF (buffer goods handling elements); long haul elements, i.e. transportation links; service elements, i.e. transportation and logistics companies implementing transportation and warehousing of cargoes in the general system of the cargo delivery. It is suggested to consider TN as a logistics chain, since the TN configuration, its purpose in the delivery system, and logistics functions performed in its LF and transportation sections reproduce the morphology of a classical logistics chain connecting a cargo sending customer with a cargo receiving customer, while providing a transparent, integrated, and seamless service for cargo traffic. A general view of TN is shown in Fig. 1.



Classical general structure of TN

Fig. 1. 1. General structure of TN.

A generalized set-theoretical model of TN looks as follows: $TN = \{LF; E; C; W\}$ where LF is a set of the logistics facilities that form part of TN, in units; E is a set of the logistics and "near-transportation" process operations enhancing the cargo (goods) consumer qualities and added value, in units: $E = \{E_1, E_2, E_3\}_i$; where E_1 is a set of minimally required logistics intra-warehouse operations for cargo handling (receipt-dispatching, loading-unloading, sorting) of a standard assortment, in units; E_2 is a set of extended logistics services "outside the warehouse": cargo forwarding, insurance, customs clearance, the last mile and other services of extended assortment, in units; E_3 is a set of the logistics services aimed at enhancing consumer properties of cargoes (assembly, installation, pre-sale preparation, labeling, packing, and other services of maximum assortment), in units; C is the set of criteria characterizing the condition of TN:

$$C = \prod_{i=1}^{i} \left(C_{tech} + C_{log}\right) C_{persp}$$

where C_{tech} is the TN condition criterion reflecting infrastructure support and technical equipping of both TN as a whole and its individual elements (sections and nodes); C_{log} is the TN condition criterion reflecting assortment and quality of the transportation and logistics services performed by TN in the region, and customer satisfaction with such services; C_{persp} is a coefficient taking into account scenarios for the development of RZD OJSC's terminal and warehouse infrastructure and/or regional programs of economic and social development, the coefficient is taken equal to 1.0 when the region average area occupied by LF does not exceed 30% of the total shopping floor area of federal chains; equal to 1.5 when the region has more than 1 project for the development of RZD OJSC's terminal and warehouse infrastructure; equal to 1.3 in case of a stable growth of GRP over the last 5 years; equal to 1.8 if requirements in clauses 2 and 3 are satisfied; W is the TN configuration option, i.e. a complex of relations between the TN nodes and transportation sections: $W = \{W_i\}$ *where* $i = 1, 2..n$.

3.2 Factors that Determine Formation of the Terminal Network

The authors have identified factors that determine the structure of the terminal network. Two indicators (highlighted in Table 1) have been suggested by the authors [19].

Table 1. Factors that determine the formation of terminal network.

Factor	Description	Units
Infrastructure F_{inf}		
P_{ar}	Density of automobile roads in the region	km/sq.km
I_{rw}	Traffic density of railway lines	tons/km
L_{far}	Length (if any) of federal automobile roads in the region	km
N_{rzd}	Presence of the facilities of base network of terminal and warehouse infrastructure of RZD OJSC in the region (according to the Roadmap for Creation of a Network of Terminal And Logistical Centers in the RF),	units
K_{wrh}	Indicator of quality of the terminal and warehouse services $K_{wrh} = \frac{S_{qual}}{\sum S_{reg}}$ S_{qual} is total area of high-quality warehouse space of A or A+ class according to international classifications, in thousand sq.m; $\sum S_{reg}$ is total area of warehouse complexes in the region, in thousand sq.m	dimensionless
R_{infr}	Available handling reserves in the terminal and warehouse infrastructure of the region	tons/year
Transportation F_{tran}		
Q_{rt}	Volume of cargo transportation by rail	thousand tons/year
Q_{at}	Volume of cargo transportation by motor roads	thousand tons/year
Q_{other}	Volume of cargo transportation by other modes	thousand tons/year
R_{tr}	Availability of reserves in throughput of transportation communications	tr.units/year
N_{th}	Number of large transportation hubs in the region	units
K_{TLP}	Indicator of transportation and logistics provision in the region $K_{TLP} = \frac{K_{wrh}}{\sum\left(\frac{N_{RZD}}{N_{wrh}} + N_{wrh}\right)}$ where K_{wrh} is indicator of quality of the terminal and warehouse services N_{wrh} is total number of LF in the region, irrespective of their class, in units; N_{RZD} is total number of LF of RZD OJSC, in units	%
Market F_{mrkt}		
N_{pr}	Presence of national economic and transportation projects being implemented in the region	units
Q_{grp}	Gross regional product	rubles
$Q_{wholesale}$	Wholesale volumes	rubles
Q_{tr}	Volumes of transportation services	rubles
N_{pop}	Population	million people

3.3 Model of Terminal Network as a Logistics Chain

Composition of terminal network can be represented as a complex of a certain number of LF located in a certain number of the network U sections possessing certain parameters to provide transportation: $TN = \{LF_i; U_i\}$, where LF is a subset of n number of LF of the i-th type (according to the authors' classification) located in section u (j is for unimodal and j' is for multimodal) forming part of TN, units; U is a subset of n number of transportation sections of j and the j'-th type connecting customers and LF into TN, in units. The above is illustrated in Fig. 2.

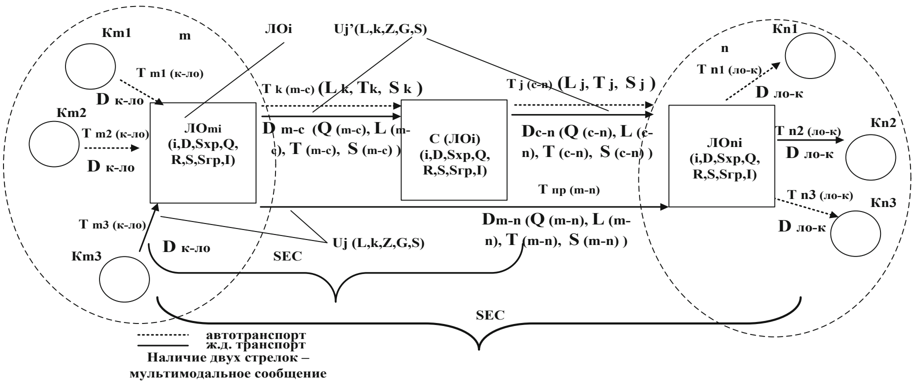


Fig. 2. TN as a logistics chain.

A certain volume of cargo, length of traffic section, time of delivery in traffic section, and cost of traffic by the k-th transport mode corresponds to each edge being the direction of the cargo flow moving from senders m (oval) to receivers n (oval): $\boldsymbol{D}_{mn} \in \{Q_{mn}; L_{mn}; T_{mn}; S_{mn\,k}\}$. Tariff distance, delivery time, and cargo traffic tariff correspond to each of the k-th transport mode (edge labels): $\boldsymbol{T}_k \in \{L_{mn\,k}; T_{mn\,k}; S_{mn\,k}\}$. The edges and their labels are U: transportation sections of the j-th type (j for unimodal and j' for multimodal): $\sum U_{in}^{j,j'} = \sum\{L; k; Z; G; S\}$, where L is length of the TN section, in km; k is type of transport servicing this transportation section (unit); Z is technical equipping of the TN section (LF coverage), G is traffic density of the TN section; are costs for running maintenance and repair of the TN section, in c.u./year.

A certain type (in the authors' classification, 1…9) corresponds to each of n nodes of the chain, i.e. LF (squares); location (coordinates), in km; storage area, in sq.m; cargo handling capacity (throughput), in thousand tons/year (cont./year, trays/year, etc.); R is radius of customer service by LF, in km; S is assortment of the transportation and logistics services performed by LF, in names; S_{crg} is cost of cargo handling, in c.u./unit; I are investments in construction of LF, in c.u. To decompose the TN structure for analysis and subsequent optimization of TN, we will introduce a notion of the **TN sector**, which is a complex of certain transportation sections and certain LF connected by a portion of the logistics chain of cargo delivery along the route from the initial (cargo sending) customer to the final (cargo receiving) customer.

$SEC_i = \left\{ \sum U_{i_n}^{j,j'}; \sum LF_{i_n}^{j,j'} \right\}$ with numbers of LF and sectors: $N_{LF\,ni} \geq 2; 1 \geq N_{sec\ ni} < N_{LF\ ni}$

TN configuration $CNF(TN_{alt})$ is morphological structure of the TN elements:

$$CNF(TN_{alt}) = VAR\{TN_i\}||CNF(TN_{alt})$$

where $CNF(TN_{alt})$ is an alternative of TN configuration; || is disjunction or logical "or"; $VAR\{TN_i\}$ is option of parametric structure of TN including type of LF and composition of services they provide to customer; (transportation, logistics, and additional services).

3.4 Mathematical Model of Terminal Network as a Logistics Chain

$$K(LF_m)_i \rightarrow T_{k(m-c)} \rightarrow C(LF_i) \rightarrow T_{j(c-n)} \rightarrow K(LF_n)_i$$

where $K(LF_m)_i$ is a consignor customer using the services of the logistics facility LF of the i-th type in the cargo departure point m; $T_{k(m-c)}$ is the k-th transport mode operating in the cargo delivery section from cargo departure point m to a central LF; $C(LF_i)$ is the TN central LF of the i-th type to which cargoes arrive by the k-th transport mode and are dispatched by the j-th transport mode; $T_{j(c-n)}$ is the j-th transport mode operating at the delivery section from the terminal network warehouse (LF) of the i-th type to destination point n; $K(LF_n)_i$ is a consignee customer using the services of the logistics facility LF of the i-th type in the cargo destination point n.

Set-Theoretical Model of Terminal Network

Let there be a set of LF of the i-th type in the zone of TM market coverage, with f $\in$ F. LF may operate as standalone facilities or as part of the logistics chain.

Part 1 is service (price and prime cost of cargo handling at LF). We will denote a set of the integrated logistics services implemented by each LF as $KF.KF \in F, K_F \in \left[F_{k\,1}, F_{k\,2}, F_{k\,3}, \ldots, F_{k\,f}\right]$. For each LF $F_{k\,f} \in F$, the price $\left(C_{k\,f}\right)$ and prime cost $\left(S_{k\,f}\right)$ of one unit of the j-th logistics operation (cargo unit handling at LF) are known. Then $LOG, LOG\left(\sum_i \sum_N \sum_j LF\right) = (C_{k\,f} - S_{k\,f})$, at each of N number of LF of the i-th type which implement assortment J of the logistics services, is gross revenue of LF owner upon performing the logistics services to customers. To perform the integrated service, LF defines a set of participants (contractors) for each logistics operation to ensure operation of a given logistics link. Each of such operations will have its corresponding transaction costs related to organization of its performance (cost of services of a third-party contractor company or prime cost of cargo handling by using own resources): price $\left(C_{k\,f}\right)$, prime cost $\left(S_{k\,f}\right)$, and corresponding transaction costs (I_{kf}). Apparently, the more participants (providers) of separate logistics services LF includes, in performing its "one stop" service, the higher transaction costs and the lower the reliability of the entire logistics chain, which in turn calls for insurance against risks for both the customers and the contractors. Therefore, the total cost of the cargo passage through TN will be equal to the cost of the integrated logistics service of traffic process with involvement of LF: for the customer: $LOG'\left(\sum_i \sum_N \sum_j LF\right) = (C_{k\,f\,av} - C'_{k\,f})$ is investment attractiveness of LF for the customer, where $C'_{k\,f}$ is the cost of the logistics service at LF used by the customer, in c.u.; $C_{k\,f\,av}$ is average cost of service at competing LF in the market of the region of presence, in c.u.; for TN (LF) owner: $LOG\left(\sum_i \sum_N \sum_j LF\right) = (C_{k\,f} - S_{k\,f})$ is gross revenue. In the service aspect of LF, for assortment of services provided by LF, $J_{LF\,n} \in [j_{i\,1}, j_{i\,2}, j_{i\,3}, \ldots, j_{i\,n}], j_i$, taking into account cost C_{j_i}, volume n_{j_i}, and transaction costs for their performance (if any) I_{j_i} we may write: LF serv $= \prod(j_i; \mathrm{n}_{j_i}; C_{j_i}; I_{j_i})$.

Part 2 is transportation (tariff cost of cargo traffic through TN with handling at LF, including “the last mile” automobile sections). Let there be a set of LF f of the i-th type in the zone of the TM market coverage, with f $\in$ F. Let us denote the set of LF belonging to the designed TN as $RF.RF \in F, R_F \in \left[F_{r\,1}, F_{r\,2}, F_{r\,3}, \ldots, F_{r\,f}\right]$. Cargo traffic through TN consists of the following elements:

1. pickup from/to the departure railway station or, to be more precise, to a railway LF. But we also should not forget that, directly at the site of the cargo production, there is another LF, which the customer used for accumulating the cargoes;
2. LF at the site of the cargo production/consumption;
3. handling at a railway LF;
4. long haul traffic by railway transport between LF (block train),
5. cargo handling at a railway LF at the destination point,
6. cargo pickup to/from the railway station of destination,
7. LF at the site of the cargo production/consumption.

Links 1, 2 and 6, 7 can be served by both road transport and by industrial railway transport. Therefore, tariff cost of the cargo traffic through TN for the i-th cargo delivered from point m to point n by the k-th transport mode, providing the j-th package of the transportation services, the total cost of traffic (provision of purely transportation, loading and unloading, and setup operations without using LF, i.e. except for part 1 of this model) over all the TN sections will be equal to: for the customer ordering the service, $LOG'_{tran\ mn}\left(\sum_i \sum_k \sum_j C_{mn}\right) = C_{tariff}$, where C_{tariff} is tariff for the cargo delivery from point m to point n, with points m and n possibly being either LF or the cargo delivery/destination points at the boundary points of the traffic distance, in c.u.; for the LF (TN) owner: $LOG_{tranmn}\left(\sum_i \sum_N \sum_j LF\right) = (C_{k\,f} - S_{k\,f})$.

Part 3 is configuring the best TN option, taking into account 1 and 2.

It is necessary to find such an alternative of the TN composition with respect to LF types, their throughput and location, that will deliver minimum to the target function:

$$\text{ALT (TN, LF)} = \text{VAR}\ \left(LF_{iQ(XY)1}, \text{LF}_{iQ(XY)2}, .., \text{LF}_{i\,Q(XY)\,\mathrm{n}} \in \text{TN}\right) \sum\nolimits_{n=1}^{n} (s_{inv}) \to \min(T)$$

“Such an alternative combination of a certain number n of LF of certain type i, throughput Q (in sq.meters or in tons of the handled cargo) and location (XY) within

TN, the total capital investments in construction and technical equipping of which will ensure minimum payback period T is recognized as the best TN option". The problem of finding the best option of the terminal network becomes a three-level and two-step task. Levels:

1. at the first level, the issue of selecting the type and other parameters of LF included into TN is solved;
2. at the second level, the issue of an option of the TN configuration in terms of the number, location, and throughput of LF it includes is solved;
3. at the third level, the issue of organizing the traffic through the designed TN in terms of the customer focus and logistics is solved.

Steps: Thus, the first step is the LF and TN design, while the second step is organizing the traffic through the designed TN. The main objective of optimizing of technical equipment and functioning of TN includes finding such parameters of TN as a whole and its individual elements (section and nodes) that will ensure minimum total reduced costs while satisfying restrictions for the operational and economic considerations.

Search for the best option of terminal network, in a general case, is reduced to determination of the number, throughput, and location of the TN nodal elements, i.e. LF of various types. This requires solving the task of efficient distribution of cargo operation both over individual TN sectors (their sizes usually qualify them as major transportation nodes) and over individual LF of the network. Thus, using the set-theoretical model of TN and the method to find the best option of the terminal network, integrated optimization of transportation and warehouse becomes possible, not only with respect to individual nodes or transportation sections, but also to configuration of individual TN sectors, making integrated decision while taking into account operation of transport, organization of warehousing, and management of delivery system.

4 Results and Discussion

The approach to interpretation of the parametric set for the task of modeling the terminal networks suggested by the authors has not been applied before. Highly appreciating the role of scientific research by Profs. Reser [20], Malikov, Dybskaya [1], and many other Russian scientists, as well as foreign colleagues Rodrigue, Higgins [21], Richards [15] and others, it should be pointed out that researchers in the area of logistics traditionally consider the role of LF in two aspects: in storage and handling of the goods and material flow or in providing transportation services.

Highly appreciating the achievements of modern scientists, note that, unfortunately, the researches are not of a fully integrated nature, and this is reflected in a rather one-sided consideration of the terminal systems: as objects of design (V. Dybskaya), objects of optimization and parametrization (T. Prokofieva), as an economic and geographic entity (J.-P. Rodrigue), as a logistics system (D. Bowersox), as a system of international business transit (S. Reser). Meanwhile, interrelation of the transportation terminal and warehouse infrastructure with the traffic process itself is not considered. Only economic, logistics, geographic, and design aspects of the essence of LF and TN have been covered so far, but technology of interaction between different modes of transport at LF within TN, design of complex delivery systems, i.e. integrated multi-aspect transportation and logistics approach to design and operation of TN as not just logistics but as a complex transportation and logistics system, have not received sufficient attention yet.

The proposed economic and mathematical model has the following features:

1. TN representation as a logistics chain,
2. integrated approach unifying the parameters being important for the TN and LF design and operation in technical, technological, economic, transport, and logistics aspects,
3. block module representation of the structure of parametric description of TN and LF as transportation and warehouse systems,
4. search for the best option of the TN building, with the use of the authors' target functions and parameters in notation of the theory of sets, elaborated with a three-level and two-step solution of the TN design task,
5. application of the authors' terminological, economic and mathematical toolbox, representation and composition of TN and LF.

The research results can be used as an economic and mathematical toolbox in design, development planning, and evaluation of facilities of the terminal and warehouse infrastructure of RZD OJSC.

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A Model of Cluster-Modular Development of Passenger Traffic in the Urals Federal District, Russia

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Abstract. Clusterization of economy makes it possible to form a comprehensive vision of the national policy on the development of the regional transportation industry, improve its productivity, performance, and competitiveness, provide more opportunities for innovative development, optimize the interaction between a variety of actors of the regional economic development, such as the government, large and small businesses, the academia, and the public. The article demonstrates that the highest regional competitiveness of territories is supported by strong positions of the interacting groups of companies that are created on the basis of cluster forms and models of joint activities. The paper describes economic rationale and advantage of a cluster-modular approach and a system of public-private partnership, proposes a cluster model of transportation business.

1 Introduction

High dynamics and stochasticity of the processes of reforming the social and economic relations in the Russian society and structural transformation of all activity areas require development of fundamentally new methods and techniques to set up and manage complex and unordered objects. The experience of highly competitive developed economies indicates the need to create new forms and models of transport and logistics clusters (TLC).

Development of the management problem in the cluster-modular approach and the related setup of production and training of personnel has a long-standing tradition both abroad and in Russia.

Clusters have been researched by the following Russian and international scholars: E. V. Budrina, P. V. Vorobyev, D. V. Grushevsky, G. B. Kleiner, D. G. Rodionov, V. P. Tretyak, N. A. Shibanov, A. Yu. Yudapov, A. Marshall, K. Arrow, J. Jacobs, M. Porter, R. Sternberg, and others. These authors have looked into the assets, classification, identification of clusters, and factors that influence the clusters successful development. They created a map of clusters and researched the methods to support the development of clusters at the international and regional levels.

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Recent years have witnessed an upsurge of the society interest to public-private partnership (PPP) in cluster management. The scientific studies often cover this topic only partially and do not take into account the fact that private initiatives can have a positive effect. The problems of standards, methods, and ways of setting up a cluster that affect its performance remain understudied.

For the Russian reality, this topic is highly relevant, particularly for passenger traffic in the Urals Federal District (UFD).

The studies have shown that, in the UFD's suburban service, railway transportation ranks first in the passenger turnover (64%) and is second to the road transport in the number of transported passengers (44%). The percentage of suburban traffic in the total passenger traffic of RZD OJSC is 27%, and the share in the total number of transported passengers reaches 90% [1].

Nevertheless, suburban rail transport in Russia suffers from the following systemic problems: partial reimbursement for special rate public transportation by the governments of the RF constituent entities; unprofitability and lack of investment attractiveness; cross-financing of suburban transportation at the expense of the financial outcome of RZD OJSC; underdeveloped legislative framework for the current level of development of the suburban rail transportation market; since the mid-2000s, the route network has reduced, which led to a drop in the number of transported passengers and passenger turnover in suburban traffic. Similar problems are also typical for the UFD, as shown in Fig. 1 [2].

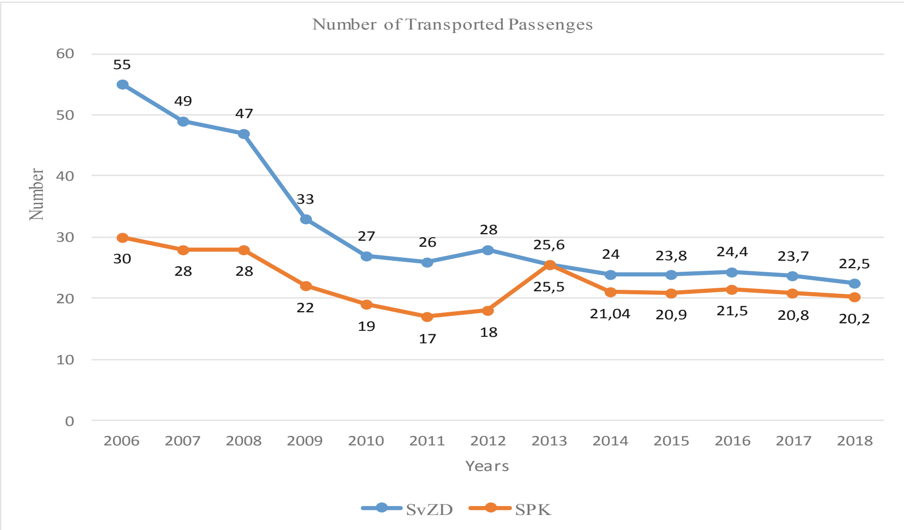

Fig. 1. Number of transported passengers

It shows a decrease in passenger traffic due to those problems.

The Sverdlovsk Region Government adopted Resolution No. 28-PP of January 25, 2018 On the Development of the Transportation Industry of the Sverdlovsk Region until 2024, which provides for an increase in subsidies from the federal and regional budgets to 16 billion rubles per year and a two-and-a-half times increase in passenger transportation vs. 2018. This resolution should ensure meeting the needs of railway passengers. The more so, a steady population influx is expected in the Sverdlovsk Region because it is hosting international events, such as a chess tournament, EXPO, etc.

The purpose of this research consists in:

- building a model for choosing an optimal structure and composition of a transport cluster in the UFD;
- a system of public-private partnership (PPP) under the cluster-modular approach in the area of rail transportation in the UFD;
- the presented mathematical model.

2 Research Method*s*

The modern scientific literature provides the concept of transport and logistics clusters as a network of suppliers, producers, consumers of industrial infrastructure elements, and research institutions, interrelated in the process of creating added value.

V. M. Samuylov and A. D. Pokrovksaya provided the definition of a cluster in the "Bulletin of USURT" journal in 2016: "A transport and logistics cluster (TLC) is a geographically localized group of enterprises being standalone in the industry and combining formal autonomy and internal competition with cooperation, presence of a single center, and a service system. The purpose of functioning of the group is to implement the core competencies in the territory of presence by the most efficient way and to achieve synergistic effects from the well-established operation. The modern scientific literature also understands TLC as a network of suppliers, producers, consumers of industrial infrastructure elements, and research institutions, interrelated in the process of creating added value" [3]. These authors sug-gest a more specific definition of the cluster, clarifying its attributes, such as: a set of enterprises, orientation on innovation, existence of mutual relations between enterprises, geographical localization. The purpose of functioning of a TLC with the suggested definition is to implement all efficient ways and competencies in the territory of presence and to achieve synergistic effects from the interconnected operation.

The cluster is not a legal entity. The transport and logistics cluster's structure is not unified under a single agreement. The structure implies that the relations between individual enterprises in the cluster should be long-term, rather stable, targeted at passengers in a specific territory, and catering to a specific market sector.

The structure, forms, and specific features of the cluster are shown in Table 1.

Clusters provide an opportunity for a constructive and effective dialog between the government and the regions. Clusters have no clear boundaries. Boundaries are in constant motion. The primary competition is performed through the formation of structures of efficient clusters.

A successfully developing regional system builds on cluster technologies and extensive cooperation within clusters, encourages participants to aggregate their resources for promotion of technologies, innovation, and advanced training of personnel, which makes this form beneficial both for the business and for the authorities of the region.

Table 1. Structure, forms, and specific features of cluster

Cluster	
Structure	manufacturers and suppliers
	engineering and consulting firms
	research-and-development organizations and universities
	banking institutions and banks
	administration of regions
	professional and non-governmental organizations
Forms	a standalone system with a well-defined strategy and allocated budget, which spans a number of industries and various aspects of cluster development
	a system focused on certain aspects of cluster development, such as networking among businesses or between business and research institutions
	a system which is an element of other economic development strategies
	a shared goal in a series of other uncoordinated events targeting a specific industry
	the form of the cluster may change and depends on the goals and objectives of the cluster
Specific features	availability of a large enterprise being the leader and determining the long-term economic, innovative, and other strategies of the cluster as a whole
	geographical localization of the bulk of the enterprises participating in the cluster
	stability and dominant role of economic relations between the enterprises
	long-term coordination of the interaction between the system participants within the principal management systems, production programs, innovation processes, and quality control

The main objective of the regional authorities when implementing the region cluster development strategies is to build enabling infrastructure and support cluster development processes [4].

3 Research Results

A structure of the transport and logistics cluster for the UFD is proposed. The UFD has a unique geographical location at the intersection of international transport routes from North to South and from East to West. The strategic objective is to build, in the region, one of the main centers of application and consolidation of transit passenger traffic. The leading role in its activities will be played by such companies as Demidov International Airport PJSC, Sverdlovsk Railway (a branch of RZD OJSC), the Federal Passenger Company, the Sverdlovsk Suburban Company, and others. Within cluster, the cluster modules need to be identified. The authors have defined the basic concept of a functional correspondence module. It can reflect multifunctional characteristics of any process based on a single methodology (Fig. 2).

Existing passenger companies today have limited resources. The development of passenger traffic requires intensive investments and support from national and regional

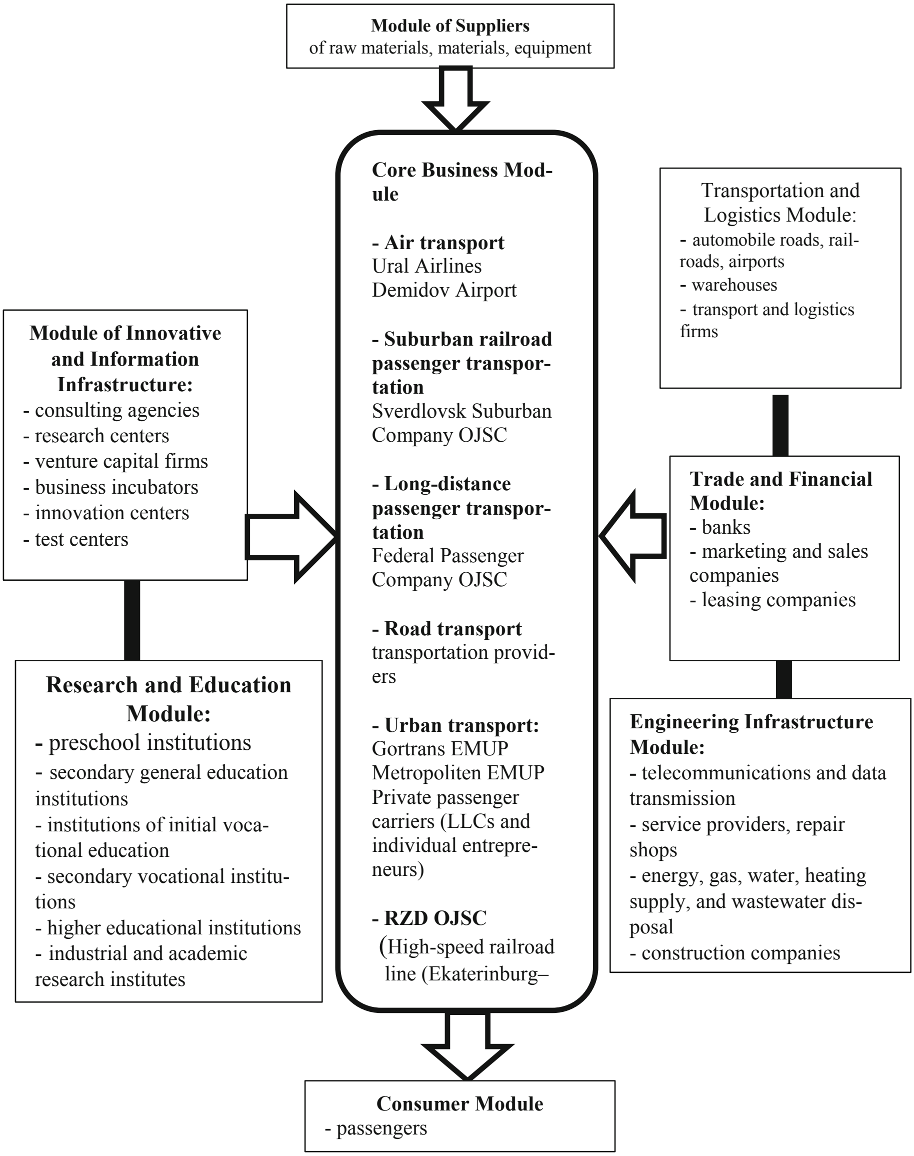

Fig. 2. Structure of transport and logistics cluster.

governments. Capital-intensive projects of national importance pay back over several decades and, naturally, a private investor would not agree to participate in them without guaranteed efficiency and reliability of investment of their own funds.

When reviewing this cluster, its participants constantly detect scantiness of resources, while solving problems. For this purpose, it is supposed to manage passenger companies in the form of a public-private partnership (PPP). We have proposed a model of concession mechanism (Fig. 3).

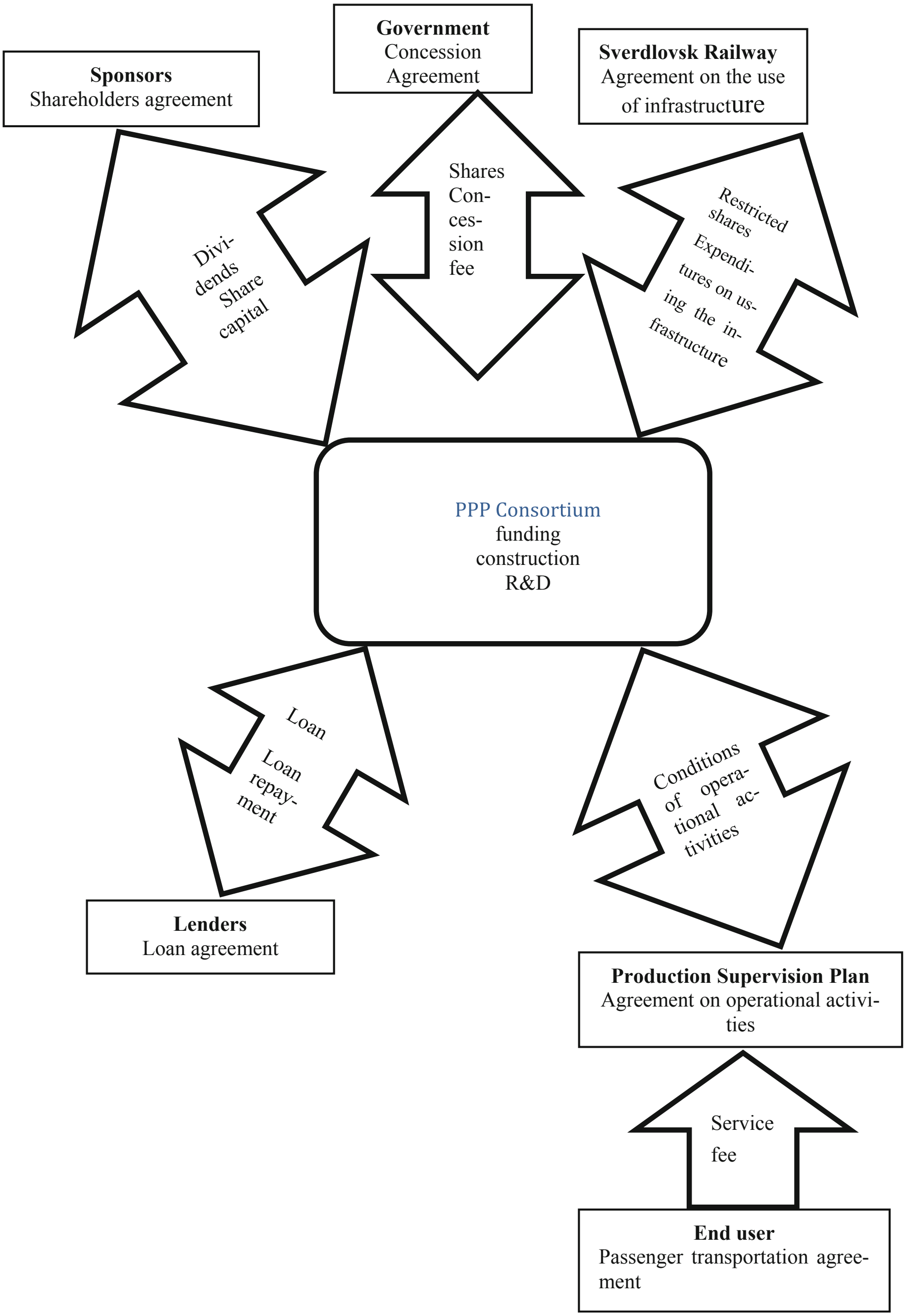

Fig. 3. Example of the PPP structure in passenger complex.

PPP ensures: transparency and responsibility of the parties, consensus among all the partners and their early-on involvement; a clear structure.

Notably, the limited resources are used effectively, communication, cooperation, coordination, collaboration, and trust-based relationships are promoted between stakeholder economic entities, the public and private sectors closely cooperate, and the government is more of an intermediary than an investor.

We believe that PPP offers advantages both for investors and the government. In particular, advantages for investors include an acceptable return on investment, clear risk sharing, higher turnover, growth and diversification fueling. Advantages for the government include access to co-financing, use of private management experience, an opportunity to focus on core competencies, and acceleration of processes.

Moreover, the new structure can use the synergistic effect, which results from activities of the united firms and is greater than the sum of results of their independent functioning.

In addition to the suggested PPP, when forming the cluster, the issues of the institutional environment and financial viability should be borne in mind. To that end, let us consider the following mathematical model.

The following "input-output" type model was used for modeling of alternatives for identifying the transport cluster in the UFD: $A * X + C = X$ where C is the vector of total input of the companies, X is the vector of total profits of the companies, A is the matrix of a_{ij} elements.

This model enables assessing the relations established between enterprises and identifying all participants for a potential cluster, and also answering the question: is it possible, given the structure of economic relations between the companies under consideration, to talk about such level of profit that would allow forming the cluster growth vector and benefiting from the efforts for its creation? To this end, it has been taken into account that the companies' revenues are generated not only from the redistribution (exchange) of products and services but also from the use of certain "primary" resources by each company.

Let us denote the number of the k^{th} primary factor spent by the j^{th} company to generate revenue in the amount of x_j as b_{kj}^0, and the amount of the k^{th} primary factor required to produce one "unit" of revenue of the j^{th} company as b_{kj}. The definition of these values suggests the following expression: $b_{kj}^0 = b_{kj} \times x_j$. Thus, for each j^{th} company, there are n + m (n being the number of companies, and m being the number of production factors which is the same for all companies) types of representation of its output volume:

$$x_j = \frac{a_{ij}^0}{a_{ij}},\ i = 1, \ldots, n; x_j = \frac{b_{kj}^o}{b_{kj}},\ k = 1, \ldots, m$$

where "a" in the numerator is the volume of "import" of goods and services from the I$^{\text{th}}$ company to the j$^{\text{th}}$ one. This volume is required to generate the profit in the amount of Xj (for example, this may be the entire volume of supplies of any machines or parts from the factory to SPK OJSC, so that SPK OJSC would generate the profit amounting to Xj in a given period).

For any i and k, the following ratios are modeled:
$\frac{a_{ij}^0}{a_{ij}} = \frac{b_{kj}^0}{b_{kj}}, i = 1,\ldots,n, k = 1,\ldots,m$ Therefore, the following equations are valid:

$$a_{ij}^0 = a_{ij}x_j, i,j = 1,\ldots,n,$$
$$b_{kj}^0 = b_{kj}x_j, k = 1,\ldots,m, j = 1,\ldots,n$$

Summing up both parts of these equations for j, we get expressions that describe the total costs of production factors for all companies:

$$\sum_{j=1}^{n} a_{ij}^0 = \sum_{j=1}^{n} a_{ij}x_j, i = 1,\ldots,n$$
$$\sum_{j=1}^{n} b_{kj}^0 = \sum_{j=1}^{n} b_{kj}x_j, i = 1,\ldots,m$$

Since these equations deal with products of each of the companies (the revenue of each one is used both for production and final consumption), it should be described as follows:

$x_i = \sum_{j=1}^{n} a_{ij}x_j + c_i, i = 1\ldots,n$ or, in matrix form, $A * X + C = X$

Let us introduce matrix B which is construed as a technological matrix for primary resources and suppose that vector $v = (v_1,\ldots,v_m)$ of the stock of all primary resources is known, i.e.

$$\sum_{j=1}^{n} b_{kj}^0 \leq v_k, k = 1,\ldots,m$$

Then $B \times X \leq v$. Let us denote price vectors of the secondary and primary resources as $p = (p_1,\ldots,p_n)$ and $w = (w_1,\ldots,w_m)$, respectively. It is important which output vector $x = (x_1,\ldots,x_n)$ will maximize the revenues from selling the final product $c = (c_1,\ldots,c_n)$, given the available stock $v = (v_1,\ldots,v_m)$ of primary resources. This leads us to the following problem of linear programming:

$(p, c) \rightarrow$ max under constraints: $x = A \times x + C$, $B \times X \leq v$, $X \geq 0$.

Since the core of the problem is the maximization of revenues through the output vector, it is reasonable to reformulate the problem by expressing demand vector c as the objective function: $(p, (E - A)X) \rightarrow$ max under constraints: $B \times X \leq v$, $X \geq 0$.

According to the known rules, let us formulate a dual problem for it with $w = (w_1,\ldots,w_m)$: $(w, v) \rightarrow$ min under constraints: $B^T W \geq p(E - A)$, $w \geq 0$

Let us introduce the change in the prices scale $\overset{\approx}{p} = (E - A)p$ and formulate the dual problems in a more compact form:

$\left(\overset{\approx}{p}, x\right) \rightarrow$ max under constraints $B \times X \leq v$, $X \geq 0$

$(w, v) \rightarrow$ min under constraints $B^T W \geq p(E - A)$, $W \geq 0$

The solution of the former provides the vector of demand for products $c = c(p, w)$, and the latter—the vector of supplsssy of primary factors $v = v(p, w)$.

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Having obtained vector $c = c(p, w)$, let us compare it with the current statistics, and if it is greater for companies under consideration than the level of demand that they (each of them taken separately) cover at the moment, then the UFD does have the potential for creating a local industrial passenger cluster to perform passenger transportation efficiently. The cluster will incorporate the enterprises and organizations that have an evidence of advisability of their participation in cluster. The strategy of its creation implies movement in one of the following directions: top-down (advisory bodies for coordination and monitoring are created first, the strategy is defined for the cluster as a whole, and it is supported with resources); bottom-up (developing individual projects and programs that would bring potential cluster participants together); and a mixed option, when both approaches are combined simultaneously.

Analysis of the institutional environment for creating such a cluster suggests that the environment is favorable for the cluster effective functioning (both for participants and the cluster as a whole, and in terms of socioeconomic criteria of the regional economy development) in the UFD.

4 Results and Discussion

The model for choosing the optimal structure and composition of participants of the regional cluster was based on the idea of taking into account the properties of the cluster as a special modeled structure and the specifics of the cluster-modular approach to the participants integration. The cluster-module participants should basically provide a well-established and stable system and an innovative approach to solving problems, i.e. proliferation of new technologies, knowledge, and products—the so-called technological network that rests on a joint research base. The cluster participants possess additional competitive advantages due to the opportunity to have internal specialization and standardization and to minimize the cost of innovations implementation. Their structure includes small businesses which allow forming innovative growth points for the regional economy; clusters provide firms with a high level of specialization in servicing a specific market niche, etc.

This research has revealed a downward trend in the passenger traffic. To address this problem, a PPP arrangement has been suggested as part of the cluster-modular approach in the area of railway transportation; a mathematical model was provided to demonstrate the efficiency of the cluster-modular model. Research papers on this issue.

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Dangerous Zone During Transportation of Dangerous Goods by Rail

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Abstract. The provision of chemical, biological, radiation, and fire safety for people, property, infrastructure facilities, and natural environment is the focus of attention of the UN specialized agencies, national governments, managers, and specialists of industrial complexes that manufacture and operate hazardous facilities. According to the analysis, during transportation of dangerous goods by all modes of transport does not ensure an adequate level of risk, as a result of which abnormal situations, various breakdowns, incidents, and emergencies continue to occur. The manifestation of risk causes considerable damage to the transport workers, transportation infrastructure, transported goods and freight units, natural environment, residents of neighboring communities, and people who happened to be in a dangerous zone. The topicality of research is dictated by the necessity of further improving the methods for protection and damage prevention, reduction in social and economic costs and environmental damage. The purpose of research is to develop elements of an integrated security system for zone of dangerous goods by federal railway transport with the possibility to employ them on international scale and in other modes of transport. Improving the concept of dangerous zone during transportation of dangerous goods stands in as the first-priority work stage of the development process. Solving the main tasks of the research was based on such proven and fruitful theoretical and experimental methods as computer modeling, comparative typology and circular expert estimations, statistical analysis, probability theory, theory of similarity, and others. The most meaningful results of the development are both of theoretical and practical importance. The theoretical result consists in development of a new approach to the concept of dangerous zone during transportation of dangerous goods by rail. The practical result involves development of proposals for improvement of the Railway Transport System of Emergency Prevention and Response; introduction of amendments into the Safety Rules for Response to Emergencies related to Dangerous Goods during Their Transportation by Rail; emergency cards for dangerous goods and a number of other technical guidance documents. Processing of the experimental data has established that the expected effectiveness of the development is 7.5–10%.

Keywords: Dangerous goods · Danger zone · Emergency situations · Railway transport · Regulatory isolation radius · Transportation safety

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1 Introduction

The transportation of dangerous goods has been and remains the most important component that determines the operating conditions of the manufacturing, extractive, defensive and other, virtually all, sectors of any economically developed country of the world. Depending on the infrastructure transportation development, the share of each mode of transport in a country is different. However, the railway transport is of particular importance for the Russian Federation, especially with respect to long-distance, international, and multimodal (mixed) transportation. Meanwhile, analysis of statistical data demonstrates that transportation of dangerous goods by all modes of transport does not ensure an adequate level of risk. The manifestation of risk causes considerable damage to the transport workers and passengers, transportation infrastructure, transported goods and freight units, natural environment, residents of neighboring communities, and people who happened to be in a dangerous zone.

The global system that provides chemical, biological, radiation, and fire safety for people, property, infrastructure facilities, and natural environment is a “pyramidal” hierarchical structure. Its basic levels are: (1) UN specialized agencies (UN ECOSOC), (2) international transport organizations, (3) national governments, (4) specialized associations, ministries and agencies, and (5) economic entities in transportation area. The topicality of research is dictated by the necessity of further improving the methods for protection and damage prevention, reduction in social and economic costs and environmental damage, which is only possible with regard to the interaction between the above elements.

This research of the new approach to the concept of dangerous zone during transportation of dangerous goods by rail is an integral part of a draft Research and Development (R&D) Program for 2018–2022 approved by the management of the Siberian Transport University (STU) and by the founder (the Federal Railway Transport Agency). The purpose of the R&D Program with the working title Revision of the Regulations concerning Transportation of Dangerous Goods by Rail and Development of a Draft Decree of the Government of the Russian Federation concerning Enhancement of Safety of Transportation Activities involving Dangerous Goods is to achieve the targets stipulated by the Strategy of RZD Open Joint-Stock Company (RZD OJSC) [1].

The purpose of the research is to develop elements of an integrated security system for the transportation of dangerous goods by federal railway transport with the possibility to employ them on international scale and in other modes of transport. Improving the concept of dangerous zone during transportation of dangerous goods stands in as the first-priority work stage of the development process.

The timeliness, importance, and topicality of this development can be (perhaps, indirectly) confirmed by the fact that President of the Russian Federation signed Decree No. 97 of March 11, 2019 On the Fundamentals of the State Policy of the Russian Federation in the Area of Chemical and Biological Safety for the Period till 2025 and Beyond [2] during preparation of this publication. The document defines the objective, principles, key priorities, and the main tasks of the state policy in the area of chemical and biological safety for the period till 2025 and beyond, and this imparts the traits of a strategic direction to our development.

2 Research Methods

Solving the main tasks of the research was based on such proven and fruitful theoretical and experimental methods as computer modeling, comparative typology and circular expert estimations, statistical analysis, probability theory, theory of similarity, and others. The most meaningful results of the development are both of theoretical and practical importance because, as will be confirmed by the relevant data, they allow increasing the accuracy of response operations and decreasing the accident damage and the cost of response.

The following elements, among other things, served as the initial methodological assumptions:

- investments in prevention measures ensuring safety of complex technogenic systems make economic sense, as the estimate of prevented damage is, on the average, generally 5–10 times larger than the losses [3, 4];
- investments in the "new technological paradigm measures" are most efficient in social and economic aspects since they create synergy in the interaction between all components of the following complex: man → rolling stock → infrastructure → natural environment.

3 Topicality, Practical and Scientific Importance of Research

The topicality of research is dictated by the necessity of further improving the methods for protection and damage prevention, reduction in social and economic costs and environmental damage during transportation operations involving dangerous goods.

The prerequisites to the scientific and practical importance of research are, among others, the following:

1 The basic results of development of emergency cards for dangerous goods were obtained more than 20 years ago [5]; since then, considerable changes were made in the organizational and technical support of prevention and response to emergencies related to dangerous goods.
2 Substantial results were obtained in the technological support of emergency recovery work, especially in the information and telecommunication area, and a program of innovative development of RZD OJSC were launched **[**1**].**
3 The list of UN dangerous goods (UNDG) [6] that can circulate within the railway operating domain of member states of the Organization of Railway Cooperation and of the Council for Rail Transport of the Commonwealth of Independent States (CIS) member states, the Latvian Republic, the Lithuanian Republic, and the Estonian Republic has been extended significantly.
4 A certain array of information regarding hazardous, physical and chemical, and other properties of substances, materials, and products have been gained over the past period of time, so it is expedient to correct not only the isolation radii but, possibly, other sections of the emergency cards, respectively.

4 Research Results. Theoretical Prerequisites

Research on the key problems of transport safety, for example, those described in [4, 7, 8] are based on the first noxology axiom that defines the potential hazard of technosphere, an infinity of sources of danger (SD) and the principal inaccessibility both of 100% safety of a facility to be protected (FP) and of 100% reliability of a safety system (SS) or protection system (PS) as a basic methodological principle. Theoretical and methodological background of design of SSs and PSs in technogenic systems [7, 8] is a purposeful reduction of a negative hazardous impact (Wfact) at a FP. This impact is identified and localized in space (X, Y, Z) at certain times, Δt, to meet the permissible conditions of hazard or safety as follows:

$$W_{fact}\{X(\Delta t)\cdot Y(\Delta t)\cdot Z(\Delta t)\} < W_{PDU} \quad (1)$$

where W_{PDU} is a certain level of impact accepted as maximum allowable or specified.

Any technical system employs a combination of danger parrying methods including active methods (ASS) directed at the sources of danger (SD ← ASS) and passive ones (PSS) directed at the facility to be protected (PSS → FP). It is a common practice to use the concept of risk R [4, 7, 8] as a quantitative measure of danger in technogenic systems. Among the passive risk reduction methods, the method of removal (isolation, containment) is most universal. In practice, it is not always possible to draw a clear line between them, since some protective means can have the features of ASS and PSS to different extents.

With the advancement of the methods for prediction and prevention of risks [4, 7, 9], a growing number of researchers place a particular emphasis on redundancy of the passive protection standards. Thus, for example, the authors of publication [9] propose to make amendments in SP 36.13330.2012 Trunk Pipelines. Revised edition. SNiP 2.05.06-85, which provide that the tabulated values of the minimal distances from the axis of liquefied petroleum gas trunk pipelines to communities should be reduced by 40–60%. A conceptual study [4] postulates that all safety aspects of railway transport provide for an excessive safety margin, so its reasonable reduction is one of the tasks set before the transportation science.

This article, which, as stated in the introduction, is performed according to the integrated program aimed at improvement of safety during transportation of dangerous goods by rail attempts to conduct a critical analysis of the existing isolation standards for the sources of danger in the events of emergencies. Such approach, which we consider to be new, requires a correct definition of initial concepts.

A dangerous zone is an accident area within which there is a threat of damage caused by explosion, fire, toxic exposure, radiation, burns, freezing injuries of people and animals [10]. Its standard size, the so-called specified isolation radius (SIR), is established by emergency cards for dangerous goods [5, 10].

Our scientific hypothesis consists in the assumption that the SIRs in a considerable number of emergency cards were established in accordance with an out-of-date scientific and methodological base that needs a certain revision. Based on this, a new approach to the concept of dangerous zone during the transportation of dangerous goods with subsequent development of practical recommendations can be proposed.

4.1 Central Ideas of the Initial Concept

1 The existing SIRs were established based on the analysis of a certain number of emergencies (critical situations, incidents) that actually happened to dangerous goods in the past, with regard to the experience of containment and remediation of consequences, and the estimation of damage. With this, the "you can never be too safe" rule taken from everyday practice was followed, and so attempts were made to model situations and to predict scenarios proceeding from possible combinations of the worst factors.
2 Based on the analysis of international experience, a concept of group emergency cards was adopted. This concept stipulates that dangerous goods are grouped according to certain classification criteria and combined in an emergency card for which an isolation radius R_{SIR} of dangerous section is established.
3 The isolation radius, R_{SIR}, of dangerous zone is established as the maximum value under the worst-case scenario typical for the goods being most dangerous and most unfavorable in this respect. As for the other goods of this emergency card, this margin is further increased thus reaching a considerable value for the least dangerous goods.
4 This problem got substantially complicated after making a decision (1998–2000) on development of emergency cards for dangerous goods transported under generalized shipping names. Generalized shipping names specify the characteristic properties of a group of goods and contain the "not otherwise specified" (n.o.s.) definition. The necessity of developing emergency cards for the "dangerous goods, n.o.s." stock items (that exist not only at the regulatory level but in the international transportation practices as well, and, consequently, need both SSs and PSs) has determined such measures as their inclusion into cards for specific goods or development of new cards that contain only generalized names. In both situations, it was necessary to proceed from a combination of the most unfavorable conditions when establishing R_{SIR}.

4.2 Central Ideas of the New Concept

1 All R_{SIR} specified in the emergency cards should be revised and objectified, which can imply not only a change in the standard size but also a number of substantial changes, for example, in the number and layout of emergency cards and in the indications contained therein.
2 The uncertainty related to establishing R_{SIR} for emergency cards containing dangerous goods under generalized shipping names, "dangerous goods, n.o.s." and related possible errors should be reduced by certain methods. Refusal to include such goods that have the greatest transportation danger into the UNDG is among these methods. One of the transportation danger criteria is a packaging group referred to as packaging group I for such dangerous goods. In our opinion, such goods should be fully classified in a mandatory order with subsequent inclusion into respective databases and registers of hazardous substances including the UNDG under a specific name with assignment of a unique number.

3 The R_{SIR} radii should be left as reference amounts, since these standards, even if allowance is made for a certain degree of subjectivity in their definition in individual emergency cards, were agreed and approved by a large number of competent authorities, such as more than 25 ministries, agencies, and major corporations, including the Ministry of Railways, in the Russian Federation; and 14 railway administrations being the Council for Rail Transport of the Commonwealth members, at the international level. These standards were adopted, virtually without discussion or amendments, when confirming the Regulations concerning Transportation of Dangerous Goods by Rail as Appendix 2 to the Agreement on International Goods Transport by Rail.

4 Along with the specified isolation radius, we introduce the concept of the refined isolation radius R_{RIR} related to the basic standard R_{SIR} by means of refinement or adjustment coefficient, $K_{RIR.}$ Within the concept under development, this is the parameter that allows for reasonable changes in the basic standard having regard to the factors that affect the emergency propagation and corresponding response measures. As for the basic standard, this can be either a decrease (which is most probable) or an increase (in a number of cases concerning dangerous goods of classes 1 and 2) within the following limits: $K_{RIR} = 10^{-2} \ldots 10^2\ R_{SIR.}$

5 The structure of this coefficient, just like the entire concept of the new approach, is based on the deterministic and probabilistic approach, so refinement or adjustment of the standard parameter is carried out on the basis of expression (2):

$$R_{RIR} = K_{RIR} \cdot R_{SIR} = k_0 \prod_{i=1}^{n} k_i \cdot R_{SIR}$$
$$R_{RIR} = K_{RIR} \cdot R_{SIR} = k_0 \prod_{i=1}^{n} k_i \cdot R_{SIR}, \quad (2)$$

where K_0 is a dimensionless coefficient related to the features of the transportation route and the mode of transport (it is taken equal to 1 as the first approximation for railway transportation);

ki are dimensionless refinement coefficients (DRC) that take meaningful emergency propagation factors into account;

n is the number of dimensionless refinement coefficients that increases as the model gets refined and complicated. In this respect, the model reflected by Eq. (2) is characterized by an "open" type that allows taking a large number of factors into account.

As with the traditional approach (the initial concept), the DRC coefficients account for the meaningful factors of emergency development. Typically, the most important factors among them are: weight and volume of the transported goods (a rail tank car, a container, a cylinder, a tank, etc.), the aggregate state of goods (gas, liquid, powder, crystals), the degree and types of cargo-related danger (explosion hazard, inflammability, toxicity, corrosiveness, and other properties). The objectified relationship of factors and quantitative assessment of the DRCs are the new elements.

6. Isolation of the dangerous zone assumes that rescuers (provided with relevant personal protective equipment) should be located along the FP perimeter to ensure the containment of emergency and protection of people who happened to be for various reasons in the territory affected by the emergency. Reduction in the RSIR size entails reduction in the cost of emergency response procedures, primarily due

to a decrease in the number of involved rescuers. The cost reduction can be assessed from a simple relationship (assuming that the dangerous zone has a circular shape) that takes the decrease in the number of rescuers into account as follows:

$$\Delta N = N_1 - N_2 = 2\pi \frac{R_{SIR}}{L_{is.s.}} - 2\pi \frac{R_{RIR}}{L_{is.s.}} = \frac{2\pi}{L_{is.s.}} \cdot (R_{SIR} - R_{RIR}) = \frac{2\pi \cdot R_{SIR}}{L_{is.s.}} (1 - K_{RIR}) \quad (3)$$

where *ΔN* is the reduction in the number of rescuers;

N1, N2 are the numbers of rescuers that provide isolation of dangerous section of size R_{SIR} *and* R_{RIR}, respectively;

Lis.s. is a statutory length of an area (perimeter of the zone to be isolated) controlled by a single rescuer.

5 Research Results. Practical Results and Their Discussion

We have conducted a statistical analysis of a dangerous zone statutory isolation radii provided in the emergency cards for dangerous goods of classes 1, 2, 3, 4, 5, 6, 8, and 9, and in the regulatory and technical documents that contain references to the numbers of emergency cards [5, 10, 11]. It has been established that emergency cards for a number of hazardous goods selections are absent, which creates a high-level threat of related emergencies in implementation of actual transportation by rail.

The regulations [11] outline the transportation conditions of new dangerous goods under UN 3499-3526 numbers; however, they are not included into the group [5] or individual emergency cards, and the isolation radius is not determined for them. As a result of the conducted work, isolation radii have been determined for new dangerous goods based on relationship (2), proceeding from the coefficient being equal to 0.9: RRIR = KRIR RSIR = 0.9 RSIR.

The characteristics of dangerous goods that do not have corresponding emergency cards in the national and international rules, isolation radii and numbers of the recommended (existing) emergency cards are provided in Table 1.

It follows from Formula (3) and Table 1 that the determined effect is (1 − KRIR) * 100%, which is equivalent to the reduction of costs by 7.5–10% (only at the first approximation, with the possibility of further reducing the standards and costs).

The practical outcome consists in improving the transportation process safety management methods for dangerous goods on rail. Proposals for improving the safety during transportation of dangerous goods by rail have been developed. Among them, most promising are as follows:

1 adjustment of the existing emergency cards and development of new ones for dangerous goods along with extension of the list of goods admitted to international traffic;
2 making amendments in the Safety Rules for Response to Emergencies related to Dangerous Goods during Their Transportation by Rail;

Table 1. The characteristics of dangerous goods that do not have the corresponding emergency cards in the national and international rules

Main and additional types of hazards	UN numbers of new dangerous goods	Characteristics of cargo-related hazards	R_{RIR}, m	Numbers of emergency cards (forecast)
2, 2.1	3501, 3510	Flammable gases	45, 180, 270	204, 205, 206, 214, 218
2, 2.1 + 8	3505	Flammable, corrosive gases	180	220
2, 2.2	3500, 3511	Non-flammable, non-toxic gases	45	201, 213, 215
2, 2.2 + 5.1	3513	Non-flammable, oxidizing gases	45	202
2, 2.2 + 6.1	3502, 3504	Non-flammable, toxic gases	180	220
2, 2.2 + 8	3503	Non-flammable, corrosive gases	180	211
2, 2.3	3512	Toxic gases	180	203
2, 2.3 + 2.1	3514, 3522, 3523, 3525, 3526	Toxic, flammable gases	180, 270	207, 208, 209, 210, 212, 219
2.3 + 2.1 + 8	3517	Toxic, flammable, corrosive gases	180	220
2.3 + 5.1	3515	Toxic, oxidizing gases	180	220
2.3 + 5.1 + 8	3518, 3520	Toxic, oxidizing, corrosive gases	180	220
2, 2.3 + 8	3516, 3519, 3521, 3524	Toxic, corrosive gases	180	220
8	3507	Corrosive substances	45	815
8 + 6.1	3506	Corrosive, toxic substances	45	811
9	3499, 3508, 3509	Other hazardous substances	45	906

3 development of proposals for improving the Railway Transport System of Emergency Prevention and Response;
4 making considerable amendments in a number of other regulatory and technical guidance documents on transportation of dangerous goods, provision of process safety, application of collective and personal protective equipment, and substantiation of the list that will be provided in the next paper.

When discussing the main provisions of the new concept presented in this work, it is said that the development, determination of the conditions for the carriage of goods presented under generalized "not specifically indicated" names presents certain methodological difficulties, since the set of initial parameters is small (they are all contained in the name). These methodological difficulties increase both in determining the standard isolation radius and in solving the broader task of developing emergency cards. The problem that arouses our concern and our attention concerns, of course, not only and not so much scientific and methodological correctness, but the justification for achieving the necessary level of security. The security level is determined, first of all, by the development of specific practical recommendations in the emergency card for the protection of railway personnel, railway infrastructure and environmental objects (in the accident zone). The lack of relevant information causes uncertainty and, possibly, a certain subjectivity. Table 2 presents examples of two goods and the logical difficulties of "deciphering" the properties for the design of protective equipment (emergency cards).

Table 2. Examples of dangerous goods of generalized transport names and a set of parameters that impede the adoption of practical recommendations: (1) - identifiable properties with the possibility of modeling; (2) - hardly or completely unidentifiable properties and uncertainty of the recommended protective measures.

UN number, name	Basic properties and measures arising from them	Suggested personal protective equipment	The need for fire and explosion protection	Proposed first aid measures
2810 Liquid poisonous, organic, n.o.s.	Liquid state (1), therefore, spreads (at positive temperatures), isolation of the danger zone by technical means is required. Volatility, evaporation (2)	Requires respiratory, eye, skin protection (1), Recommended brands, types, samples of personal protective equipment (2)	Flammability (2) explosion hazard (2), emission of toxic combustion products (2)	Intake of water and antidotes inside (2) Skin flushing with water (2)
2811 Solid substance, organic, n.o.s.	Solid state (1) - isolation of the danger zone with improvised means	Requires respiratory, eye, skin protection (1), Recommended brands, types, samples of personal protective equipment (2)	Flammability (2) explosion hazard (2), emission of toxic combustion products (2)	Intake of water and antidotes inside (2) Skin flushing with water (2)

Thus, at least 50% of the signs and associated protective measures are difficult to identify. The proposed measures should cover the entire range of possible negative consequences. The data presented above indicate that the proposed measures in existing emergency cards should be subjected to additional verification on a new methodological basis.

6 Conclusion. Implications. Recommendations

This stage of research allows drawing the following main implications and proposing recommendations:

1. State of the art for the analysis methods of technogenic hazards and risks for the rail transport facilities requires critical re-evaluation of the entire set of issues, theory and practices, railway traffic stability and safety promotion experience during response to emergency situations related to transportation of dangerous goods.
2. Reduction in frequencies of incidents, emergencies and critical situations during transportation of dangerous goods remains a priority task of state policy, and the Ministry of Transport of the Russian Federation and RZD OJSC play the critical part in solving this task. Solving this task requires an insistent search for new solutions and their implementation including systematization, objectification, and improvement of emergency cards.
3. The uncertainty related to establishing isolation radii RSIR of dangerous sections for emergency cards containing dangerous goods under generalized shipping names, "dangerous goods, n.o.s." and resulting possible errors should be reduced by certain methods. Refusal to include such goods that have the greatest transportation danger into the UNDG is among these methods. One of the transportation danger criteria is a packaging group referred to as packaging group I for such dangerous goods. In our opinion, such goods should be fully classified in a mandatory order with subsequent inclusion into respective databases and registers of hazardous substances including the UNDG under a specific name with assignment of a unique number.
4. Development and introduction of the second version of the Response to Emergencies Related to Dangerous Goods information management system as an element of information technologies in transport seems to be an objective challenge in the light of optimization of labor and financial resources. It is necessary to increase the rate of reduction in the frequency of emergencies to an acceptable level and to decrease social and economic costs related to these emergencies and response operations. Among other things, these objectives can be achieved by increasing expenses for R&D.

According to the assessment obtained by processing experimental data, the expected effectiveness of introduction on a company or country basis is 7.5–10%. Currently, we are preparing a proposal for the Ministry of Transport of the Russian Federation regarding the creation of a mechanism by means of which the statutory cost saving will be aimed at technology upgrading and liquidation of potential and actual dangerous zones with dangerous goods. Within the approach under development, its universal character has been substantiated, which opens up potential for application in other modes of transport and transport and logistics companies. We will describe the attempt to extend the approach under development in our next paper.

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Author Index

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