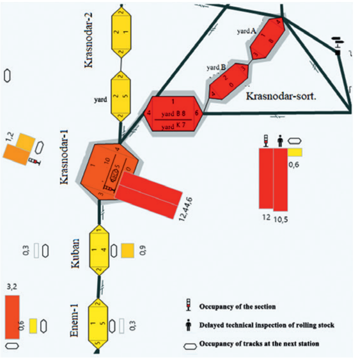
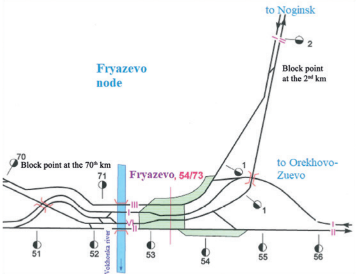
THEORY



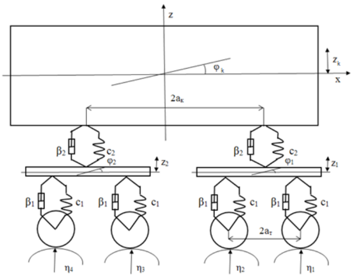
TRANSPORT NODES 166

The suggested systemic approach allows drawing new definitions of notions of transport nodes and developing new classifications.



TRANSPORTATION BY RAIL 173

Revealing the best parameters of vibration dampers is based on physical and mathematical models. Approaches, models, formulas, computation examples are proposed, while the final goal is to provide comfort of passenger travelling and safety of goods transported.



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On the Principles of Design of Transport Nodes




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ABSTRACT

The methodology developed by the authors refers to designing, calculating, and optimising transport nodes based on the original systemic approach as a main method. The use of the methodology will make it possible to design transport nodes more rationally and to evaluate their development projects more correctly.

A «system» is understood as a general natural form of structuring organised substance, which enables it to function stably in a changeable environment. The basic principles are formulated as follows: the system consists of elements, each of which is also a system; active self-maintenance is developed in the system, that is, active actions are counteracting external adverse influences; it is shown that self-maintenance is provided by adaptability, and in transport systems the self-maintenance is particularly provided by adaptive technology.

A contradiction (a dialectical one) arises: on the one hand, the elements are independent systems that have their own system parameters and mechanisms for their active maintenance, and on the other hand, they are subordinate creatures capable of flexibly changing their work to maintain the parameters of the supersystem. It is necessary to find harmony between the levels of development of these opposite properties. Transport nodes are also considered from these systemic positions. Exposition of several definitions of nodes by leading national scientists is followed by a statement showing that they all contradict the new systemic approach.

Suggested system definition of a node describes it as a set of stations. The authors also propose a new classification of transport nodes, formulate criteria for their rational design depending on the classes, and propose correct design and optimisation principles.

Keywords: transport node, system, simulation model, station, adaptability, technology, design, optimisation.

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INTRODUCTION

The article presents the results of solving the *task* of developing theoretical foundations for designing effective transport nodes[1], as well as correct methods to be used for their design and optimisation. The theoretical basis refers to the original version of the *systemic approach*, where the «system» is understood as a natural form of structuring organised substance, which provides it with stable and effective functioning in a random environment.

RESULTS

Systemic Approach and Transport Nodes

A correct understanding of the essence of transport nodes and methods of their design is of great importance in the context of development of transport infrastructure.

Design principles mean design method, and choosing a method is not an easy task.

According to Georg Wilhelm Friedrich Hegel, «Method, therefore, is not an external activity of subjective thought, but the very soul of the content» [1, p. 423].

Alexander I. Herzen has no less authoritative point of view: «The method in science is more important than any amount of knowledge». «The method follows from the object and is not introduced to it arbitrarily» [2, p. 134, 155].

Thus, to choose fundamentally new approaches to calculating transport nodes, one must answer the question: what is a transport node? Definitions there-of are suggested in several research works in the field of transport science.

Academician Vladimir N. Obraztsov wrote: «A railway node is a point where at least three railway lines (three directions) of a relatively equivalent mainline nature are connected to each other, and where there is one or several distribution stations, which serve to exchange of traffic of passenger and cargo trains and wagons, as well as for passenger transfer and transshipment of goods to other modes of transport: waterways, highways, narrow-gauge railroads, etc.» [3, p. 7].

A node is called here a «*point*» which contains intersecting lines and at least one station. How can a single station be a node? This follows from the presence of intersecting lines (Pic. 1). This is the definition of a geometric character. The term «*point*» later became popular.

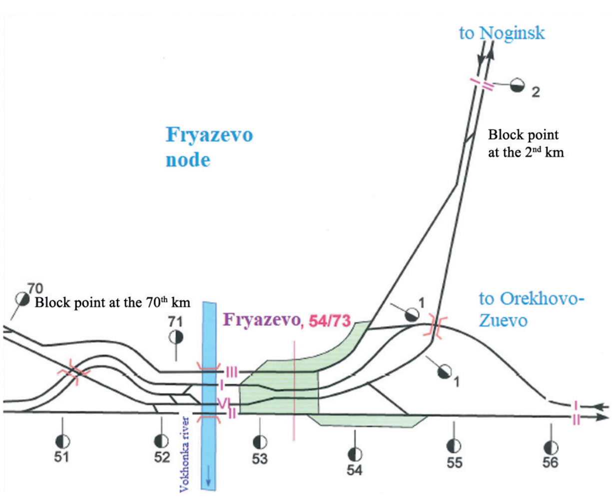
V. N. Obraztsov gave the following definition of a transport node: «A transport node is a *point* of intersection and branching of routes of various modes of transport» [4, p. 433].

Professor Prokopy V. Bartenev believed that «...a transport node is a *point* of concentration of various modes of transport» [5, p. 452].

Professor Vladimir A. Persianov noted that, although the above definitions are basically correct, they are insufficient, since they do not fully reflect the entire essence of the transport node, and that the classification of transport nodes contains more random than consistent features [6, p. 355].

The Institute of Systemic Transport Problems (then affiliated structure of the Academy of Sciences) proposed a more meaningful definition: «A transport node is a *complex of transport*

[1] The authors in the context of the research use the original Russian term «transport node» as the most general one, without further differentiation into, e.g., nodes, hubs, multimodal interchange nodes, multimodal interchange hubs, etc. – *Translator's note.*



Pic. 1. «Node» consisting of a single station (compiled from the album of plans and layouts of railway nodes and stations, developed by JSC IERT [Institute for Transport Economics and Development]).

structures and [track] developments at the point of junction of several modes of transport (including at least two modes of mainline transport) that jointly operate transit, local and urban transportation of goods and passengers» [7, p. 181].

But again, the «*junction*», and the structures can hardly be considered something definite.

The recently published work on the nodes states the following: «A railway node is a *point* of intersection or branching of several lines that unite a number of stations and block points linked by connecting lines and working according to a single technology (in interaction). The railway node includes marshalling yards, cargo and passenger stations with their structures; main and connecting tracks; block points and bypasses; feeder roads; all types of flying junctions located within the boundaries of the node; independent production units of railway transport (factories, traction substations, material warehouses, etc.)» [8, p. 787].

Here, the notorious «point» includes not only «stations and factories», but also «connecting tracks, block points, and bypasses, and all types of flying junctions».

If a transport node is a «junction» that includes different «structures», then it is difficult to determine the content of this conceptual term, and, therefore, it is difficult to choose an adequate design method.

Several decades ago, scientists representing various fields widely discussed the so-called «systemic approach». The term «system» and its variations are often used in different phrases and context: «to consider from a systemic standpoint, problems are of a systemic nature», etc. There is even an institute for systems analysis[2]. Maybe it is worth considering the transport node from a systemic point of view as well?

Let's see what is understood in science by the notion of a «*system*».

Based on the works of Friedrich Engels [9, pp. 392, 550, 563, 570, 585], the philosopher Anatoly N. Averyanov suggested a definition that follows: «The system is a limited set of interacting elements» [10, pp. 18, 24].

The mathematician Nikita N. Moiseev believed that «the concept of a «system» is one of those for which it is difficult to give an accurate definition. For our purposes, the intuitive concept of a system, that everyone studying a subject has, is sufficient» [11, p. 130].

But a whole field of science, the systems theory, cannot be built on an intuitive concept.

There are also such approaches that attribute too broad classes of objects to systems. Here is what, for example, Anatoly N. Averyanov writes in the above cited work: «…unorganised aggregates… are systems, although not integral ones…», further noting that «…unorganised aggregates consist of elements; the elements of specific aggregates are interconnected, no matter if this connection is external or accidental; …it is important that this connection unites the elements into aggregates of a certain form, which we call a heap, a pile, a crowd, etc., depending on the properties of its elements and the links between the elements that differentiate those aggregates from external environment» [10, pp. 21–22].

But if one and the same concept includes, e. g., a transport node and a heap of stones, then what content can a theory based on this concept have?

It is widely believed that there is no generally accepted definition of the concept of a «*system*». Naturally, there is no certainty as to what problems the theory should solve.

Academician Axel I. Berg expressed the following opinion: «Despite the widespread use of the notion of the *«system»*, until now there is no generally accepted definition of it» [12, p. 68].

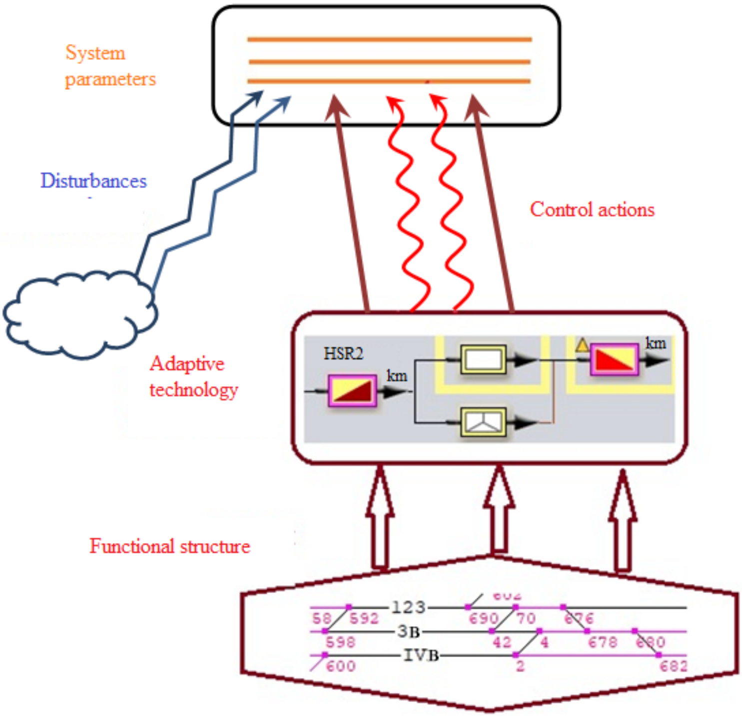
To some extent, currently, there are attempts to touch upon this problem but without going beyond the usual definition of the concept of a «*system*». For example, in [13] the authors write: «The system is such a general concept that it is very difficult to provide it with a definition that could be universal for all cases of life. Systems are simple, complex, and super-complex, etc. An ordinary sash fastener is a simple system. Personal computer is a complex system. The economics of passenger transportation is a super-complex system».

When both «sash fastener» and «economics of passenger transportation» are deemed to be equivalent concepts, this approach can hardly be a theoretical basis.

As we can see, not all is correct with the systemic approach.

A new approach to this problem was proposed in works [14; 15]: «a system is an integral holistic formation with active self-maintenance, while its elements are also systems». Here «active self-

[2] Institute for Systems Analysis of the Russian Academy of Sciences. – *Translator's note.*



Pic. 2. The main features of the systemic design of an object (developed by the authors).

maintenance» is just as important as «integrity». Avicenna said that life is given to a person with an indispensable condition to fight for it every day [16, p. 272]. For artificially created systems, this is the main difference from all other objects (there is integrity in a meat grinder, a bicycle, but there is no active self-maintenance).

That is, *a system* is a form of structuring organised substance that allows it to stably (and efficiently, that is, without large static spare resources, but due to adaptability) exist in an environment where there is a disorganisation. This form has been developed by nature. This form must be studied, stated clearly and then used to design sustainable and efficient transport systems.

Active self-preservation ensures adaptability. For technical systems, this will be an adaptive technology.

The essence of systems analysis follows from the concept of a system. It should use the following steps:

• To determine the general function and parameters that characterise it.

• To formulate the function and system parameters of the elements.

• To investigate the adverse effects on the system as a whole and on the elements as a system.

• To determine the mechanisms of active counteraction to these disruptive influences.

Definitions

Transport node is a group of systems of various modes of transport interrelated by infrastructure and technology that jointly process flows in a certain area.

Railway node is a group of stations interrelated by infrastructure and technology that jointly process flows in a certain area.

District is a certain isolated integrity in the social (settlement), industrial (plant) or transport relation. In the latter, it is the fulfilment of a certain transport task according to a single plan: provision of coordinated transport services to heterogeneous objects in the area, processing the flow when transferring it from one line to another, etc.

Processing of flows:

• Disassembly and assembly of trains.

• Loading, unloading, reloading.

• Embarkation, disembarkation, transfer of passengers.

The signs of the term «jointly» are evident if operational control is additionally present, that is, there is a flexible interaction of the systems included in the node (this is a higher level).

A node is a system only when there is a common function for the whole node, and if there are parameters that characterise the function and mechanisms of their active maintenance in the presence of disturbing factors (Pic. 2). Otherwise, it is not a system.

We might single out also the following foreign works as examples of studies dedicated to the analysis and design of transport nodes, railway stations, areas [17–21].

So, here are the features of the system:

• *There is a common function and parameters* that characterise it, while there are permissible limits of the parameters.

• *There are destructive influences* that can bring the parameters beyond the permissible limits.

• *Regarding each set of destructive effects, there are active reactions* that neutralise harmful effects.

• Active reactions are provided mainly due to *adaptive technology.*

• *The structure* should be largely determined by the function, that is, the structure should be *functional*.

Differences from the existing definition:

• Here *a node* is *a system of a higher organisational level*, the elements of which are systems of the lower level, and not connecting lines, tracks, sidings, junctions, berths, etc.

• The main thing here is *the nature of interaction* of the systems included in the node, and *not its geometric characteristics*, which directly depend on the terrain and location of the object served by the transport.

From this point of view, transport nodes are clearly divided into two classes:

• *A* class: nodes *are* systems.

• *B* class: nodes *are not* systems.

This means that a systemic approach should be used in the study of the former (*A* class) nodes, while some other technology should be applied to the latter (*B* class) nodes.

The analysis shows that only industrial and port transport nodes can be classified as belonging to *A* class.

There, the structure is really what is called a «frozen function». These nodes have functional integrity, have a system-wide function and mechanisms to maintain it. They are strongly affected by the proximity to production loading facilities.

Transit nodes (*B* class) cannot be considered fully fledged systems. What is the general function of a node that includes, say, a passenger and cargo stations along with a marshalling yard? Each station has its own individual function and there is no adaptive interaction between them. They, as a rule, are located near a large settlement: otherwise, they will not be able to hire the necessary number of employees.

But here comes another problem of interaction between stations. There is an intersection of flows and with it the need arises to build expensive interchanges and flying junctions at different levels.

Here, rather, there is a problem of designing a node with minimal and functional losses considering specific geographic conditions. These conditions precondition emergence of various node layouts. Nevertheless, some principles of their rational organisation can be formulated:

a) Stations should be located as close as possible to the facilities served:

$$\forall_i \forall_j \left| l_{ij} \to \min \right.,$$

where l_{ij} is distance of the *i*-th station from the *j*-th terminal.

b) The location of the infrastructure of stations should ensure:

– minimum of intersecting flows:

$$\sum_i \sum_j \boldsymbol{u}_{ij} = \boldsymbol{min},$$

where *i* is the origin point of the intra-node flow; *j* is intersection point.

c) Minimum of intra-node mileage:

$$\sum_i \sum_j \boldsymbol{u}_{ij} \boldsymbol{l}_{ij} = \boldsymbol{min},$$

where u_{ij} is transportation flow between the *i*-th and *j*-th station of the node;

l_{ij} is length of u_{ij} trains mileage.

Then, constraints of topographic nature and creativity of designers take effect.

To calculate transport nodes of both classes, a two-stage approach should be used.

The objectives of the first stage will be:

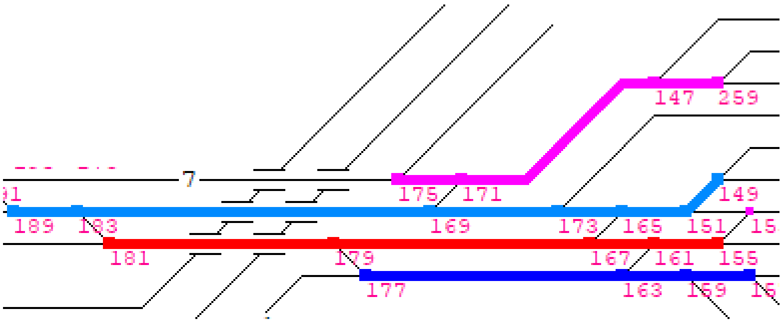
• Determination of the general parameters of a node.

• Assessment of inter-station interaction, that is, structural and functional links between stations.

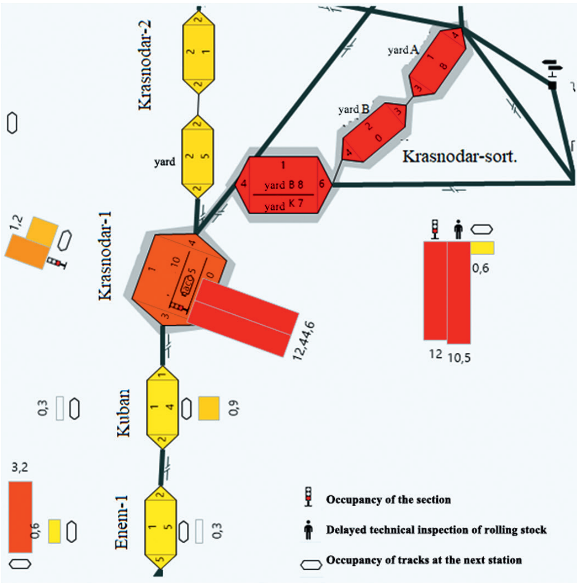
• Identification of stations that experience problems.

At the second stage, the task will be to thoroughly and comprehensively study stations experiencing problems.

A two-step approach will reduce study costs and speed up the entire process.



Pic. 3. Structural channels in the neck (developed by the authors).



Pic. 4. Possible reasons for train delays at the stations of the node (developed by the authors).

At the first stage, it is advisable to apply integrated modelling, and at the second, to use detailed simulation models.

An integrated study can be carried out using:

• Optimisation flow models.

• Integrated simulation models.

In the general case, three problems can be solved using flow models:

• To make a rough estimate of the transit and processing capacity of stations.

• To assess the transit capacity and delays in inter-station structural links.

• To optimise the process of adaptive interaction of stations (for *A* class nodes).

It is more useful to use dynamic models, for example, a dynamic transport problem [22]. Even for *B* class nodes, this is important since the delays due to intersection of flows will be presented in dynamics. This is important for analysis since flows are generally uneven.

The development of an enlarged simulation model requires development of a special technology [23]. Instead of switches, at the necks, so-called structural channels are introduced, reflecting the number of possible parallel movements (Pic. 3).

In the yard, instead of the total track capacity, its functional capacity is specified, that is, the maximum filling, at which its functional properties are still preserved. The reliability of macro-modelling was verified by comparative calculations regarding, respectively, detailed, and integrated models [23].

In Russia, the IMETRA simulation software package [Certificate of state registration of computer programs No. 2015662972] can now be considered as most effective. The package provides comprehensive information about the parameters of the node, as a rule, in a form convenient for the researcher (Pic. 4).

CONCLUSION

Classification of transport nodes from the standpoint of a new systemic approach better reflects their nature.

A two-stage approach should be used to calculate transport nodes. The first stage should be dedicated to investigating of inter-station interaction with the help of integrated models, the second stage based on the detailed models should be dedicated to the study of the stations experiencing problems.

The classification of transport nodes allows for a more reasonable development of methods for their design and optimisation. Using them while assessing infrastructure development projects will result in a significant effect.

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Dynamics of the Rolling Stock and the Choice of Parameters of Vibration Dampers

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ABSTRACT

Modern railway rolling stock should meet requirements regarding comfort (maximum travel speed with minimum vibrations of wagons, noiselessness of movement, etc.).

To eliminate the influence of dynamic loads, rolling stock is equipped with vibration dampers. The objective of the work is to select the parameters of the vibration dampers of rolling stock, depending on its characteristics, to ensure the due indicators of comfort and safety of transportation of passengers and goods by rail. To achieve this objective, applied methods of mathematical modelling were based on numerical programming of operation of dynamic systems. The indicators of vibration dampers are evaluated according to the results of studies of the dynamics of the rolling stock (in particular, of vibration protection rates).

Assessment of dynamic state of the rolling stock implies application of methods of mathematical and physical modelling, which include the development of a physical and mathematical model, a calculation algorithm, and computer programming. The study of the mathematical model by numerical methods makes it possible to carry out a multifactorial experiment using a large number of input parameters (factors) and to select the characteristics of vibration dampers that are optimal for the conditions under consideration.

To solve dynamic problems, the harmonic perturbation model, which is the most widespread, was specified in the form of a sinusoid with a period corresponding to the rail length.

A quantitative assessment of the vibration process (frequency, amplitude) makes it possible to identify the main processes occurring in the system under consideration under various types of external load. The introduced assumptions related to rigidity, mobility and geometric immutability of the system allow determining the methods for obtaining a mathematical model and considering the vibrations as flat ones.

The equations were solved in MathCad Prime 4.0 package using the Runge–Kutta method with automatic step selection. The subsequent study of the properties of the dynamic system was carried out by changing the resistance parameter of dampers of the first stage of spring suspension, while recording the values of the amplitude of the vibrations of the system and the period.

The analysis of the results has shown that the vibration period of the body and bogies under any changes in the resistance parameter of the damper remains unchanged, while rational parameters of resistance of axle box dampers have been revealed for specified indicators. Hydraulic vibration dampers with the revealed parameters used on rolling stock help to reduce wear and damageability of running gears, improve ride comfort and traffic safety, as well as to reduce repair and maintenance costs.

Keywords: *railway, dynamics, rolling stock, vibration damper, parameter estimation, mathematical model, vibration process, amplitude, displacement, speed, acceleration, motion.*

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INTRODUCTION

To successfully promote products globally, a manufacturer of railway rolling stock should not be guided exclusively by the requirements stated by technical indicators, such as strength, stiffness, stability of rolling stock, since there are also requirements regarding comfort (maximum travel speed with minimal vibrations of wagons, noiselessness of movement, etc.). The latter factors are also important for transportation of different groups of goods.

Currently existing passenger coaches do not always meet the requirements for comfort and safety. It is necessary to develop and create new types and series of coaches that would not only meet modern world standards, but also surpass them.

However, modern scientific and technical literature (e.g., [1, p. 13]) pays less attention to comfort than to the safety of transportation, while these requirements are different in each specific region or a country. Recently, these specifications have started to refer to high speed passenger trains more frequently. In Europe, these requirements are regulated by the European Union Agency for Railways (ERA)[1], in the United States by the Department of Transportation and by the Federal Railroad Administration[2].

It is known that structural elements of rolling stock perceive weight loads, loads arising in the mode of unsteady motion (traction, braking), inertial loads arising when moving in curved sections of the track. The listed loads are static loads. The dynamic loads arise due to movement of the vehicle along the railway track with geometry and track irregularities.

To eliminate the influence of dynamic loads, modern rolling stock is equipped with vibration dampers. The choice of their parameters depending on the features of rolling stock to ensure the indicators of comfort and safety of movement of passengers and goods by rail is still carried out by trial-and-error method.

The *objective* of the study is to evaluate the parameters of vibration dampers of rolling stock, depending on the action of dynamic loads with specific indicators. For this, numerical *methods* of mathematical and physical modelling were applied using MathCad software, followed by an analysis of the results obtained.

RESULTS

Indicators of the Dynamic Properties of the Rolling Stock

Vibration processes resulting from the action of dynamic loads are assessed by indicators of the dynamic properties (DPIs) of rolling stock. DPIs include [2, p. 148]:

• *Vibration protection:* the degree of protection of equipment of the locomotive and the railway track from vibrations arising during movement.

• *Traffic safety:* the degree of safety provided during movement.

• *Running smoothness:* the degree of impact of vibrations of rolling stock on the human body.

These indicators are assessed based on the results of research on the dynamics of rolling stock. Let us dwell in more detail on the main indicators of vibration dampers. These indicators comprise:

• Maximum values of body acceleration values in vertical and horizontal directions, $\ddot{q}_{\max}$.

• Maximum displacement values at the end points of the body $q_{\max}$, determined by the dimensions and operating conditions of the automatic couplers.

• Maximum values of the dynamic factors in the horizontal (F_{DH}) and vertical directions of the first (F_{D1}) and second (F_{D2}) spring suspension stages [2, p. 232];

• Safety margin factors of spring deflection value regarding the dynamics F_{fm}.

The maximum displacement of the ends of the body is determined using the known formula as the amount:

$$q_{max} = 0,5\left(\Delta q_{2-1max} + \Delta q_{2-2max}\right) + a_b \frac{\Delta q_{2-1max} + \Delta q_{2-2max}}{2a_2},$$

where $\Delta q_{2-1\max}$ and $\Delta q_{2-2\max}$ are maximum spring deflections (stroke of the hydraulic damper rod) of the central suspension of the first and second bogies, respectively;

a_2, *ab* – half of the base and body length, respectively.

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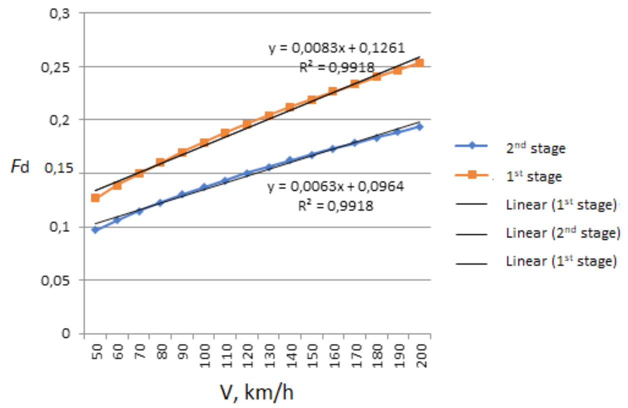
[1] E.g., chapters B11 Applicable national technical rules for vehicles; B12 Vehicle authorisations in: the Report on Railway Safety and Interoperability in the EU, European Union Agency for Railways, 2020. [Electronic resource]: https://www.era.europa.eu/sites/ default/files/library/docs/safety_interoperability_progress_ reports/report_on_railway_safety_and_interoperability_in_ the_eu_2020_en.pdf. Last accessed 17.02.2021.

[2] E.g., Passenger Equipment Safety Standards; Standards for Alternative Compliance and High Speed Trainsets. A Rule by the Federal Railroad Administration on 11/21/2018. [Electronic resource]: https://www. federalregister.gov/documents/2018/11/21/2018-25020/passengerequipmentsafetystandardsstandardsforalternativecomplianceandhighspeedtrainsets. Last accessed 17.02.2021.



Pic. 1. Graphs of dependence of F_{D1} and F_{D2} on speed of vehicle's movement V (compiled by the authors).

The indicator of horizontal dynamics F_{DH} is determined by the formula:

$$\sum F_{FY} = R_A + R_B - Q - L = -3{,}125 + 98{,}25 - 20 - 75 = 0{,}125 \approx 0.$$

$$F_{\mathrm{DH}} = \frac{Y_{frf}^{\mathrm{dyn}}}{L_a},$$

where Y_{frf}^{dyn} is dynamic component of the horizontal maximum frame force (frame forces are transverse forces of interaction between the wheel set and the bogie frame of a railway rolling stock unit);

L_a – axial load.

Changes in the dynamics of the first and second stages are shown in Pic. 1.

Pic. 1 shows that it is rational to determine the dependence of the vertical dynamic indicators of the first F_{D1} and the second F_{D2} stages of the spring suspension, depending on speed of vehicle's movement, by a linear dependence of the type $y = ax + b$, as evidenced by the values of variances, which tend to unity for each obtained function. Moreover, it can be seen from the Pic. 1 that with an increase in speed, the dynamic factor decreases. For example, at a speed of 200 km/h, it decreases by 1,37, which indicates a revision of the parameters of hydraulic dampers for high-speed rolling stock.

Failure to respect smoothness indicators due to the action of vibrations in transient and steady-state modes of movement negatively affects the performance ability of drivers, of service personnel, and the well-being of passengers. These indicators are assessed with various indicators: frequency and amplitude of vibrations.

The authors of numerous studies [3, pp. 1–4; 4, pp. 1–3] note the negative impact of vibrations on the human body, which leads to irreversible consequences associated with changes in its physical and psychological state, which is aggravated over time due to the cumulative nature of the impact of vibrations.

Methods of Mathematical and Physical Modelling of the Indicators of the Dynamic State of the Rolling Stock

Rolling stock design widely uses methods of mathematical and physical modelling to determine the indicators of the dynamic state of vehicles. The method of mathematical modelling includes development of a physical and mathematical model, of an algorithm for computing and computer programming. The study of the mathematical model by numerical methods makes it possible to perform a large number of numerical experiments with exhaustive search (variation) of strength, cargo loading, and other parameters of the vehicle, the conditions of its operation, which allows choosing the parameters of the vibration damper design that are optimal for the specific (selected) conditions.

Technical problems associated with vibration processes are based on the generation and solution of multi-mass systems of differential equations (DE), which, as a rule, are solved by numerical methods. The results obtained as a result of the solution make it possible to obtain a mathematical model of the process occurring in the system and to estimate the parameters of the vibration process quantitatively. In our case, the system of differential equations of the system under study is based on the developed design scheme [5, p. 17; 6, p. 125] and is two-mass. The development of the design scheme, based on the research conditions and purposes, considered external forces, influencing the dynamic state of the rolling stock under consideration, as a technical system.

When creating a dynamic model, the operational and technical characteristics of the rolling stock were considered as external factors, which in mathematical terms were presented as «harmonic disturbance», expressed as a sine function with an argument corresponding to the rail length [5, p. 17; 6, p. 125; 7, p. 192]. Such a choice of input parameters is typical, for example, for the situations of moving along a single uneven track, of entering a curve, in case of impact at the rail joint, collision of vehicles, etc. It has been established [6, p. 131; 7, p. 214] that dissipative characteristics of the railway rolling stock, which include free vibrations, damp out in a short time. Proceeding from this, the definition of indicators of dynamic properties will be considered in the mode of steady forced vibrations.

It is known [8, p. 230] that disturbances causing forced vibrations in the rolling stock can be divided into:

• kinematic;

• force-based (due to application of external forces);

• parametric.

Kinematic disturbances arise due to geometric irregularities of the track arising in the profile and in the plane, irregularities on the rolling surface of the wheel. Force-based vibrations are excited by the traction moment, periodic forces from the imbalance of the rotating parts of diesel engines, electric motors, compressors, etc. Parametric disturbances are caused by changes in a parameter of the system, for example, in wear parameter.

When analysing vibrations of a vehicle, its natural vibrations can be represented in the form of a second-order differential equation with the missing right-hand side

$$M\ddot{q} + B\dot{q} + Cq = 0. \quad (1)$$

Determination of the parameters of the vibration process of the vehicle (natural frequency and amplitude) will make it possible to make a decision on the choice of a vibration damper, which reduces the vibration process itself to a minimum. The problem stated is solved for small deviations of the system from the equilibrium position. In the study of the vibration process obtained as a result of the analysis of the considered model, stability of motion becomes an important indicator. The running stability is reduced to the study of the zero solution of the system according to linearised equations of the perturbed motion of the system, which is a necessary but insufficient condition for ensuring stable operation of the system under consideration. Further analysis of the model, depending on the action of the external load in the form of forced vibrations, makes it possible to determine the indicators of the dynamic properties of the wagon.

Results of the Practical Phase of the Study

The study of the model was conducted using MathCad software package platform. The results obtained make it possible to evaluate influence of changes in the suspension parameters on vibrations of the moving parts of the vehicle. Variable parameters belong to vehicle speed, which makes it possible to determine critical speeds and maximum displacements in the suspension system corresponding to each other. Also, by changing suspension parameters, it is possible to outline ways to reduce negative phenomena. This approach to solving the problem is called direct modelling [7, p. 72; 9, p. 42; 10, p. 54; 11 p. 92].

The solution of differential equations of movement of the vehicle by numerical methods will make it possible to assess the main processes occurring in the system under various combinations of external influences. For this, nonlinear functions are introduced into the system that do not change the structure of the model. The mathematical model represented by dependence (1) can be sophisticated by introducing the right-hand side by introducing a functional characterising the vibration process, which leads to obtaining new indicators of dynamic movement of the rolling stock.

When conducting research on the dynamic mode (vibrations of the rail vehicle), we introduce the following assumptions:

• The car body and bogies are considered absolutely rigid bodies in comparison with stiffness of springs.

• The track is considered absolutely rigid due to high rigidity of its elements.

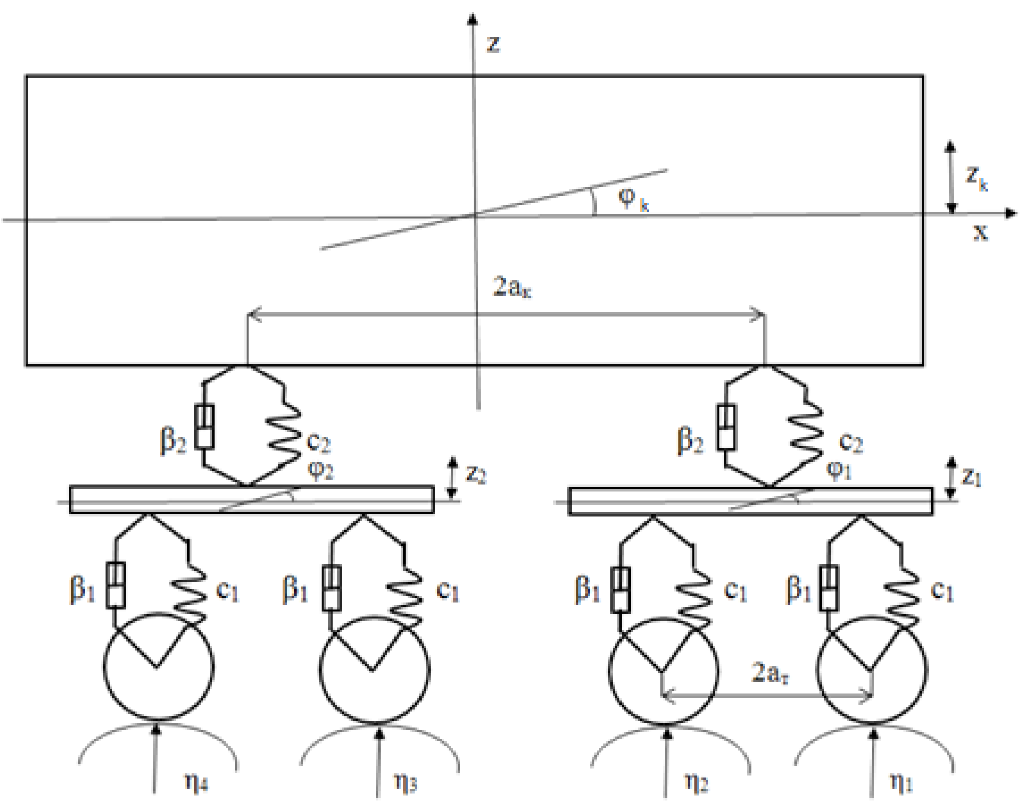
• Spring suspension is considered to be inertialess due to smallness of the masses involved in the vibration.

• Forces of internal inelastic resistance in the elements of the track and body and the resistance of the environment are not considered.

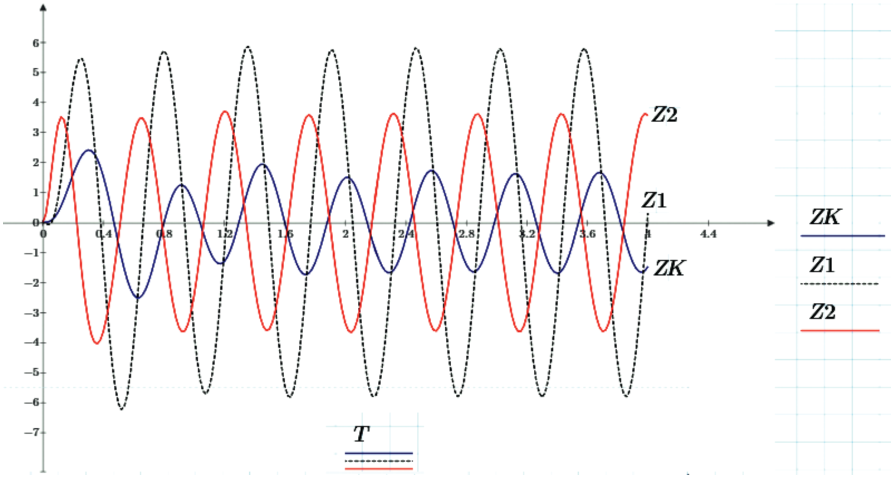
Table 1

Initial data of the design scheme of vehicle vibrations in the vertical longitudinal plane

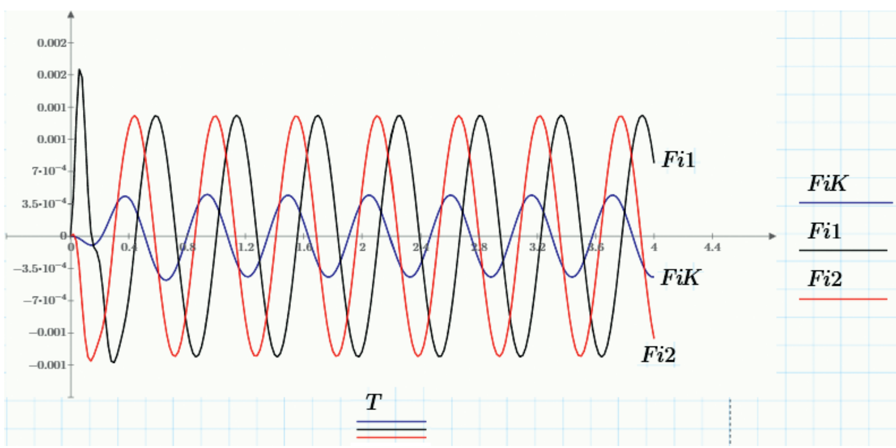
Parameter	Designation and dimension	Quantity
Gross body weight, tare	m_k, kg	40000•17000
Bogie weight (sprung)	m_t, kg	7500
Moment of inertia of the body: gross tare	J_{ky}, kg•m^2	1,32•10^6 7,2•10^5
Moment of inertia of the bogie	J_{ty}, kg•m^2	1900
Body base	$2a_k$, m	18
Bogie base	$2a_t$, m	2,6
Vertical rigidity of the first stage of spring suspension	c_1, kN/m	120
Vertical damping of the first stage of suspension	β_1, kN•s/m	10
Vertical rigidity of one spring set of the second stage of spring suspension: tare gross	c_2, kN/m	310 625
Vertical damping of one spring set of the second stage of spring suspension	β_2, kN•s/m	80
Speed of motion	V, m/s	45



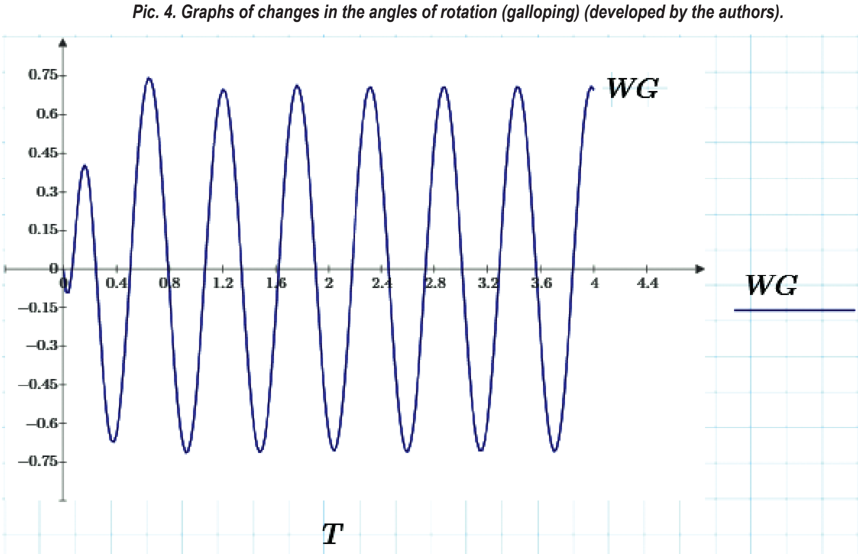
Pic. 2. Design scheme of vehicle vibrations in the vertical longitudinal plane [5, p. 93].



Pic. 3. Graphs of changes in displacements (bouncing) (developed by the authors).

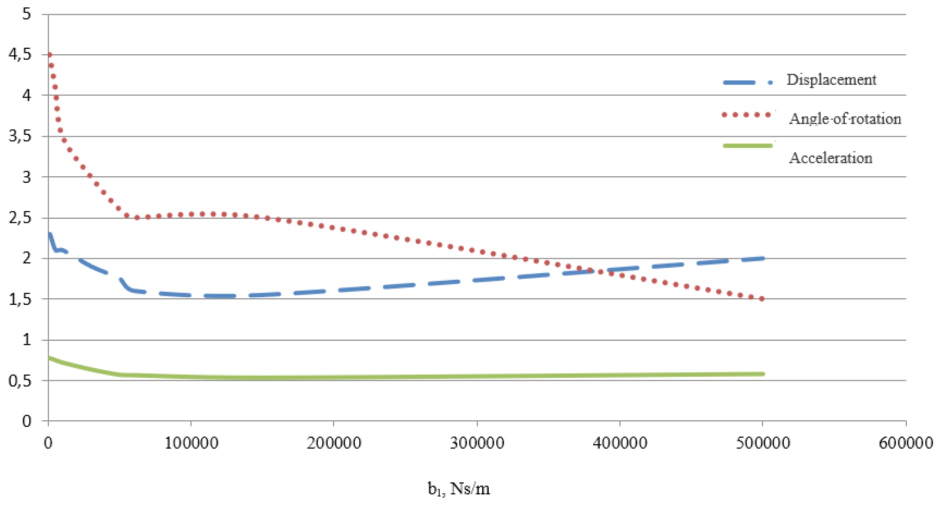


Pic. 4. Graphs of changes in the angles of rotation (galloping) (developed by the authors).



Pic. 5. Graph of changes in acceleration of the body over the bogie (developed by the authors).

Coloured images in Pics. 3–5 are designated as follow: Displacements: z_k (blue), z_1 (dotted line) and z_2 (red); angles of rotation: φ_k (blue), φ_1 (dotted line) and φ_2 (red).



Pic. 6. Dependence of the magnitudes of displacement, angle of rotation and acceleration on the resistance parameter b_1 (developed by the authors).

• Wheel sets are in constant contact with the rails.

• Perturbations from the right and left rails are assumed to be the same (the last assumption allows us to consider the vibrations as flat).

A design scheme has been developed (Pic. 2) to obtain a mathematical model of vibrations in the vertical longitudinal plane for a rolling stock having an axial formula 2–2 with two-tier suspension when passing along irregularities in the track.

The initial data of the design scheme shown in Pic. 2 were based on the operational and technical characteristics of rolling stock shown in Table 1.

Considering the design scheme as a two-mass system, we write down the systems of differential equations of vibrations:

– of the body:

$$m_k\ddot{z}_k+\beta_2(2\dot{z}_k-\dot{z}_1-\dot{z}_2)+c_2(2z_k-z_1-z_2)=0$$

$$J_{ky}\ddot{\varphi}_k+\beta_2 a_k(2a_k\dot{\varphi}_k-\dot{z}_1+\dot{z}_2)+c_2 a_k(2a_k\varphi_k-z_1+z_2)=0;$$

– of the first bogie:

$$m_t\ddot{z}_1-\beta_2(\dot{z}_k-\dot{z}_1+a_k\dot{\varphi}_k)-c_2(z_k-z_1+a_k\varphi_k)+$$
$$+2\beta_1\dot{z}_1+2c_1z_1=\beta_1(\dot{\eta}_1+\dot{\eta}_2)+c_1(\eta_1+\eta_2)$$

$$J_{ty}\ddot{\varphi}_1+2\beta_1a_t^2\dot{\varphi}_1+2c_1a_t^2\varphi_1=a_t(\beta_1(\dot{\eta}_1-\dot{\eta}_2)+c_1(\eta_1-\eta_2));$$

– of the second body:

$$m_t\ddot{z}_2-\beta_2(\dot{z}_k-\dot{z}_2-a_k\dot{\varphi}_k)-c_2(z_k-z_2-a_k\varphi_k)+2\beta_1\dot{z}_2+2c_1z_2=$$
$$=\beta_1(\dot{\eta}_3+\dot{\eta}_4)+c_1(\eta_3+\eta_4)$$

$$J_{ty}\ddot{\varphi}_2+2\beta_1a_t^2\dot{\varphi}_2+2c_1a_t^2\varphi_2=a_t(\beta_1(\dot{\eta}_3-\dot{\eta}_4)+c_1(\eta_3-\eta_4)).$$

The equations were solved in MathCad Prime 4.0 package using the Runge–Kutta numerical method (the computation step in MathCad software package is selected automatically). The study of the properties of the dynamic system was performed by changing the resistance parameter of dampers of the first stage of spring suspension in the range of values from 1000 to 500000 N•s/m, the values of the amplitude of vibrations of the system and the period being recorded.

A graphic interpretation of the computation results is shown in Pics. 3–5.

The analysis of the results has shown that the vibration period of the body and the bogies with any changes in the resistance parameter of the damper remains unchanged: for bogies it is of 0,57 s, and for the body it is of 0,50 s (Pic. 6).

At b_2 = 80000 N•s/m the parameters of resistance of axle box dampers b_1 are within the range from 80000 to 150000 N•s/m, so we can recommend them as rational parameters. Hydraulic vibration dampers with the specified parameters used for the rolling stock help to reduce wear and damage to running gears, improve ride comfort and traffic safety, as well as to reduce repair and maintenance costs.

CONCLUSIONS

Safety of movement and operation of rolling stock is due to a set of dynamic quality indicators: vibration protection, traffic safety and smoothness.

It was found that it is rational to determine the indicator of the vertical dynamics of the first F_{D1} and the second F_{D2} spring suspension stages depending on the speed of vehicle movement by a linear dependence of the type $y = ax + b$, as evidenced by the values of variances that tend to unity for each function obtained. As the speed increases, the dynamic factor decreases. For example, at a speed of 200 km/h, it decreases by 1,37, which indicates the need to revise the parameters of hydraulic dampers for high-speed rolling stock.

The disturbing factor acting on the considered dynamic system is deemed to be presented by a model which is a periodically changing function, for example, a sinusoid, the argument of which changes with a period corresponding to the rail length (multi-support beam). It has been established that the main characteristic of hydraulic vibration dampers is the dependence of the change in the resistance force of the hydraulic damper on the piston movement speed.

The selected design schemes of the vibration process in the vertical longitudinal plane during vehicle movement allow estimating the basic dynamic properties of the system under the accepted assumptions that do not contradict the theory of elasticity and dynamics of solids and do not significantly affect the calculation results.

Analysis of the results of the study of the dynamic model has shown that the vibration period for the first and second wheel sets remains unchanged for any changes in the viscosity parameter of the hydraulic dampers:

• For the first wheel set it is equal to 0,57 s, and for the second it is equal to 0,50 s.

• The vibration amplitude of the first wheel set is minimal at $b_1 = 50000$ and $b_2 = 80000$ N•m/s (with a further changes in ratio, this value begins to increase).

The use of hydraulic vibration dampers with the characteristics identified during the study for the rolling stock, besides satisfying the requirements for comfort, improvement of the running smoothness and traffic safety when transporting passengers and goods, helps to reduce wear and damage to the running gears of cars and, as a result, to diminish their repair and maintenance costs.

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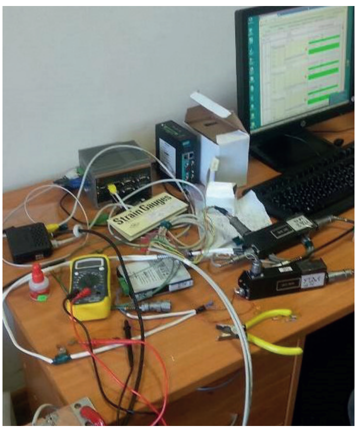
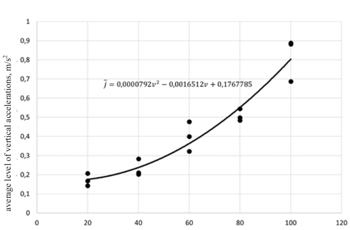
SCIENCE AND ENGINEERING

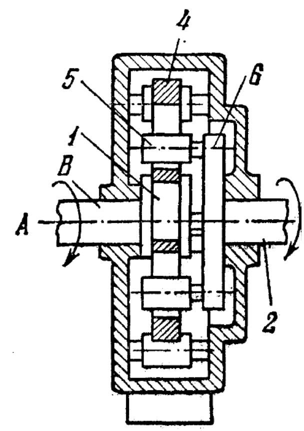


AUTOMATED MONITORING 182, 194

Automated structural health monitoring of bridges. Control measurements of horizontal displacements and of vertical settlements. Tensiometry and interpretation of its results.

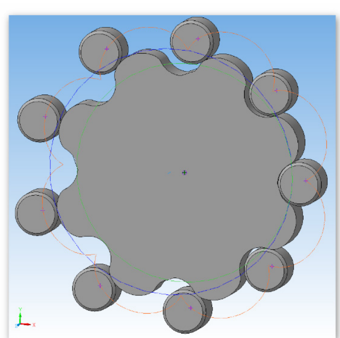
How is it possible to forecast optimal time for regular maintenance with in-vehicle accelerometer and what is the impact of the road surface?





MANUFACTURING AND TRAINING 200

Is it a universal tool? It is difficult to identify the boundary between the fields where digital modelling is equally in demand: design, manufacturing process, training of future engineers.



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Techniques for Processing Experimental Data for Structural Health Monitoring of Bridges

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ABSTRACT

Reliability of transport artificial structures and transit of trains at sanctioned speed should be provided with the necessary and sufficient load-bearing capacity, strength, rigidity, and stability of engineering structures.

The objective of this work was to substantiate the possibility of using well-known methods for controlling the stress-strain state of structures using automated systems of structural health monitoring of bridge spans.

It is extremely important regarding operation of transport artificial structures designed according to the standards of the first half of the 20th century.

Under these conditions, the experimental determination of the stress-strain state of bearing structures of bridges becomes the most important component of the task of a comprehensive assessment of physical wear and tear as well as of operational reliability of the structures. Monitoring the structural health and technical condition of bridges and planning of timely measures aimed at the repair, strengthening or reconstruction of spans will extend their service life and ensure safety during operation.

Maximum permissible deflections of spans under a movable temporary vertical load have been revealed since to ensure smooth movement of vehicles it is necessary to control horizontal longitudinal and transverse displacements of the top of the bridge piers, as well as vertical settlements.

The paper suggests methods of interpreting data measured by inclinometers and electric strain gauges, tensiometers to use them in an automated system for monitoring the structural health of railway bridges. The method of strain measurement is described in detail in the proposed options for installing resistance strain gauges on structures to measure tensile-compression stresses and longitudinal forces due to a temporary vertical load.

Monitoring the technical condition of bridge structures, using the methods for measuring deflections and deformations proposed by the authors in this article, will make it possible to assess the change in bearing capacity of the structure over the entire period of operation.

The study used regulations and experience of the Russian Federation and the Republic of Kazakhstan.

Keywords: *transport, infrastructure, artificial structures, bridge, bridge span, superstructure, deflection, stress, deformation, monitoring.*

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Текст статьи на русском языке публикуется в первой части данного выпуска.

INTRODUCTION

In accordance with the rules and regulations in force in many countries including the Russian Federation, reliability of transport artificial structures and transit of trains at sanctioned speed should be provided with the necessary and sufficient load-bearing capacity, strength, rigidity, and stability of engineering structures during the entire service life.

Long-term operation of transport artificial structures, designed according to the standards of the first half of the 20th century considering the then designed moving loads of that period, led to appearance of defects and malfunctions that affect the conditions of train running on bridge and speed of rolling stock. Therefore, the experimental determination of the stress-strain state of bearing structures of bridges becomes the most important component of the problem of a comprehensive assessment of physical wear and tear and operational reliability of the structure. Monitoring the structural health of bridges built according to the old design standards, and timely measures for repair, strengthening or reconstruction of spans, will extend their service life and ensure safety during operation.

The set of rules for design of bridge structures has stipulated the maximum permissible deflections of superstructures due to a movable temporary vertical load to ensure smooth movement of vehicles. During monitoring, it is necessary to control horizontal longitudinal and transverse displacements of the top of the bridge piers, as well as their vertical settlement.

Now, there are several methods for monitoring the technical conditions and structural health of superstructure of large and unique railway bridges.

The *objective* of this work was to substantiate the possibility of using well-known methods of control of the stress-strain state of structures using automated systems of structural health monitoring of bridge spans.

THE APPLIED METHODS

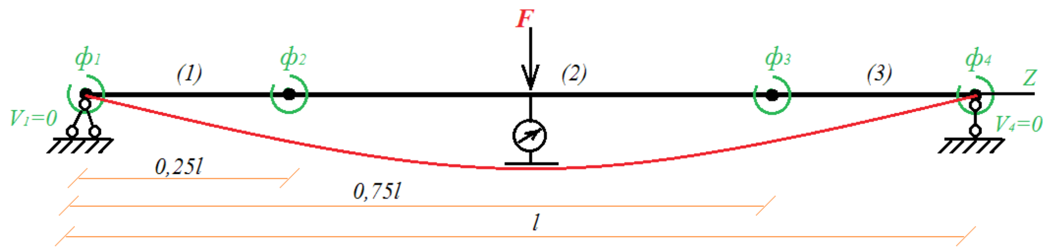
When developing automated monitoring systems, it is recommended to use electronic deflectometers (flexometers), inclinometers with an electrical output signal. To measure deformations (stresses), electrical resistance strain gauges (tensiometers) are used: strain gauge sensors or strain gauge resistors. The deflections of bridge spans under load are determined using geodetic instruments, mechanical and electronic deflectometers with wire connection, as well as inclinometers: tilt and angular displacement sensors. Currently, though being relatively new devices, inclinometers allowing the conversion of a tilt angle in a proportional output electrical signal have been adopted for widespread industrial use [1, p. 20].

The use of mechanical and electronic deflectometers with wire connection in testing flyovers can significantly increase the accuracy and simplify the process of measuring deflections in comparison with geodetic measurements. However, the need to have a rigid connection with the ground, the so-called reference point, relative to which the measurements take place, makes it impossible to use them to measure the deflections of bridge spans located over water obstacles [1, p. 20].

In recent years, with long-term measurements (monitoring) of deflections of bridge spans, it became possible to use inclinometers: tilt and angular displacements sensors.

The analysis of the stress state of elements of full-scale structures, as a rule, is performed based on measuring deformations on the surfaces of the studied objects. Among the experimental methods for measuring deformations (mechanical, acoustic, electrical, optical, moiré, mesh methods, etc.), most researchers prefer measurements using electrical resistance strain gauges: strain gauge sensors or strain gauge resistors [2, p. 13]. The strain gauge best meets the cost-effectiveness criterion, having the optimal combination of characteristics traditionally used for evaluating a strain gauge system. These characteristics are:

- Calibration constant of the sensor, which must have temperature and time stability.
- The error in measuring deformations, which should not exceed 1 μm/m in the range of deformations ± 5 % (± 50 000 μm/m).
- Length and width of the sensor that must be small enough to adequately measure the deformation at the point.
- Inertia of the sensor, which should be small enough to register high-frequency dynamic processes.
- Linearity of the sensor response within the entire measurement range.
- Efficiency of the sensor and associated devices.
- Minimum requirements for skills of the operating personnel required to install equipment and perform measurements [2, p. 13].



Pic. 1. Design scheme of the superstructure (Report on research and development work on the topic «Creation of a monitoring system for potentially dangerous objects of railway transport using GLONASS/GPS/GALILEO systems». Moscow, FSUE ZashchitaInfoTrans, 2020, 154 p.).

Currently, strain gauges are used in more than 80 % of stress state studies conducted in the industry of the USA, Japan, and other developed countries. Besides, strain gauges are widely used as sensitive elements of sensors designed to measure forces, moments and pressure [2, p. 13].

RESULTS

Methodology for Interpreting Data Measured by Inclinometers

It is known that the maximum deflection of the bridge span structure (in the middle of the span) should not exceed the limiting value:

$$f_{max} \le f_u, \qquad (1)$$

wher f_u is limiting deflection value, regulated, e.g. in the Russian Federation and the Republic of Kazakhstan, respectively, by clauses 5.43 of SP 35.13330.2011 [1] and 5.6.1 of SP RK 3.03-112-2013 [2].

According to the requirements of clause 5.43 of SP 35.13330.2011 and clause 5.6.1 of SP RK 3.03–112–2013, vertical elastic deflections of span structures, calculated under the action of a movable temporary vertical load, for railway bridges should not exceed the values:

$$\frac{1}{800-1,25\cdot l}\cdot l, \text{ but not more than } \frac{1}{600}\cdot l, \qquad (2)$$

where l is calculated span length, m.

For the span structure of a railway bridge l = 126 m, the limiting deflection value, regulated by clause 5.43 SP 35.13330.2011 and clause 5.6.1 SP RK 3.03-112-2013, is:

$$\frac{1}{800-1,25\cdot 126}\cdot 126 = 0,196 \text{ m.}$$

When determining the deflection of structures by the direct method, by measuring the vertical displacement in the central part of the span, it is necessary to fix the displacement sensor on a fixed support. In most cases, especially with long spans, this is not possible. In practice, indirect methods of measuring the quantities are mainly used, according to which the deflections of the structure are calculated. In this case, the deflection is proposed to be determined indirectly, through the measured values of the angles of rotation of the structural nodes.

In case of determining the deflection by an indirect method, through the measured values of the angles of inclination of the structural nodes, the unknown function of deflection along the length of the beam can be determined using the methods of strength of materials [2, p. 28], considering the differential dependence of the deflection on the angle of rotation:

$$dv/dz = \phi(z). \qquad (3)$$

The proposed method for determining deflections through the angles of inclination is applicable for beam elements with one span and two rocking piers (Pic. 1).

The deflections of the beam over the piers equal to zero are taken as the boundary conditions. The method gives the greatest convergence in the case when the points of measurement of the angles of rotation are made at a distance from the piers equal to 25 % of the span length. The disadvantages of this method refer to the constraints imposed on the sensors' attachment points for measuring the angles of rotation. The advantages refer to a high degree of convergence (deviation is no more than 5 %) and the use of a small number of sensors for measuring the

[1] SP [here and further SP means Code of practice for construction industry of the Russian Federation] 35.13330.2011. Bridges and pipes. Updated edition of SNiP [here and further SNiP means Construction standards and rules] 2.05.03-84. [Electronic resource]: https://docs.cntd.ru/document/1200084849. Last accessed 24.05.2021.

[2] SP RK [here and further SP RK means Code of practice for construction industry of the Republic of Kazakhstan] 3.03-112-2013. Bridges and pipes. Astana, 2013. [Electronic resource]: https://www.egfntd.kz/upload/NTD/%D0%A1%D0%9F%20%D0%A0%D0%9A/113%20%D0%A1%D0%9F%20%D0%A0%D0%9A%203.03-112-2013.pdf. Last accessed 24.05.2021.

Table 1

No.	Z_2, mm	Z_3, mm	α_{IN2}, arc. sec.	α_{IN2}, arc sec.	φ_2, radian	φ_3, radian	$v\left(\frac{l}{2}\right)$, mm
1	31500	94500	-18	-18	$-8{,}722 \cdot 10^{-5}$	$-8{,}722 \cdot 10^{-5}$	-3,14
2	31500	94500	-360	-360	$-1{,}744 \cdot 10^{-3}$	$-1{,}744 \cdot 10^{-3}$	-62,80
3	31500	94500	-1152	-1152	$-5{,}582 \cdot 10^{-3}$	$-5{,}582 \cdot 10^{-3}$	-200,96
4	31500	94500	-1152	-1152	$-5{,}582 \cdot 10^{-3}$	$-5{,}582 \cdot 10^{-3}$	-25,63
5	31500	94500	-1152	-1152	$-5{,}582 \cdot 10^{-3}$	$-5{,}582 \cdot 10^{-3}$	-197,23
6	31500	94500	-1152	-1152	$-5{,}582 \cdot 10^{-3}$	$-5{,}582 \cdot 10^{-3}$	200,96
7	31500	94500	-1152	-1152	$-4{,}846 \cdot 10^{-3}$	$-5{,}330 \cdot 10^{-3}$	162,45

angles of rotation. In this method, it is assumed that it is sufficient to describe the deflection function of a beam element with one span by a third-order polynomial with four unknown coefficients:

$$v(z) = az_3 + bz_2 + cz + d. \qquad (4)$$

From the differential dependence (3), the function of the angles of rotation is determined by an expression of the form:

$$\phi(z) = 3az_3 + 2bz + c. \qquad (5)$$

Finding the values of unknown coefficients requires solving a system of four equations:

$$\begin{cases} v(z_1) = az_1^3 + bz_1^2 + cz_1 + d \\ v(z_4) = az_4^3 + bz_4^2 + cz_4 + d \\ \varphi_2 = \varphi(z_2) = 3az_2^2 + 2bz_2 + c \\ \varphi_3 = \varphi(z_3) = 3az_3^2 + 2bz_3 + c. \end{cases} \qquad (6)$$

After solving the system of equations (6), the values of the beam deflections are calculated according to the dependence (4).

Solving the system of equations (6), to find the unknown coefficients, we use the boundary conditions (Pic. 1) $v(z_1) = 0$; $v(z_4) = 0$; $z_1 = 0$; $z_4 = l$ (we will not use the boundary conditions $z_2 = ¼ \cdot l$ and $z_3 = ¾ \cdot l$ since some deviations are possible when installing the sensors measuring angles of rotation). Solving the system of equations (6) under the given boundary conditions, we obtain the following expressions for the unknown coefficients:

$$d = 0;$$

$$a = \frac{\phi_3(2z_2 - l) + \phi_2(l + 2z_3)}{3(z_3^2 - z_2^2)(2z_2 - l) + 2(l^2 - 3z_2^2)(z_3 + z_2)};$$

$$b = \frac{\begin{bmatrix} \phi_3(2z_2 - l) + \\ +\phi_2(l + 2z_3) \end{bmatrix}(l^2 - 3z_2^2)}{\begin{bmatrix} 3(z_3^2 - z_2^2)(2z_2 - l) + \\ +2(l^2 - 3z_2^2)(z_3 + z_2) \end{bmatrix}(2z_2 - l)} + \frac{\phi_2}{(2z_2 - l)}; \qquad (7)$$

$$c = \frac{\phi_2(4z_2 - l)}{(2z_2 - l)} - \frac{\begin{bmatrix} \phi_3(2z_2 - l) + \\ +\phi_2(l + 2z_3) \end{bmatrix}(l^2 - 3z_2^2)}{\begin{bmatrix} 3(z_3^2 - z_2^2)(2z_2 - l) + \\ +2(l^2 - 3z_2^2)(z_3 + z_2) \end{bmatrix}(2z_2 - l)}.$$

Substituting the values of the coefficients (7) into the formula (4), we obtain the following expression for determining the deflection in the middle of the span:

$$v\left(\frac{l}{2}\right) = \frac{l^2\left(18z_2^2 - 14z_2 l + l^2\right)\begin{bmatrix} \phi_3(2z_2 - l) + \\ +\phi_2(l + 2z_3) \end{bmatrix}}{\begin{matrix} 24(z_3^2 - z_2^2)(2z_2 - l)^2 + \\ +16(l^2 - 3z_2^2)(z_3 + z_2)(2z_2 - l) \end{matrix}} + \frac{\phi_2 l(16z_2 - 3l)}{4(2z_2 - l)}. \qquad (8)$$

For the considered span of a railway bridge, l = 126 m. The values z_2 and z_3 are measured after installing tilt angle meters on the span structure. It should also be noted that the values of the angles of rotation ϕ in radians measured by inclinometers are substituted into expression (8):

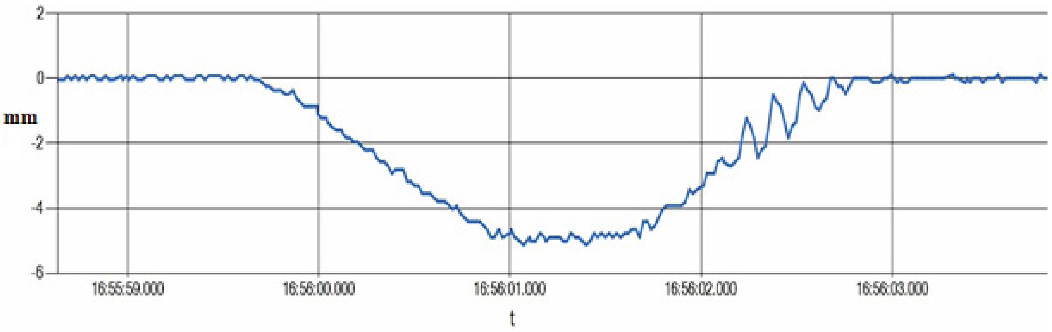
$$\phi = \frac{\pi\alpha_{IN}}{3600 \cdot 180}, \qquad (9)$$

where α_{IN} is the value of the angle of rotation according to the readings of the IN-D3ts-3600 inclinometer in arc seconds.

Some values of the deflections calculated by expression (8) at various values of the initial and measured parameters are given in Table 1.

When conducting trial operation of the monitoring system, it is advisable to provide software with a module for visualising the measured data [3–7]. It is advisable to visualise the data obtained from inclinometers by constructing diagrams of the deflections of the bridge span during rolling stock movement. An example of a deflection diagram for a split span is shown in Pic. 2 [8–10].

It is recommended to evaluate the performance of the structures according to the actually measured values of the deflection at each passage of rolling stock over the bridge in accordance with Appendix V to SP



Pic. 2. An example of a deflection diagram of a split span structure (Technical report. Inspection and testing of the railway overpass according to the scheme 16,5+23,6+16,5 m over the road of the II category at the 56th km (kilometric point PK9 + 50) of Kulsary–Tengiz railway line. Almaty, JSC KazATK n.a. M. Tynyshpaev, 2018, p. 126).

Table 2

Threshold values of controlled deflections in terms of «norm/alarm/accident»

No.	Indicator name	f_{max}, mm	$K = f_{max}/f_u$
1	Threshold value of the boundary «norm/alarm»	0…137,2	0…0,7
2	Threshold value of the boundary «alarm/accident»	137,2…196	0,7…1

* The given numerical values are refined according to the results of accumulation and statistical analysis of the values of deflections of the middle of the span, measured during the monitoring process, arising under the actually planned moving load.

79.13330.2012[3] and with Appendix G to SP RK 3.03-113-2014[4] using a coefficient calculated by the formula:

$$K = f_{max}/f_u, \quad (10)$$

where f_{max} is maximum deflection value in the middle of the span determined according to expression (8);

f_u is limiting deflection value in conformity with the clause 5.43 SP 35.13330.2011 and the clause 5.6.1 SP RK 3.03-112-2013.

The values of the coefficient *K*, greater than unity, calculated from the values of maximum deflections, unambiguously indicate a significant difference in operation of the structure elements as compared to the assumptions adopted in the calculations (the elements of the structure do not work within elastic limits). In these cases, it is urgent to develop measures to ensure reliable operation of elements. For the period of trial operation, it is recommended to accept the threshold values of controlled deflections, in terms of «norm/alarm/accident», given in Table 2.

Method for Interpreting Data Measured by Strain Gauges

According to the requirements of clauses 6.9, 6.18 SP 79.13330.2012[3] and clauses 7.2.6, 7.3.6 SP RK 3.03-113-20146[4], internal forces (forces, moments) in structural parts and elements of railway bridges under a movable temporary vertical load during dynamic tests (when rolling stock passes), should not exceed the internal forces arising under the temporary vertical load, determined by the calculation method according to the current regulatory documents.

To determine the forces arising from a moving temporary vertical load during the passage of a rolling stock, it is necessary to measure deformations, and then, using the law of deformation for the material in question, to calculate stresses and forces. Deformations are measured by strain gauges, which are easy to attach to the surface of the structure's material.

Strain gauges (tensiometers) are complex electrical devices that allow strain measurement. Since the measurement range of resistance of the strain gauge is very small, it reaches for a 120 Ohm sensor about 0,00024 Ohm for a strain of 1 μm/m. This means that a deformation of 1000 μm/m will change the

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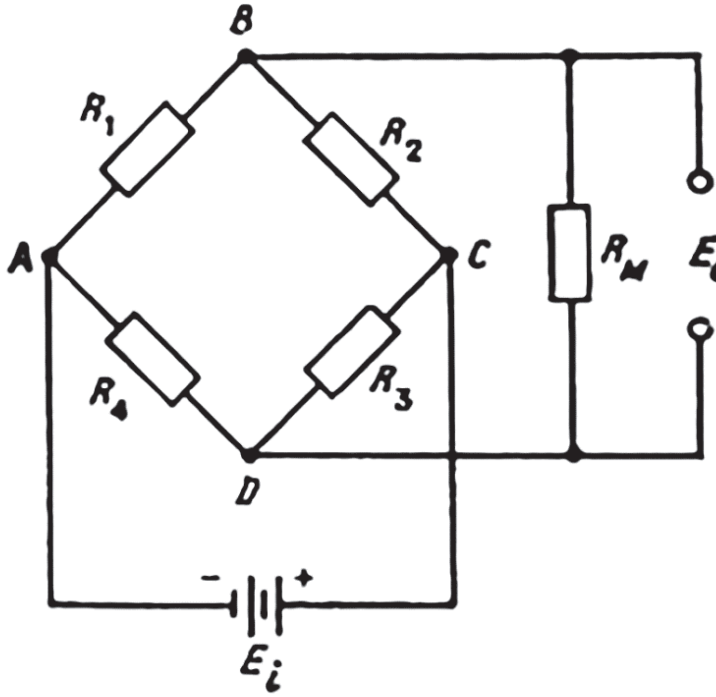
[3] SP 79.13330.2012. Bridges and pipes. Inspection and testing rules. Updated edition of SNiP 3.06.07-86. [Electronic resource]: https://docs.cntd.ru/document/1200095530. Last accessed 24.05.2021.

[4] SP RK 3.03-113-2014. Bridges and pipes. Inspection and testing rules. Astana, 2014. [Electronic resource]: https://www.egfntd.kz/upload/NTD/%D0%A1%D0%9F%20%D0%A0%D0%9A/114%20%D0%A1%D0%9F%20%D0%A0%D0%9A%203.03-113-2014+.pdf. Last accessed 24.05.2021.



Pic. 3. Wheatstone bridge with constant voltage source [2, p. 38].

resistance of 120 Ohm sensor to 0,240 Ohm. To measure such small voltages, bridge circuits are most often used in measuring instruments. These circuits operate from a direct current or voltage source.

Pic. 3 shows a circuit of operation of a measuring bridge powered from a DC voltage source (Wheatstone bridge). Wheatstone Bridge is depicted by an equilateral rhombus, where the sides are branches, and the tops are the nodes of the bridge. A voltage source and four resistor strain gauges (R_1, R_2, R_3, R_4) form a bridge. R_M resistor allows electrical current to flow through the bridge without wasting energy.

The output voltage E_0 of the measuring bridge (the voltage difference between points B and D) is determined by the relation [3, p. 211]:

$$E_0 = \frac{(R_1R_3 - R_2R_4)}{(R_1 + R_2)(R_3 + R_4)} \bullet Ei. \qquad (11)$$

From equation (11) it follows that E*0* = 0, if the condition is satisfied:

$$R_1R_3 = R_2R_4 \text{ or } R_1/R_2 = R_4/R_3. \qquad (12)$$

If equality (12) is observed, the bridge is called balanced. This means that the small out-of-balance voltage caused by the change in resistance is measured relative to zero or near zero. This signal can easily be amplified to a high level for subsequent recording.

The output voltage E_0 occurs when the resistance of the resistors R_1, R_2, R_3, R_4 changes by the values ΔR_1, ΔR_2, ΔR_3, ΔR_4. Such changes in resistance arise, for example, due to deformation or thermal expansion of strain gauges. In accordance with equation (11), the change in the output voltage E_0 caused by these small changes in resistance is [2, p. 42]:

$$E_0 = \frac{r}{(1+r)^2} \bullet \left(\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3} - \frac{\Delta R_4}{R_4}\right)(1-\eta) \bullet Ei, \qquad (13)$$

where η is term characterising the error (nonlinearity of the bridge), described by the ratio:

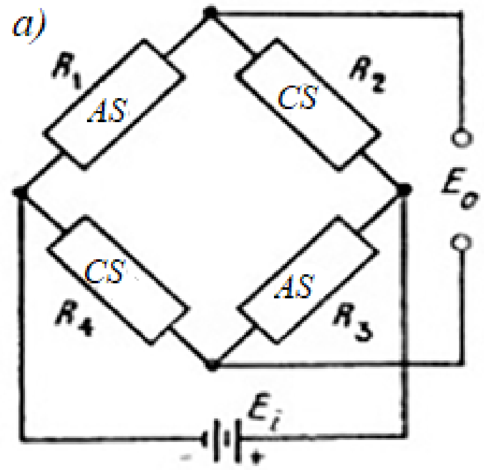
$$\eta = \frac{1}{\left(1 + \frac{1+(1+r)}{\frac{\Delta R_1}{R_1} + \frac{\Delta R_4}{R_4} + r\left(\frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3}\right)}\right)}, \qquad (14)$$

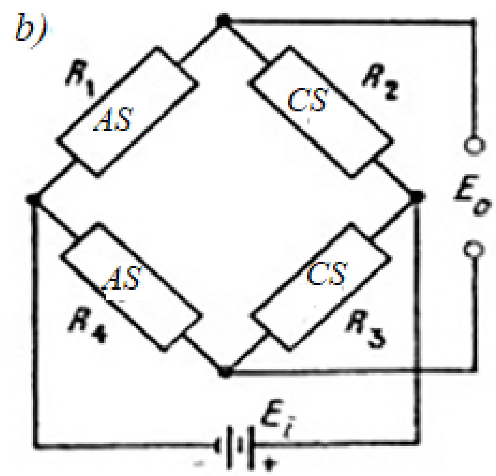
where r is the ratio of resistances R_2/R_1 or R_3/R_4.

From expressions (13) and (14), the properties of the measuring bridge that are important for practical applications follow:

• Deformations acting on the strain gauges of the opposite branches of the bridge are summed up within the limits of measuring bridge.

• Deformations acting on the strain gauges of adjacent bridge branches are subtracted within the limits of measuring bridge.





Pic. 4. Options for including strain gauges in a full bridge when measuring deformations [2, p. 56]. AS – active sensor; CS – compensation sensor. a) to measure tensile-compressive deformations εN; b) to measure bending deformations εM.

• The bridge error η (nonlinearity) is proportional to the algebraic sum of all deformations perceived by the strain gauges within the limits of measuring bridge [2, p. 43].

For the simple case there is the equality of all four resistances (i.e., $r = 1$). As it is easy to see from expressions (13) and (14), the term corresponding to the error η turns into zero when ΔR_1 and ΔR_4 are equal in magnitude and opposite in sign when $\Delta R_2 = \Delta R_3 = 0$, and when ΔR_2 and ΔR_3 are equal in magnitude and are opposite in sign with $\Delta R_1 = \Delta R_4 = 0$. This result is important since the nonlinear operation of the bridge is not essential when two active sensors are used simultaneously in opposite branches ΔR_1 and ΔR_4 or ΔR_2 and ΔR_3. With one active sensor, nonlinearity leads to an error of 1 % if $\Delta R_1/R_1$ is less than 0,02 (a value usually corresponding to a strain of 10000 μm/m) [2, p. 43].

The influence of the load resistor R_M on the value of the ideal output voltage E_0 can be determined by analysing the resistance of the load connected in series with the bridge. The result is expressed as:

$$E_{01} = \frac{R_M}{R_M + R_B} \bullet E_0 = \frac{E_0}{\left(1 + \frac{R_B}{R_M}\right)}, \quad (15)$$

where E_{01} is actual output voltage and the value is the effective bridge resistance [2, p. 43]:

$$R_B = \frac{R_1 R_2}{(R_1 + R_2)} + \frac{R_3 R_4}{(R_3 + R_4)}. \quad (16)$$

As follows from equation (16), if all the bridge branches have the same resistance R_g then $R_B = R_g$. Thus, with $R_M > 100R_g$ for a bridge with the same branches, the error does not exceed 1 %. This condition is easily implemented with most commercial measuring instruments, since R_M usually exceeds $100R_g$. It should be noted that the considered effect of the load can be considered by the appropriate calibration technique [2, p. 43].

Pic. 4 shows the circuits of integration of strain gauges in the measuring bridge according to the full-bridge circuit when using two active and compensation sensors in the four branches of the bridge used in the practice of measuring the deformations of structures. In this case, active sensors are glued to the structure in a diametrically opposite way (the same is done with compensation sensors).

Option *a* is used to measure tensile-compressive deformations ε_N arising in the structure of the main beam of the bridge span during the passage of rolling stock. Option *b* is used to determine sensitivity of the measuring system to bending deformations ε_M. It should be noted that from the point of view of sensitivity of the output voltage arising on the measuring bridge during deformation, options *a* and *b* are absolutely equivalent to each other, which follows from the analysis of expression (13).

In these options for including strain gauges in the measuring bridge, strain gauges are used that have equal resistance (from the same batch), so that *r* is equal to 1. The main advantages of this version of the bridge are temperature compensation, linearity (if all ΔR increments are the same in magnitude) and the possibility of designing measuring circuits devoid of undesirable sensitivity to bending or axial loading.

Since a strain gauge circuit is used to measure very small changes in resistance occurring in a bridge sensor, then any influence that can change the resistance of various components of the bridge is significant because it affects the magnitude of the output voltage. The main components of the measuring circuit are strain gauges (strain resistors), connecting wires and connection points (both soldered and terminal connections). Although solder connections, contacts and terminals can introduce significant errors, these problems can be solved by minimising them and using appropriate calibration techniques.

The more complex problem is associated with electrical noise. Electrical noise induced on the measuring bridge and signal lines by magnetic fields from the power supply line might be a serious problem. The magnitude of the voltage induced in the signal transmission lines by the current flowing in the power supply line is proportional to the area of the loop formed by the lines and is inversely proportional to the distances between the lines. The following precautions should be taken to reduce noise [2, p. 66]:

1. To reduce the area of the loop, only twisted conductors should be used. In twisted connection wires, the induced noise is practically the same in both wires, which leads to a significant reduction in common-mode noise. The length of the conductors should be kept to a minimum by placing the differential amplifier close to the strain gauge bridge. Excessively long conductors should not be coiled to avoid induction [2, p. 66].

2. Only shielded cables should be used. The shield must be connected to the negative pole of the power supply. In this case, there are no currents flowing from the «ground», and the shield keeps the potential close to zero. The power supply must not be connected to ground of the device to avoid ground loops in the power supply [2, p. 66].

3. It is necessary to use only differential amplifiers with effective general noise suppression [2, p. 66].

A strain measurement system typically includes one or more strain gauges, bridge resistors, allowing to build a bridge circuit, bridge ballast resistors, one or more power sources, an amplifier, and a recording device. Each of the listed elements contributes to the resulting sensitivity; therefore, calibration of the entire system is preferable of compared with an expensive calibration of each of its components [2, p. 66].

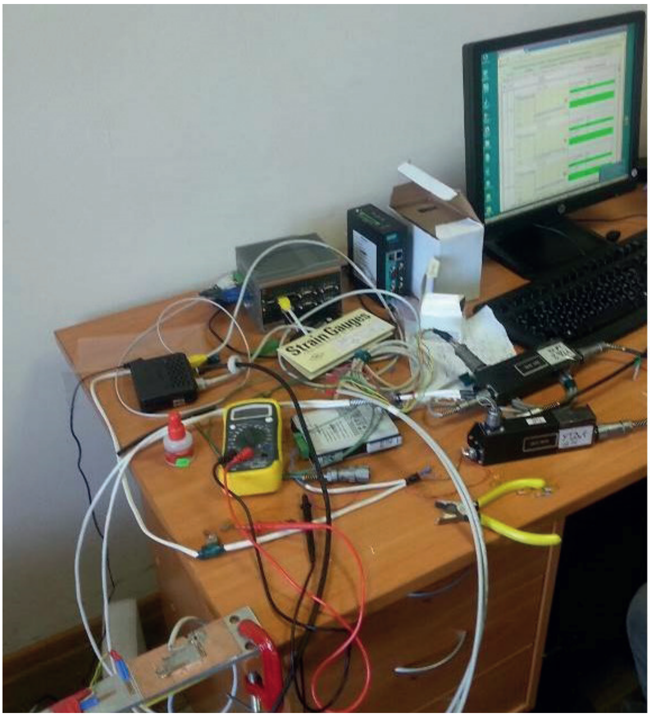
The readings of the recording device d_r are associated with the deformation in each branch of the bridge by the following relationship [2, p. 66]:

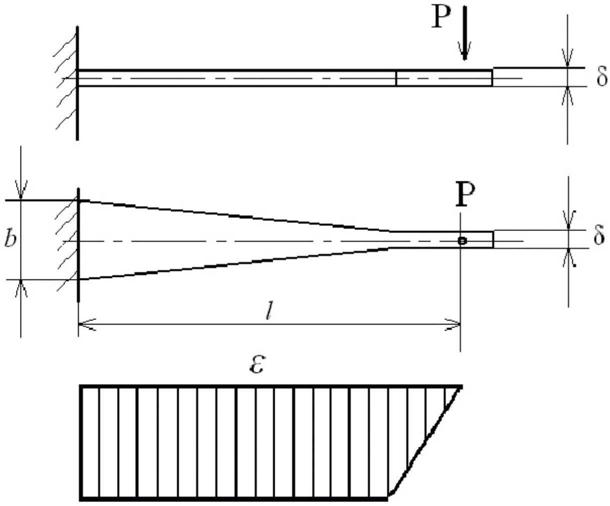
$$d_r = \frac{rGEi(1-\eta)S_g}{(1+r)^2}(\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4) = S_R\varepsilon_B, \qquad (17)$$

where *r* is ratio of resistances R_2/R_1 or R_3/R_4;

G –coefficient of amplification of the amplifier and the recording device;

E_i – bridge supply voltage;





Pic. 5. Scheme of a calibrated cantilever beam of equal resistance[5].

η – non-linear term;

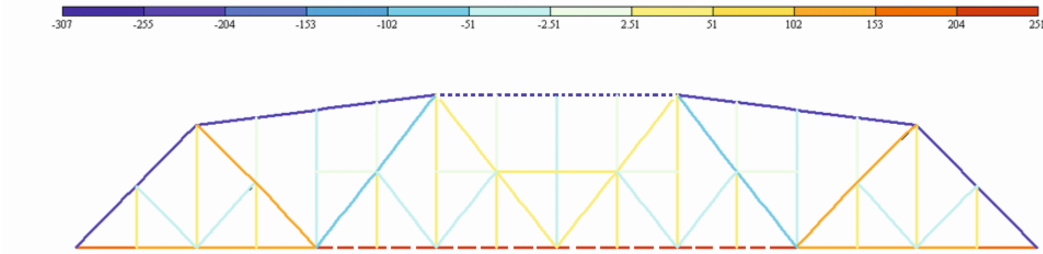
S_g – coefficient of tension-sensitivity, or of sensitivity of the strain resistor (the parameter of the strain resistor, provided for in its specifications, reflecting the behaviour of the «grid/base/glue» system), is defined as the ratio of the increment of resistance of the glued strain gauge to the relative deformation of the sample measured in the direction of the axis of the strain gauge:

$$S_g = \frac{\Delta R / R}{\Delta l / l} = \frac{\Delta R / R}{\varepsilon}, \qquad (18)$$

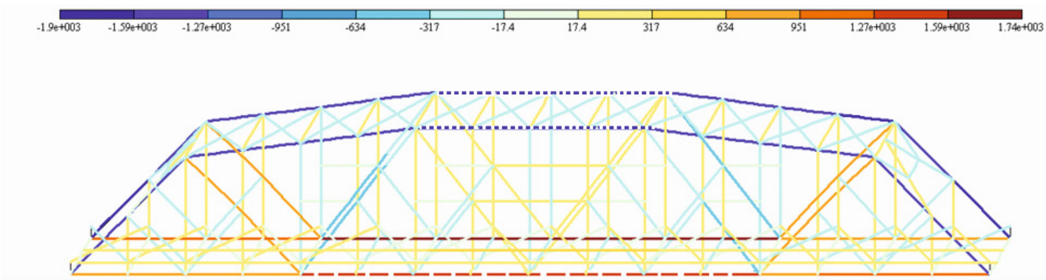
where ε_i is deformation in the i-th branch of the bridge;

S_R – overall sensitivity of the system;

[5] Report on research and development work on the topic «Creation of a monitoring system for potentially dangerous objects of railway transport using GLONASS/GPS/GALILEO systems». Moscow, FSUE ZashchitaInfoTrans, 2020, 154 p.



Pic. 6. Mosaic chart of longitudinal forces in the elements of the main truss of the span structure (SpS 2) under the permamanent load N_{per} (own weight of the structure and the weight of bridge floor according to reference guide). Blue colour (dot line) at the top (-307 – -255) indicates compressive internal forces, red colour (dash line) at the bottom (204–251) indicates tensile forces[5] (in t).



Pic. 7. Mosaic chart of longitudinal forces in the elements of bridge span structures under the joint effect of permanent load and temporary vertical load (N_v + N_{per}). Blue colour (dot line) at the top (-307 – -255) indicates compressive internal forces, red colour (dash line) at the bottom (204–251) indicates tensile forces[5] (in t).

ε_B – efficient deformation measured by the device.

Efficient deformation ε_B is expressed as follows:

$$\varepsilon_B = \varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4 = n_\varepsilon, \qquad (19)$$

where $n = 1$ for one active sensor (*AS*), $n = 2$ for two *AS*.

The sensitivity of the measuring system of the prototyped monitoring system was determined by the mechanical calibration method. The calibration was carried out as follows: the previously known deformation values were fed to the input of the measuring system, and the system's responses to these influences were recorded at the output.

The source of the reference deformation was a calibrated cantilever beam of equal resistance (Pic. 5). Strain gauges were glued on the beam of equal resistance according to the scheme *b* of Pic. 4, connecting wires (length, type etc.) corresponded to those used in the measurements of bridge structures [11–12].

The value of deformation of the beam of equal resistance was determined according to the formula:

$$\varepsilon = \frac{6Pl}{E\delta^2 b}, \qquad (20)$$

where *P* is concentrated force acting on the end of the console;

l – distance from the point of application of the force *P* to any arbitrary cross-section;

b – width of the section at the point of rigid fixing of the beam;

δ – thickness of the beam;

E – modulus of elasticity of the material of the beam.

The strain gauge sensitivity coefficient for the used batch of strain gauges (S_g = 2,09) was set in the basic settings of the recording device. After connecting the bridge circuit to the module, the measuring bridge was balanced, the indicator of the device was set to zero position. The load was created by weights that were applied to a weight-lifting suspension put on the free end of the beam. The weights were selected so that the reference deformations calculated by formula (20) were 100, 200, 500, 1000 μm/m. The proportionality coefficient (scale division of the measuring device) for the calibrated measuring system was determined by the formula:

$$K_{Pr} = \varepsilon cal/dr. \qquad (21)$$

During the calibration, it was found that the system has a linear coefficient of total sensitivity

Table 3

Threshold values of controlled deflections in terms of «norm/alarm/accident»

No.	Indicator name	N, t	$K = N_{max}/N_{tens}$
1	Threshold value of the boundary «norm/alarm»	0…1190	0…0,8
2	Threshold value of the boundary «alarm/accident»	1190…1489	0,7…1

* The given numerical values are refined according to the results of accumulation and statistical analysis of the values of longitudinal forces measured in the process of monitoring, arising under the actually planned moving load.

in the range of deformation measurements from 100 to 1000 μm/m, in this range the proportionality coefficient K_{Pr} = 2000.

When the deformation control system is launched at the tested object, the installed measuring bridges are balanced for each module used (by setting the instrument indicators to zero position). The calculation of the magnitude of the measured tensile-compression deformations ε_N arising during passage of rolling stock under the temporary vertical load during the monitoring process is carried out according to the following formula:

$$\varepsilon_N = d_r \bullet K_{Pr} = 2000\ \mathrm{dr},\ [\varepsilon_N] = [\mu\mathrm{mk/m}]. \qquad (22)$$

The calculation of tensile-compressive stresses σN, arising during passage of rolling stock under the temporary vertical load is carried out using the values of deformations εN measured in this way according to Hooke's law:

$$\sigma_N = \frac{\varepsilon_N E}{1000000},\ [\sigma_N] = [MPa], \qquad (23)$$

where E – Young's modulus of the material of the structure *[E] = [MPa]*.

The elastic modulus when calculating stresses by formula (23) is taken equal to 206000 MPa, according to the data specified in table 8.13 of SP 35.13330.2011[1].

The calculation of the longitudinal forces N arising in the structural elements of the main beam of the lower chord of the truss of the span structure of the bridge during passage of rolling stock under the temporary vertical load is carried out according to the calculated values of stresses σ_N according to the formula:

$$N = 100 \bullet \sigma_N \bullet S,\ [N] = [m], \qquad (24)$$

where S is cross-sectional area of the structure, m^2.

According to the available design documentation, the cross-sectional area of the structure of the main beam of the lower chord of the truss of the span structure of the railway bridge on the controlled section is equal to:

$$S = \frac{4 \bullet 140 \bullet 12 \bullet 2 + 2 \bullet 1000 \bullet 14 + 2 \bullet 1000 \bullet 12}{1000000} = 0{,}065\left[m^2\right].$$

It is recommended to evaluate the performance of the structures of the bridge according to the measured values of deformations, tensile-compression stresses and longitudinal forces arising in the structure during passage of rolling stock in accordance with Appendix *B* of SP 79.13330.2012[3], using a coefficient calculated by the formula:

$$K = \frac{\varepsilon_{N\max}}{\varepsilon_{tens}} = \frac{\sigma_{N\max}}{\sigma_{tens}} \frac{N_{\max}}{N_{tens}}, \qquad (25)$$

where ε_{Nmax}, σ_{Nmax}, N_{max} are, respectively, the maximum measured values of deformations, tensile-compression stresses, and longitudinal forces under the temporary vertical load;

ε_{tens}, σ_{tens}, N_{tens} are, respectively, the values of deformations, tensile-compression stresses, and longitudinal forces under a temporary vertical load, determined by calculation according to the current regulatory documents.

The values of K coefficient, greater than unity, indicate a loss of bearing capacity due to high corrosive wear of the structure (a decrease in the working area of the beam section). In this case, it is urgent to develop measures to ensure reliable operation and reinforcement of structural elements.

According to the results of calculating the longitudinal forces in the elements of the main truss of the bridge span structure [13, p. 124], performed by the finite element method, the maximum design forces from the action of a temporary vertical load in the controlled region are:

$$N_{tens} = (N_v + N_{Per}) - Nv = 1740–251 = 1489\ \mathrm{m}.$$

The calculation was carried out by mathematical modelling according to the existing design documentation for the structure, without considering the actual wear of the structures, with tolerances in accordance with SP 35.13330.2011 and SP RK 3.03-112-2013. From the mosaic chart of longitudinal forces (Pics. 6, 7), it can be seen that, according to the calculation, the lower chord of the truss suffers the greatest permanent and temporary tensile forces.

The recommended threshold values for the period of trial operation in terms of «norm/alarm/accident» for the measured longitudinal forces under the temporary vertical load are suggested in Table 3.

BRIEF CONCLUSION

The authors analysed the experimental and design data of more than 30 bridges and flyovers [14–17]. The methods proposed in this work are recommended to be used in development of automated systems for monitoring the structural health and technical condition of span structures of large and unique railway bridges.

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Using In-Vehicle Monitoring Data to Assess Road Conditions of Traffic Flows

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ABSTRACT

Developments in adaptive systems for maintenance and repair of automotive vehicles set the task of monitoring the conditions of their operation. One of the main factors determining these conditions is the type of road surface.

The article describes the results of identification of the type (and condition) of the road surface obtained by theoretical and experimental methods based on the analysis of vertical accelerations recorded on the vehicle body.

The purpose of research was to provide a possibility of continuous monitoring of the type of road surface on which a vehicle is driving, with the subsequent application of the obtained data to correct maintenance intervals. The results of experiments have shown the dependence of the vertical acceleration of the body on the micro-profile of the road surface. The described experimentally obtained profiles of vertical accelerations refer to different types of road surface in different conditions. For quantitative assessment, it is proposed to calculate the average level of accelerations as an integral average over a certain time interval.

The results of the experiments have allowed to substantiate the empirical dependence of the average level of accelerations on speed of a vehicle. Based on this dependence, a method is proposed for recalculating the current values of the average levels of accelerations obtained at different speeds into values adjusted to the base speed to ensure the possibility of their comparison.

It is shown that based on the values of average acceleration levels obtained through operation monitoring regarding a previously known type of road surface, it is possible to determine its condition. A short algorithm is formulated for practical implementation and assessment of road conditions of traffic flows. As for hardware, it is proposed not to equip a vehicle with additional sensors but to use operational standard accelerometers as part of in-vehicle emergency call systems, e.g., ERA-GLONASS equipment units.

Keywords: transport, road transport, vehicle operation monitoring, operating conditions, adaptive maintenance systems, GLONASS, ERA-GLONASS.

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INTRODUCTION

In current conditions characterized by downsizing of motor enterprises and an increase in the share of vehicles operated by individual owners [1], the scheduled preventive system for organising vehicles' technical maintenance and repair processes (TM and R) loses its effectiveness while being continuously used in most cases [2; 3].

Hence the relevance of developing the so-called adaptive systems of maintenance and repair, which will make it possible to decide on implementation of technical actions individually for each vehicle, thereby increasing the efficiency of the processes of ensuring their technical readiness [4–6]. The modern level of technology and information technology facilitates solution of this problem making it possible to implement such a component of intelligent transport systems as monitoring of vehicle operation [7].

World practices in development of vehicle operation systems show that large world manufacturers of automotive equipment have started implementation of flexible maintenance schedules for new models being adjusted in real time depending on operating conditions [8]. First, this approach to maintenance is being implemented for trucks and special equipment, vehicles operated in special conditions, for which increasing the efficiency of operation is especially important and gives a significant economic effect [9]. So, flexible maintenance plans can be applied today to trucks of Mercedes, Scania, Volvo brands [10]. Russian domestic manufacturers (KamAZ) are also developing similar systems, though they have not been widely used yet [11].

However, both international [12–16] and domestic [7; 17; 18] approaches consider mainly telemetry data on working processes in the vehicle's units, control actions of the driver and vehicle speed as sources of information for making decisions on when to proceed with maintenance. The type of road surface is not considered while it is one of the main factors of external environment.

In this regard, the *purpose* of the article is to present the results of research aimed at developing a method for assessing road conditions of traffic flow based on operation monitoring data.

RESULTS

As shown above, one of the main standards for maintenance and repair is the frequency of maintenance. In the scheduled preventive system, it is determined considering the basic maintenance frequency and the values of correction factors, which take into consideration, among other things, road conditions [19].

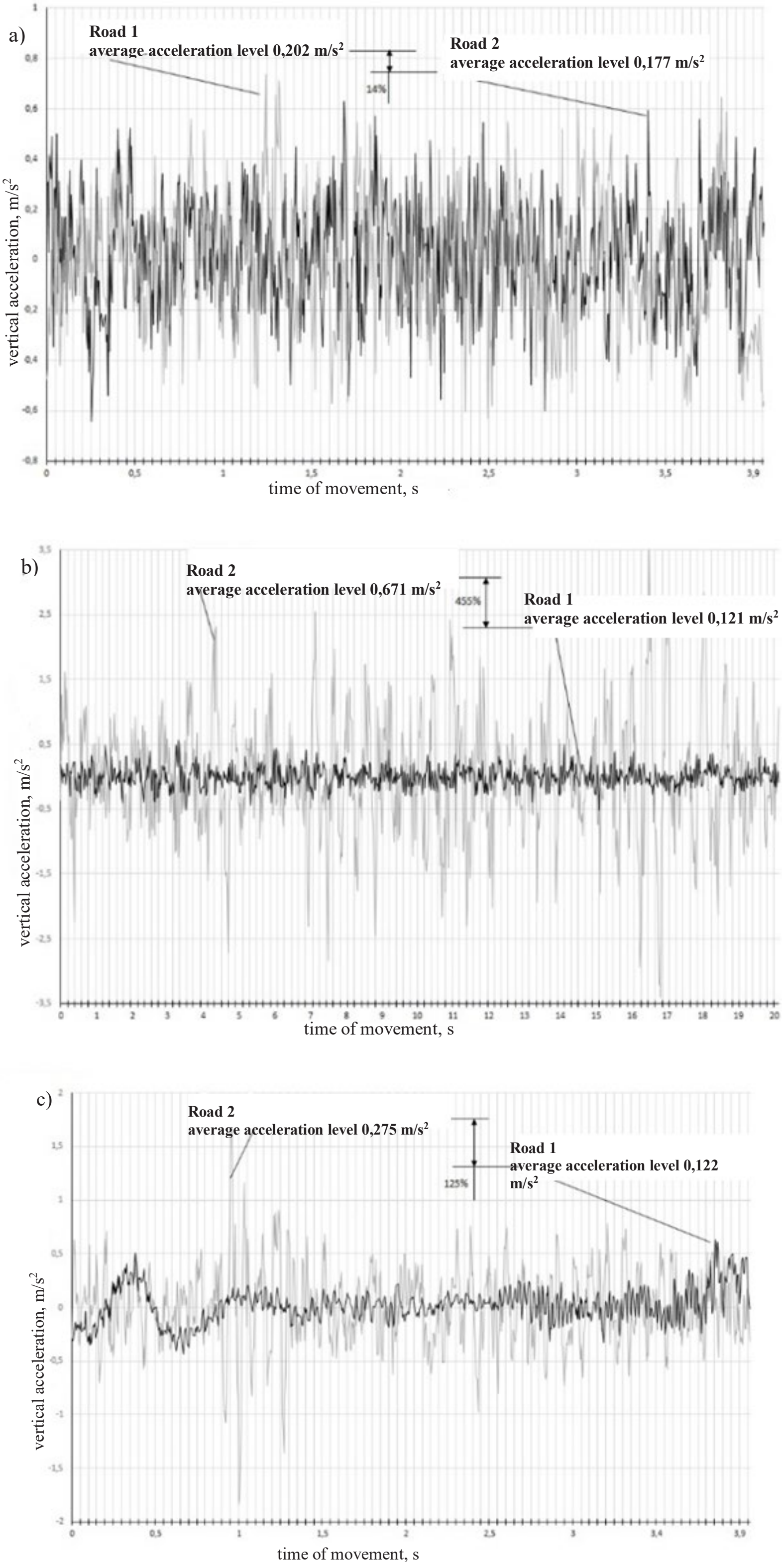
A version of the adaptive TM and R system determines values of correction factors individually for each vehicle based on the operation monitoring data. When implementing this approach, to determine in real time the type of road surface on which the vehicle is driving, it is proposed to use continuous monitoring of vertical accelerations of sprung masses recorded on the vehicle body.

This method is based on the interaction of vehicle's wheels with road irregularities which is the main source of forced oscillations of vehicle's structural elements. The degree of force action of oscillatory processes on structural elements is estimated by the parameters associated with accelerations, and the parameters of oscillatory processes of vehicle's structural elements during movement are directly related to a micro-profile of the road along which this movement is carried out [20]. The micro-profile, in turn, determines not only the type, but also the condition of the road surface. Thus, to determine in real time the type and condition of the road surface, it is possible to use continuous monitoring of vertical accelerations recorded on the vehicle body.

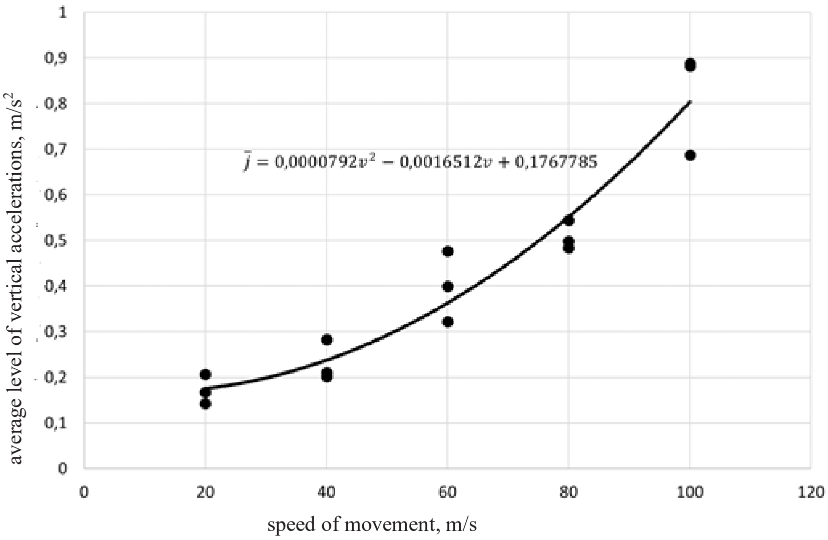
To confirm this hypothesis, experimental research *methods* were used: vertical acceleration profiles were constructed with a step of recording parameters of 5…10 ms were built using the signals from a three-position accelerometer, rigidly fixed on the vehicle body. The results are shown in Pic. 1.

To ensure the possibility to identify the type and condition of the road surface not only by a visual method (in the form of graphs), but also in an automatic mode based on mathematical processing of an array of data on vertical accelerations, the value of the average level of accelerations is suggested calculated by the formula:

$$\bar{j}(t) = \frac{1}{\delta}\int_{t-\delta}^{t} j(t)dt, \qquad (1)$$



Pic. 1. Profiles of vertical acceleration of the M1 vehicle body when driving on roads with different types of surfaces in different conditions (speed 30 km/h):
a) Road 1 and road 2: asphalt concrete in good condition.
b) Road 1: asphalt concrete; road 2: soil, improved with local materials.
c) Road 1: asphalt concrete in good condition; road 2: asphalt concrete in satisfactory condition (compiled by the authors).



Pic. 2. Dependence of the average level of vertical acceleration of the body on speed of the vehicle (compiled by the authors).

where $j(t)$ is current value of acceleration at time t, m/s^2;

δ – period of time to determine the average level of acceleration, s;

$\bar{j}(t)$ – value of the average level of accelerations at time t, m/s^2.

The formula (1) is an analogue of the formulas used in the analysis of acceleration profiles to determine the level of force action and the values of impact severity index (ASI) in the ERA-GLONASS system [1]. The considered case assessed the result of the same processes, except that the object of impact is not a person (passenger), but a vehicle. In this regard, the use of formula (1) can be recognised as adequate assumption.

Experimental data and calculation results suggest that the values of average levels of acceleration can be used to identify the type of road surface. So, the same road surfaces have similar acceleration profiles and slightly different values of the average level of acceleration (Pic. 1a), while average levels of acceleration for asphalt concrete and unpaved surfaces can differ by up to 4,5 times (Pic. 1b).

At the same time, for an asphalt concrete pavement in a satisfactory condition, the value of the average level of accelerations can exceed the value for a pavement in good condition by more than two times (Pic. 1c). From the point of view of implementation of the adaptive TM and R systems, for making decisions on performing the next maintenance, it is only important to assess the force action of the road on structural elements of the vehicle, which leads to a deterioration in its technical condition. At the same time, both a native soil surface in good condition and an asphalt concrete surface in a satisfactory condition can have a similar force impact. However, if the type of road surface on which movement is carried out is known in advance, then the monitoring data of vertical accelerations and their calculated average level can be used to assess the condition of the road surface.

It should be said that the experimental data shown in Pic. 1 are valid for a single constant vehicle speed value. Since the magnitude of the force action of the road cannot but depends on speed, and speed of the vehicle is not constant during its motion, practical application of the proposed method for assessing the condition of the road surface requires an assessment of the nature of the dependence of the average level of vertical accelerations of the vehicle body on speed of movement.

For this, experimental measurements of the average level of vertical accelerations were performed for the case when the same vehicle moved along the same segment of the road with an asphalt concrete surface at different speeds.

[1] GOST [State Standard] R 54620-2011. Global navigation satellite system. Emergency response system in case of accidents. In-vehicle emergency call system. General technical requirements [Electronic resource]: https://docs.cntd.ru/document/1200095073. Last accessed 14.07.2021.

The experimental results, together with the approximating dependence, are shown in Pic. 2.

The dependence of the average level of vertical accelerations of the vehicle body on speed of movement is approximated by a power-law dependence of the second degree since forced oscillations of the body are associated with the kinetic energy possessed by the vehicle interacting with irregularities of the road micro-profile, and the kinetic energy is proportional to the square of speed.

The nonlinearity of the real dependence of the level of force parameters of the impact on the vehicle on the micro-profile of the road is also confirmed by the provisions of the current guidelines for the study of the flatness of road surfaces[2]. However, in practice, to simplify the application, it is proposed to use linear dependences of the form $\bar{j} = kv$. Their use will not lead to a significant loss of accuracy (the approximation accuracy is less by 3 % compared to the second-order polynomial dependence). This will allow to consider the condition that the average level of acceleration is equal to zero at zero speed and to bring the values of the average level of acceleration to the same «base» speed to enable a comparative assessment of the condition of the road surface at different segments without preliminary tests to determine the exact nature of the dependencies. If speed equal to 60 km/h is taken as the base speed, then the adjusted value of the average level of accelerations will be calculated using the following formula:

$$\bar{j}_{60}(t) = 60\frac{\bar{j}(t)}{v(t)}. \quad (2)$$

Also, for practical application of the described method, it is necessary to substantiate the value of the time interval δ, which is the basic one for calculating the average level of accelerations. For this, it should be borne in mind that the condition of the road surface is determined on a road segment of a certain length. Since using the described method, the condition of the road surface is assessed locally, in accordance with the recommendations[2], the length of the road segment in this case should be from 25 to 100 m. As a first approximation, an average value of 50 m is chosen to ensure accuracy. In this case, the time base for calculating the average level of accelerations will depend on speed of the vehicle at the current time:

$$\delta = 50v^{-1}. \quad (3)$$

CONCLUSION

Thus, to assess road conditions based on data on vertical acceleration of the vehicle body, the following sequence of actions can be proposed:

- Determining the coordinates of the vehicle (φ, λ) and the current moment of time t.
- Determining the vehicle speed at the current time $v(t)$.
- Determining the time base for calculating the average level of accelerations according to formula 3.
- Determining the average level of acceleration according to formula 1.
- Adjusting the average level of accelerations to the base speed according to formula 2.
- Determining the condition of the road surface by comparing the adjusted level of the average level of acceleration with predetermined threshold values.

The implementation of the proposed mechanism is possible as an additional functionality of the ERA-GLONASS system or similar systems in other countries. Its implementation will allow not only to provide individual adjustment of the frequency of vehicle maintenance, but also to carry out express monitoring of the condition of the road surface in real time.

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Modelling of Mechanisms as a Methodological Tool (the Case of Designing a Cycloidal Pin Transmission)

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ABSTRACT

The suggested modern approach to modelling of objects and systems allows not only to create models but also to use them to study the main properties of the object (system) with a high degree of clarity and adequacy, as well as to develop most important skills of young engineers in creating and implementing digital models of engineering objects.

The objective of the study is to analyse capacity of one of the modern automated computational design systems as a methodological tool.

The functionality of an automated computational design system is considered for the case of constructing a model of a planetary cycloidal pinion transmission. The resulting model allows visualising the kinematics of the designed mechanism in the form of static or moving graphic images. The model built based on the described approach contains digital images of mechanism parts, which can be transferred without modification to specialised software systems for analysing strength characteristics or manufacturing material models of a product using rapid prototyping methods.

The proposed approach allows to perfect actions referring to the analysis of properties and synthesis of new structures using tools that correspond to the modern level of technology development and to get a visual idea of the process of developing a machine from a mathematical model to its material objectification.

The research methods are based on the fundamental principles of mathematical and simulation modelling, data analysis and processing using powerful automated computational design tools.

The tools used for modelling can be used for different forms of learning, i.e., without reference to specific premises and equipment.

Keywords: transport, computer-aided design systems, automated computational design systems, planetary gear, cycloidal pin transmission.

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INTRODUCTION

Developing skills in creating complex models of future products can be named among the most important tasks of the modern manufacturing process as well as of training technical specialists who will be involved in it in future. An integral part of these competencies is the ability to use various digital tools, such as systems of automation of mathematical calculations, automated computational design systems, software packages for development of illustrative material and software programs for equipment control.

The *objective* of the study is to assess and demonstrate the possibilities of using digital design tools in development of design of a mechanical engineering product, for example, a gearbox based on a cycloidal pin transmission. This type of mechanical transmission is well known and widely used, demonstrating its effectiveness. However, training, teaching and methodological sources offer relatively small volume of information on this type of transmission.

The structural diagram of the gearbox [1] is shown in Pic. 1. Circular eccentric 1 with axis *B* rotates around a fixed axis *A*. Washer 3, covering the eccentric 1, has teeth *b*, engaging with ring pins 4 rotating around fixed axes *E*. Washer 6 is rigidly connected to shaft 2 rotating around the axis *A,* and has pins 7 rotating around the axes *D* of the washer 6 and rolling along the inner side of the circular holes, centred at point *C* of the washer 3. The dimensions of the links of the mechanism satisfy the conditions *AB* = *DC* and *BC* = *AD*, i.e., the figure *ABCD* is a parallelogram.

When the eccentric 1 rotates around the axis *A*, the washer 3 engages with the pins 4 and thereby drives the shaft 2 into rotation.

Gear ratio of the mechanism:

$$u_{21} = \frac{Z_4 - Z_3}{Z_3},$$

where Z_4 is the number of pins 4;

Z_3 is the number of teeth of the washer 3.

With an internal cycloidal-pinned gearing [2], the profile of the teeth of the smaller wheel (satellite, Pic. 2) is determined as equidistant curve 1, located at a distance $D_{pin}/2$, to the shortened epicycloid 3, which is formed during rolling of a roller with a radius of r_r along a circle 2, the radius of which is equal to R_c (the distance from the centre of the roller to the point that forms the shortened epicycloid is equal to r_{rc}). The complete epicycloid 4 is shown in Pic. 2b. The parameters of the cycloidal profile are interconnected by dependencies:

$$r_r = \frac{R_c}{Z_w},$$

where Z_w is the number of teeth of the wheel:

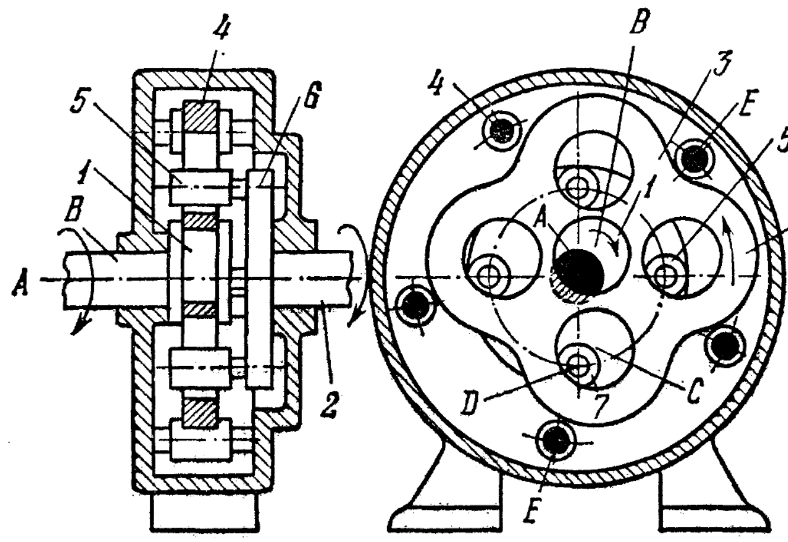
$$R_c = \frac{Z_w}{Z_{pin}} \cdot R_{rc},$$

where Z_{pin} – number of pins located along the circle of the radius R_{rc}.

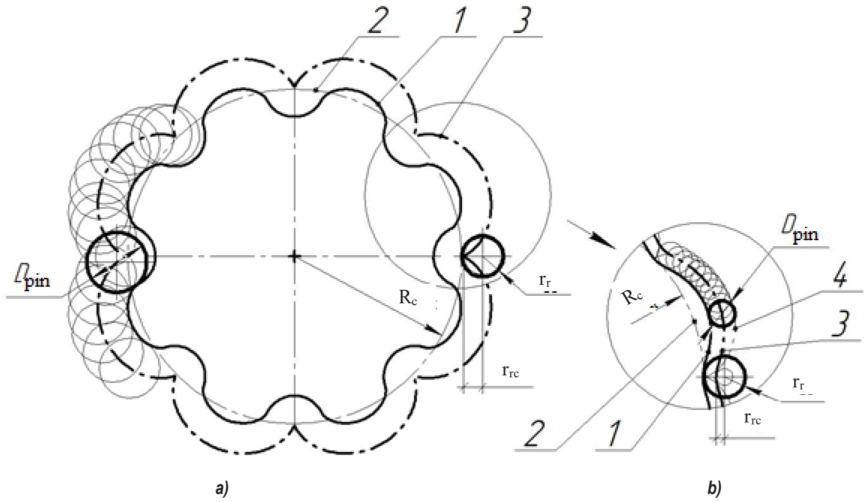
Let's introduce the notation:

$$a = \frac{r_{rc}}{r_r},$$

$$b = \frac{Z_{pin} - Z_w}{Z_w}.$$



Pic. 1. Cycloidal pin planetary gear with internal gearing [1].



Pic. 2. Diagram of formation of the profile of the cycloidal wheel (compiled by the authors).

Then the parametric equations of the shortened epicycloid, which forms the trajectory of displacement of the centre of the pin relative to the wheel, will take the form:

$$x(t) = R_c \cdot \left[(1+b) \cdot \cos bt - a \cdot b \cdot \cos(1+b)t\right];$$
$$y(t) = R_c \cdot \left[(1+b) \cdot \sin bt - a \cdot b \cdot \sin(1+b)t\right]. \qquad (1)$$

The wheel profile is formed as an internal equidistant curve to the shortened epicycloid based on the formulas:

$$x_{eq}(t) = x(t) - \frac{\left(D_{pin}/2\right) \cdot y'(t)}{\sqrt{\left(x'(t)\right)^2 + \left(y'(t)\right)^2}};$$
$$y_{eq}(t) = y(t) + \frac{\left(D_{pin}/2\right) \cdot x'(t)}{\sqrt{\left(x'(t)\right)^2 + \left(y'(t)\right)^2}}. \qquad (2)$$

derivatives $x'(t)$, $y'(t)$:

$$x'(t) = R_c \cdot \left[(1+b) \cdot b \cdot (-\sin bt) - a \cdot b \cdot (1+b) \cdot \left(-\sin(1+b)t\right)\right];$$
$$y'(t) = R_c \cdot \left[(1+b) \cdot b \cdot \cos bt - a \cdot b \cdot (1+b) \cdot \cos(1+b)t\right].$$

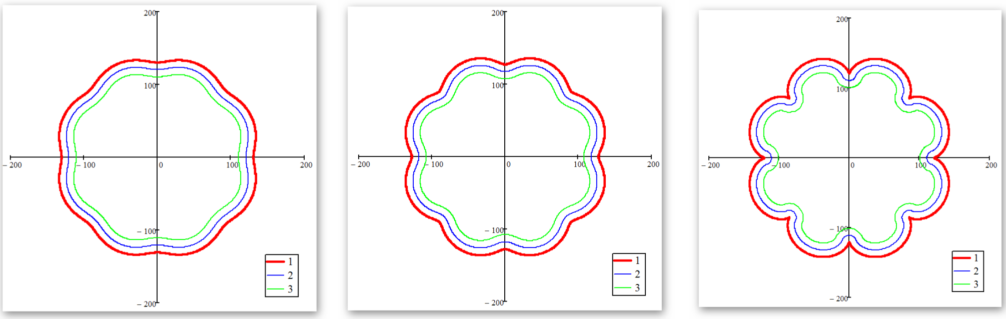
RESULTS

Modelling was carried out based on the above dependencies using the Mathcad system. The first stage provided for construction of graphs allowing preliminary assessment of the shape of the profile of the gear wheel (Pic. 3). The shortened epicycloid (trajectory of displacement of the centre of pins) corresponds to graph 1 in all pictures. A different form of this trajectory corresponds to different values of the parameter a in equations (1). Graphs 2 and 3, built according to equations (2), illustrate the position of the wheel profile with different values of the diameter of pins D_{pin}.

The functionality of the mathematical modelling system allows to quickly build a graphical model of a profile and, without long constructions, adjust the parameters and update the profile view. However, the automated system of mathematical calculations is not suitable to develop design documentation either to directly use the results of such a calculation for processing data that will form the basis of technological process.

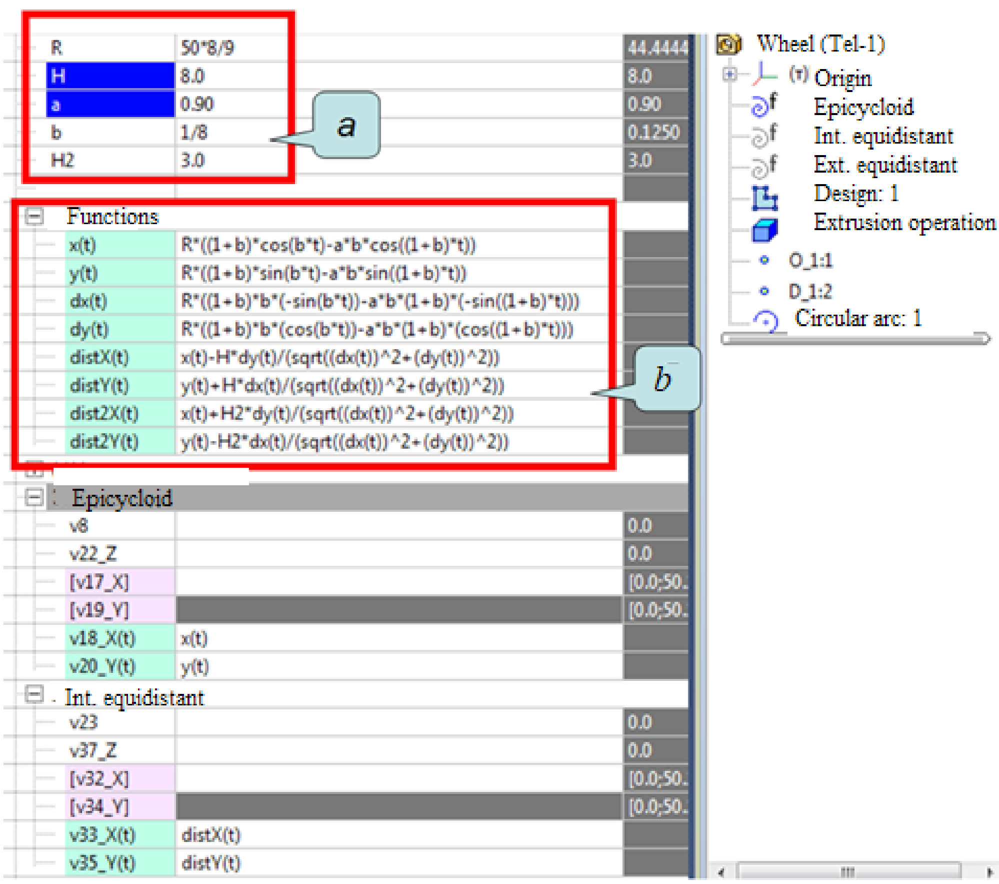
Methodological recommendations on construction of this profile [3–27] in most cases propose in fact to replicate the approach as when designing using conventional drawing tools, only converted to digital format. The curve is constructed by points using the kinematic method to determine the coordinates of nodes and the built-in system commands for constructing flat curves (NURBS, Bézier curve) from an array of points. Equidistant line construction is also performed using the built-in system command. This method is very time consuming; it requires repeated execution of the same type of operations, which can lead to errors and increase the design time. This is especially noticeable when it is necessary to adjust previously developed constructions.

Modern 3D modelling systems are capable to exclude manual steps from the process of developing a 3D model. For this, the so-called parametric capabilities of these systems are used. If, i. e., in the KOMPAS software package (ASCON, Russia) one specifies a group of model variables (Pic. 4a) corresponding to the parameters of formulas (1) and a group of user-



a) b) c)

Pic. 3. Results of modelling of the profile of a gear wheel in the automated system of mathematical calculations (compiled by the authors).

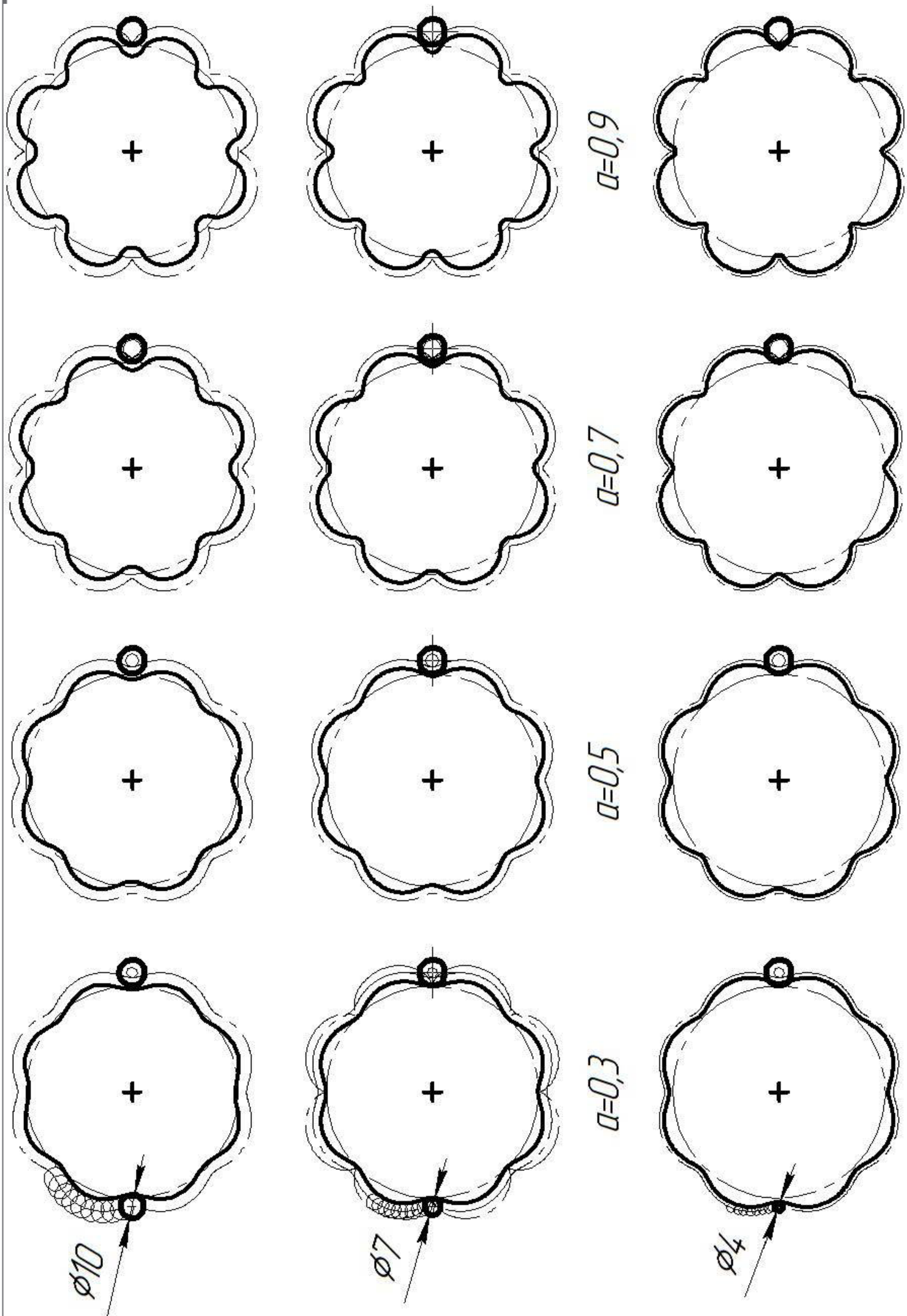


Pic. 4. The system of control variables of a 3D model of the cycloidal gear (compiled by the authors).

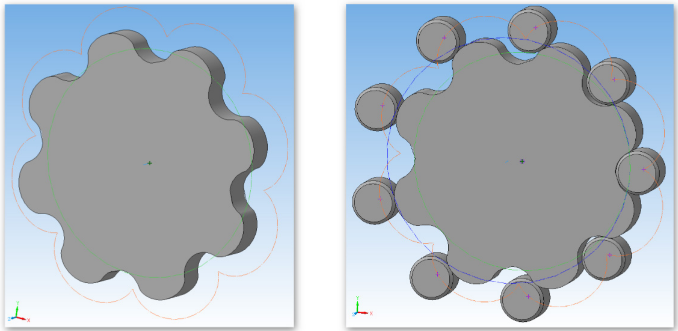
defined functions (Pic. 4b) that reproduce dependencies (2), a curve is formed in the model space that forms a closed loop to which the Extrude operation is applied. The result is a finished digital 3D model.

If it is necessary to adjust the parameters (diameters of pins, shortening factors, the radius of the circle on which the pins are located), you can limit yourself to changing the numerical values in the range of variables (Pic. 4a) and rebuilding of the contour, as well as of the entire 3D model, will be performed automatically.

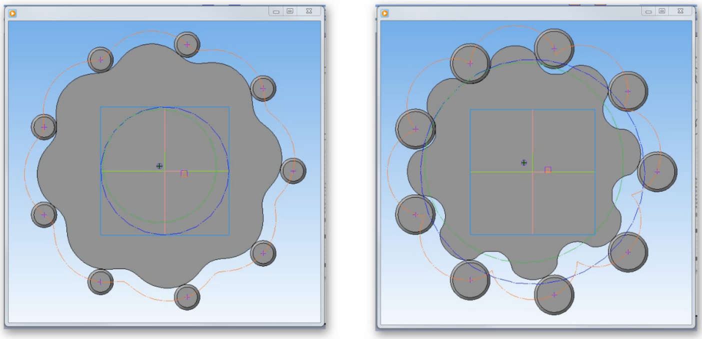
Using this approach can significantly increase flexibility and efficiency of the design process. Sketches of the working profiles of cycloidal wheels (Pic. 5) and a 3D model (Pic. 6) illustrate



Pic. 5. Working profiles of cycloidal wheels, for different values of the parameter 0,3 < a < 0,9 and the diameter of the pin d_c = 4, 7, 10 mm. (compiled by the authors).



a)



b)

Pic. 6. 3D model of the cycloidal pinned engagement (a) and freeze frames of the video file formed on its basis (b) (compiled by the authors).

the ability to quickly rebuild the model when changing transmission parameters, this can also be done in animation mode.

BRIEF CONCLUSION

The described results of modelling demonstrate within a specific case that automated computational design systems are tools allowing us to directly transform analytical (with formulae) descriptions of geometric objects into realistic digital models suitable for their direct use as objects of analysis for a number of physical features (regarding centre of mass, strength characteristics) and consumer properties (exterior, positioning in the interior of premises) properties.

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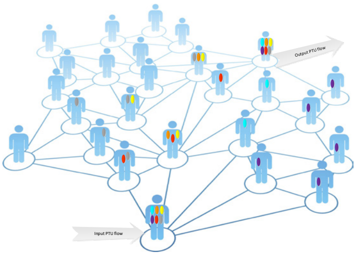
NTERNATIONAL ROAD TRANSPORTATION **208**

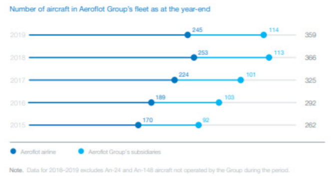
To better compete, the car fleet should be renewed. How to solve a set of interconnected problems regarding environment, energy efficiency, funding? Analysis and recommendations.



URBAN TRANSPORT **220**

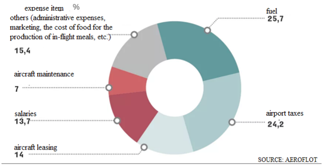
Some passenger routes in large cities can also be deemed combined ones as freight transportation is. Analysis of multimodality using digital and behavioural tools.

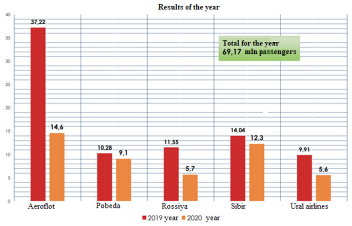
ECONOMICS



AIR BUSINESS **231**

Frequent flyers. Almost everybody knows what are the advantages of FFP, but what is the cost of the bonus reward for an air company?





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Methodological Foundations of Renewal and Expansion of Car Fleet




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ABSTRACT

Currently, Russian international road transport carriers do not have sufficient potential to successfully compete with their foreign partners. The main reasons for this are significant deterioration of the car fleet and its non-compliance to modern environmental requirements, lack of own funds for timely renovation and development of the motor transport fleet, as well as systemic lag in development of transportation technologies and their logistics support.

The objective of the article is to substantiate the choice of rational measures to solve the problem of expanded reproduction of car fleet used in international road haulage. The methodology used in preparation of the article is based on the use of general scientific methods in combination with special methods, including the analysis of statistical data on international road haulage, a comparative analysis of the state of the car fleet of Russian carriers, considering the basic conditions and operational characteristics, classification of the fleet of trucks based on typification of their operational characteristics with subsequent subdivision of this fleet into three main groups, an overview analysis and benchmarking of foreign operating experience and future development of car fleet, an analysis of the economic and legal possibilities of raising funds for renewal of car fleet.

The article examines and studies: a) urgency of solving the problem of renewal and expansion of the car fleet used by Russian carriers in international road transportation; b) foreign experience and trends in development of fleet used for international haulage; c) the main directions of providing economic opportunities for transition to expanded renewal of vehicles; d) analysis of the legal possibilities of providing public support for expanded reproduction of the motor transport fleet of Russian international road carriers including through the use of public-private partnerships.

Based on the results of the study, proposals have been developed aimed at ensuring renewal and expansion of car fleet and increasing the efficiency of international road haulage operations.

Keywords: *road transport, international transportation, deterioration of car fleet, reproduction of production assets, government support.*

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Текст статьи на русском языке публикуется в первой части данного выпуска.

INTRODUCTION

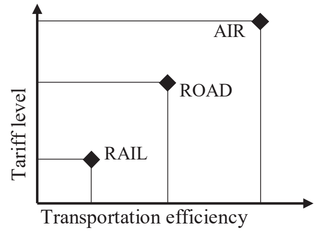
International road haulage both in the European Union and in Russia is a type of production and economic activity in demand by cargo owners. Road transport, in comparison with its main competitors, railway transport and civil aviation, is characterised by a combination of moderate tariffs with a sufficiently high speed of transportation (Pic. 1).

This combination of the most important consumer characteristics of road transport provides a stable development trend for international transportation (Pic. 2)[1].

Comparison of the conditions of transportation of goods by Russian and foreign carriers in international traffic shows that Russian carriers cannot fully compete with their foreign counterparts. The main reasons for this situation are significant deterioration of the car fleet; continued operation of vehicles of low ecological classes; lack of carriers' own funds for timely renewal of the car fleet; systemic lag in development of transportation technologies and logistics support of transportation.

Ensuring commercial load of cars in reverse direction is a significant problem for increasing efficiency of cargo transportation. At present, the volumes of import and export road haulage have practically become equal (Pic. 3). This contributes to an accelerated return on investment. Hence the relevance of consideration of the issues of rationalising the economic mechanism for renewal of worn-out car fleet and its expanded reproduction.

[1] Hereinafter, pictures and tables are developed and compiled by the authors based on statistical information of Federal State Statistics Service (Rosstat) and Avtostat analytical agency.



Pic. 1. Comparison of tariff affordability and efficiency of road transportation (ROAD), railway transportation (RAIL), and air transportation (AIR).

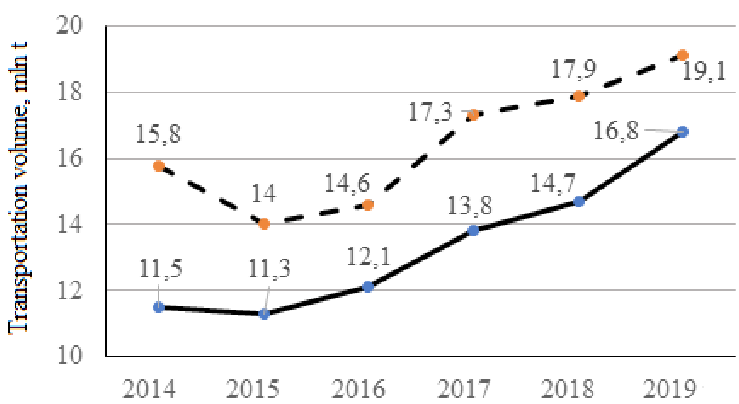
The *objective* of the article is to study the problems associated with deterioration of the car fleet used for international road transportation of goods, and its timely renewal, to propose a rational solution for timely expanded renovation of the car fleet of Russian carriers.

MATERIALS AND METHODS

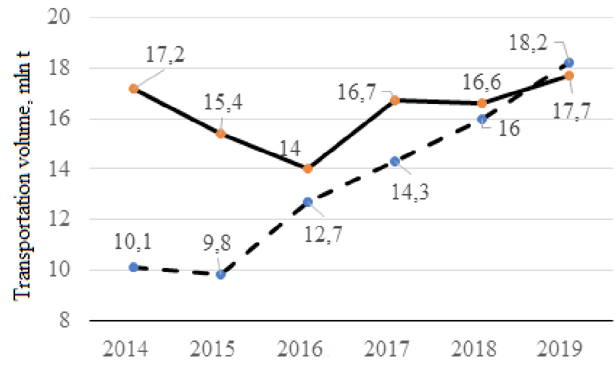
Information sources used for preparing the article comprised the results of statistical observation of the composition of the car fleet used for international transportation of goods, materials of Federal State Statistics Service (Rosstat) and Avtostat analytical agency, the results of research and development carried out with participation of the authors at JSC NIIAT (copyright know-how), scientific publications, valid normative legal acts.

The *methodology* used by the authors in preparing the article includes general scientific research and design development methods, as well as the following special and applied research methods:

• Statistical analysis of data on international road transportation of goods, availability of the



Pic. 2. The volume of international road haulage performed by Russian carriers (solid line) and foreign carriers on the territory of Russia (dotted line).



Pic. 3. Dynamics of the volume of cargo transportation in international road traffic: solid line – import; dotted line – export.

fleet of trucks[2], the conditions and characteristics of their operation, the state of physical deterioration of this fleet.

• The analysis of compliance of the car fleet of Russian carriers to current and future environmental requirements, considering the basic conditions and operational characteristics and topical problems of timely renovation of this fleet.

• Classification of the fleet of trucks based on established heterogeneous conditions and operational characteristics with subsequent division of this fleet into three main groups (that is, the method of general classification of objects and their decomposition).

• An overview study of foreign experience in operation of trucks used for international road transportation, and of prospective development of the car fleet to benchmark the results of this analysis.

• Analysis of economic and legal possibilities of attracting additional funds for renewal of the fleet to compensate for the consequences of the existing negative trend of aging of this fleet and its inconsistency with modern and future environmental requirements.

RESULTS

The State of the Car Fleet Used for International Road Haulage

The fleet of Russian carriers used for international road haulage has increased physical deterioration, which is explained by the long service life of vehicles (Table 1). For clarity of perception of information on the dynamics of the structure of the car fleet as per service life over the past few years, a diagram (Pic. 4), built according to data of Table 1, shows that the share of car fleet with a significant service life is increasing. This trend exacerbates the precarious position of Russian carriers in international transportation. The share of new cars in this fleet tends to decrease somewhat. This situation is explained by the fact that carriers do not have sufficient financial resources to renovate the worn-out part of the vehicle fleet, as well as to expand it to further develop the business.Because of the above-standard service life of cars of Russian carriers of goods in international road transportation in terms of useful life, the problem of inconsistency of a significant share of the car fleet with current and future environmental requirements and standards arose (Table 2).

Significant physical deterioration of vehicles of Russian carriers causes an increase in the cost of current maintenance and repair of the fleet. The resulting increase in the cost of transportation forces carriers to raise tariffs, which also reduces competitiveness of business entities operating in the transportation market.

The study of information on the state of the market of international road haulage and on the position of Russian carriers on it allowed us to establish subdivision of transport organisations operating from 20 to 40 vehicles into three characteristic groups (Table 3) and to study a set of issues that are essential for the success of carriers in the transport market. The grouping of carriers was carried out based on the criterion of maximum similarity of operating conditions and their economic position in the market of international road haulage.

The information presented in Table 3 shows that the general situation in the considered sector

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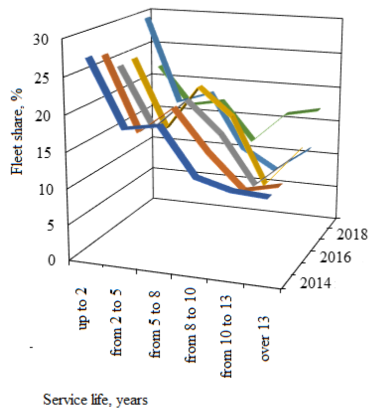
[2] The term «truck» in the original Russian text is used here and further-on by the authors in a broad sense and refers to all types of road vehicles used in international road transportation of goods without distinguishing trucks, light trucks, lorries, road tractors, trailers, semi-trailers, etc., if not mentioned otherwise. – *Translator's note*.

Table 1

Structure of the car fleet of Russian carriers used for transportation of goods in international traffic, per service life, %

Service life, years	2014	2015	2016	2017	2018	2019
Up to 2	27,4	26,9	24,5	24,7	29,8	21,9
More than 2 up to 5	18,3	16,7	16,1	14,9	17,8	16,3
More than 5 up to 8	19,1	20,4	20,4	21,3	19,4	17,2
More than 8 up to 10	12,7	14,7	16,1	17,4	11,7	11,6
More than 10 up to 13	11,4	10,1	9,4	8,1	8,9	16,0
Over 13	11,1	11,2	13,5	13,6	12,4	17,0



Pic. 4. Graphical presentation of the dynamics of the fleet of Russian carriers of goods in international road transportation (2014–2019).

Table 2

Distribution of cars of Russian carriers, performing international road transportation of goods, per ecological class, %

Ecological class	2014	2015	2016	2017	2018	2019
EURO-0	6,9	6,8	7,3	7,0	6,9	7,1
EURO-1	0,9	0,7	0,6	0,5	0,3	0,3
EURO-2	5,5	4,8	3,8	3,8	3,3	3,0
EURO-3	37,0	33,7	31,2	26,2	23,0	19,7
EURO-4	8,3	8,0	7,4	7,0	6,6	6,0
EURO-5	41,4	46,0	49,7	55,5	59,7	63,8
EURO-6	0,0	0,0	0,0	0,0	0,1	0,1

of the transportation market cannot be considered satisfactory. The main reason for this situation is the lack of opportunities for carriers to purchase new car fleet that meets modern and future environmental requirements.

The Main Directions of Restructuring the Fleet of Trucks in Europe

In contrast to Russia, in Europe, the main problem of car fleet renewal, including the trucks with a large payload capacity, is associated not with the availability of financial resources for carriers, but with the need to replace the vehicles with internal combustion engines with the fleet equipped with environmentally friendly engines while simultaneously increasing fuel efficiency and carrying capacity of vehicles. The fact is that European countries, with which Russian carriers provide transport links very important for the Russian economy, have very strict environmental legislation, and the civil society of these countries takes an active position in matters of environmental safety and environmental protection. In this regard, a significant amount of cargo transportation intended to or from these countries goes to foreign partners of Russian carriers, who have more modern vehicles of high ecological classes [1].

During the establishment of the EU, the preservation of the habitat was one of the priority goals of the member states of the Union. From 1992 to the present, six documents have been adopted that regulate environmentally unfavourable transport emissions. The emission

Table 3

Characteristics of typical groups of road transport carriers, essential for renewal of rolling stock

Characteristic	Group 1	Group 2	Group 3
Brand composition of the car fleet	Cars manufactured in the CIS countries	Cars manufactured in the CIS countries and a certain share of cars manufactured in other countries	Cars manufactured in the CIS countries and other cars mainly of the VOLVO, MAN, SCANIA brands
Average service life of cars, years	15–20	13–17	7–12
Ecological class of cars	0, 1 and 2	0, 1, 2, 3	4 and higher
Load capacity of cars	Low and medium	Low to high	Medium to extra high
Technical maintenance (TM) and routine repairs	As a rule, carried out by the drivers	Own personnel perform TM and simple repairs, while the major unit replacement and unit repair is performed in specialised workshops	Performed in specialised workshops
The scope of operation of the fleet	Transportation within the constituent entities of the Russian Federation	Transportation within the constituent entities and between the constituent entities of the Russian Federation	Transportation between the constituent entities of the Russian Federation and international road transportation
Conditions of capitalisation of the business	Minimum share capital, no capital reserves, cash gaps, zero profit or negative balance	Minimum share capital, no capital reserves, often zero profit or negative balance	Minimum share capital and minimum capital reserves. Balance sheet with a slight positive balance
Problems in the sphere of labour relations	Delays in wages, wages according to the informal scheme. Systematic violations of labour legislation	Often, remuneration for labour according to the informal scheme. Occasional violations of labour legislation	Universal (background) problems characteristic of all sectors of the Russian economy. Labour violations are relatively rare
Depreciation practices and the possibility of renovating fixed assets	Depreciation is not charged due to complete deterioration of the fleet and other equipment. Impossibility of renewal at the expense of own resources	Limited depreciation amounts due to high depreciation of the fleet. There are very few own resources for renovation of fixed assets	Depreciation is charged on vehicles that have not reached the end of service life. Lack of own resources for renovation of fixed assets
Possibilities of attracting external funding sources for renewal and expansion of the fleet	Leasing is rarely possible and only on very unfavourable terms. Money lending is excluded due to the almost zero assessed value of assets	Limited leasing option on unfavourable terms (large down payment, short lease terms, high payment rates). Lending opportunities are very limited due to the low assessed value of assets	Usually available. Leasing and loans are used
Stability of contracts with clientele	Mostly transportation contracts	Transportation contracts and transportation contracts for up to one year	Transportation contracts for up to three years and one-off transportation contracts
The current position of carriers in the road transportation market	They leave the market: about 50 % of organisations have ceased to exist during last 10 years	They leave the market or are close to a critical (unstable) state	There are limited prospects for maintaining their positions in the market
Possibility of simple renewal of the fleet	Absent	Available only partially, mainly using borrowed funds	Available using equity and borrowed capital
Possibility of renewal and expansion of the fleet	Absent	Absent	Severely limited
Forecast of viability of transport organisations	Negative	More likely negative, but with some positive confidence	Satisfactory

limit values are established according to the list of harmful substances including carbon monoxide, hydrocarbons, nitrogen oxides, etc. The main trend is gradual tightening of emission regulations.

Carriers are encouraged to operate cars with advanced power plants by various measures, including subdivision of the territories of settlements into zones which only vehicles of certain ecological classes are allowed to access.

The practices of zoning the admission of cars to certain territories, depending on the environmental friendliness of engines, are recognised in Europe as an effective measure for preserving the environment. In Europe, a policy has been adopted to abandon the use of diesel engines. It becomes not only unprofitable but simply impossible to operate non-environmentally friendly cars. In this regard, the vehicle fleet is being intensively renewed [2; 3].

The heightened public interest in European countries in the problems of environmentally friendly transport is manifested in a broad discussion of parliamentarians and wide circles of the public, constantly finds a response in the media. Here are some examples of this.

In the Netherlands, territorial ecological zoning of vehicle access is used, and a ban has been imposed on the entry into several such zones of trucks with engines of Euro-4 and below, and from 2022 entry for vehicles with engines of Euro-5 will be completely prohibited. From 2025, it is planned to impose a complete ban on the entry into cities of any trucks with engines running on fossil fuel. Only hydrogen-fuelled vehicles and electric vehicles will be allowed to enter such areas. In Germany, a ban has been established on the entry into the central parts of the largest cities (Berlin, Hamburg, Stuttgart, Aachen, Frankfurt am Main) of cars with diesel engines of environmental classes below Euro-6. It is believed that this will force automakers to produce more hybrid vehicles [3]. Serious restrictions for low-emission vehicles were also imposed in Spain. In Madrid, the city centre is almost completely closed to the entry of non-environmentally friendly vehicles. Paris authorities have banned diesel vehicles from entering the city centre, and the access of gasoline-powered vehicles has been severely restricted. By 2030, it is planned that only hydrogen-fuelled and electric vehicles will have access to the territory of the French capital.

The UK has also imposed restrictions on the use of non-environmentally friendly cars. There are restrictions on the entry into the centre of London of cars with engines below the Euro-4 standard [4].

The European Union and its member countries are trying to stimulate companies involved in production of eco-cars. Such producers are provided with loans on preferential terms and tax holidays. In the European Union, heavy vehicles make up only 4 % of the total vehicle fleet. But these cars account for about 30 % of the emissions of CO_2 and other harmful substances into the atmosphere [5]. Therefore, strategic planning for development of road transport is aimed at using market mechanisms that contribute to renewal of car fleet. It is considered a problem that information on fuel consumption of heavy vehicles is currently neglected. Therefore, monitoring of operation of heavy vehicles, the certification system, statistical accounting, and reporting are being improved. An information base is being created on the sales of heavy vehicles, operating conditions, fuel consumption and freight traffic. A tendency has been established towards the increase in the average payload capacity of operated heavy-duty vehicles. The leading manufacturers of heavy-duty vehicles in terms of the number of new vehicle sales are Volkswagen, Volvo, Daimler, PACCAR, and Iveco [4; 5].

In Europe, research and development activity has been launched with the aim of replacing in the foreseeable future diesel engines and gasoline engines with alternative power plants. The developments are aimed at increasing the energy efficiency of cargo transportation and the carrying capacity of vehicles [6]. Thus, a study of fuel consumption of cars with diesel engines and various hybrid engines in real operating conditions using the example of Finland showed that the energy efficiency of operation of heavy vehicles can be increased by 6 % when switching to hybrid engines. Specific fuel consumption per 1 ton•km decreases on average by 17 % with an increase in the total mass of a loaded vehicle from

[3] Is this the end of Euro-5 trucks? Europe declares war on non-ecological trucks [*Eto konets gruzovikov standarta Evro-5? Evropa obyavliaet voinu neekologichnim gruzoviakm*]. [Electronic resource]: https://trans.info/ru/eto-konets-gruzovikov-standarta-evro-5-evropa-obyavlyaet-voynu-neekologicheskim-gruzovikam-133630. Last accessed 26.08.2021.

[4] Offers 3 thousand euros per month, is looking for 60 drivers. But there are no volunteers… [*Predlagaet 3 tys. evro v mesiats, ischet 60 voditeley. No zhelayuschikh net*]. [Electronic resource]: https://trans.info/ru/predlagaet-3-tyis-evro-v-mesyats-ishhet-60-voditeley-no-zhelayushhih-net-252015. Last accessed 26.08.2021.

[5] EU countries finally agree on tougher environmental standards for cars [*Strany ES okonchatelno soglasovali uzhestochenie ekologicheskikh norm dlia avtomobiley*]. [Electronic resource]: https://www.dw.com/ru/страны-ес-окончательно-согласовали-ужесточение-экологических-норм-для-автомобилей/a-48329696. Last accessed 26.08.2021.

40 tonnes to 60 tonnes. Hybridisation of the engine becomes especially effective when driving over rough terrain [7]. Since the efficiency of using vehicles is determined, first, by fuel consumption, models of diesel fuel consumption by heavy vehicles have been developed that consider various operational factors [8].

The article [9] proposed an overview of promising projects for creation of a new generation of trucks, providing a significant reduction in energy consumption for transportation of goods and payload capacity of the car fleet. The development of such projects is based on the methodology of platooning. The developments refer not only to new environmentally friendly engines, but also to car control systems using information technologies, automated driving, creation of a system of mutual information exchange between various vehicles for their coordinated movement providing a minimum safety distance to increase the transit capacity of road infrastructure network.

The electrification of the fleet is recognised as a promising direction for a radical solution regarding enhancement of environmental friendliness of heavy vehicles. In this regard, it should be pointed out that the efficiency of an electric motor is twice, or even more, higher than this indicator of an internal combustion engine. Thus, the environmental effect is achieved not only due to the transition of vehicles to electric traction, but also due to a sharp reduction in energy consumption for traction.

Currently, the main disadvantage of electric vehicles is the significant mass of onboard energy sources compared to the use of hydrocarbon fuels. This increases the tare rate (unladen weight) of the car, it carries not only the payload, but also the heavy onboard energy source. The way out is to use an external source of electricity. This can be achieved by equipping the main routes with trolls. Note that in Russia there is a positive experience of operating dual-mode buses («duobuses», a trolleybus equipped with an auxiliary internal combustion engine for moving along a part of the route not equipped with trolleys), which were previously used to deliver goods from trading bases to GUM, one of the main department stores in Moscow.

Leading car manufacturers of the European Union countries carry out R&D on creation of main line trolleytrucks (or freight trolleys). Sweden became the first country to operate a trolleybus line for long-haul cargo transportation. The spread of such a fleet will be facilitated by the presence in Europe of a developed network of excellent highways. Siemens has been testing such electrified heavy good vehicle system since 2012 on two test tracks in Germany (eHighway, Pic. 5).

Consistent and comprehensive tightening of environmental requirements stimulates European carriers to purchase green vehicles when renewing their car fleet. At the same time, a significant increase in the price of such vehicles is an important circumstance in comparison with vehicles of lower environmental classes.

Known Methods of Fleet Renewal

Many people are mistaken because they believe in existence of some kind of «money box» in which depreciation charges are supposedly accumulated. The article [10] shows that this widespread myth has nothing to do with economic practices. At present, compulsory accounting records [in Russia] do not provide for depreciation funds. Depreciation charges included in the cost of transport services are not stored without movement, but immediately after receipt as part of the proceeds are used to make current payments to the organisation (figuratively speaking, they «melt»). Serious depreciation «scissors» have arisen in transport, since due to complete deterioration of a significant part of fixed assets, depreciation is not charged at all. Vehicle prices are growing significantly faster than depreciation charges based on historical prices. Purely theoretically, purchase of new vehicles at the expense of depreciation is possible only with a fleet of unworn fleet of more than 15–20 units, since depreciation charges are made annually for such a fleet, and they will be enough to purchase one car. In this regard, it is currently impossible to purchase enough new cars for renewal using the own means of transport organisations. Moreover, it is impossible to expand the fleet at the expense of the aforementioned funds.

Because of the lack of own funds for renewal and expanded reproduction of the fleet, it is possible to use funds from third-party organisations. Such funds can be provided to carriers through credit or leasing agreements.

Scientific literature does not contain a solution generally accepted by the economic community to the problem of effective renewal of fixed assets of economic entities at the expense of funds attracted from outside. The relevant theoretical

Pic. 5. Electric-powered system for heavy good vehicles on a specially built test track in the north of Berlin, Germany. (Photo: Siemens. https://press.assets.siemens.com/content/siemens/press/ui/en/search.html#/asset/sid:320d002d-fa74-4a64-882c-715abfa3b6e5).

aspects of reproduction of the rolling stock in recent years have been developed mainly within the framework of dissertation research. The work [11] considers the mechanisms of organising reproduction of fixed capital in vertically integrated economic complexes. In road transport, such connections between business entities are not common, and therefore, in this work, rather organisational, managerial, and administrative models are of primary interest for our study. T. S. Babaev studied formation of the investment policy of a transport company based on program-targeted management [12]. Attention is paid to consideration of the problems of using borrowed funds, intended for renewal of the wagon rolling stock depending on demand for transportation. D. Yu. Kashtanov [13] developed recommendations for creating a mechanism for attracting investments in the field of passenger road transport. Financial leasing and bank lending are recommended as the main mechanisms for attracting investments to renew the fleet. The work of A. E. Filin [14] studied possibilities of using financial lease (leasing) for renewal of rolling stock. Recommendations are made on the use of leasing operations, considering the specifics of railway transport. The Ph.D. thesis of I. V. Titov [15] studied the economic mechanisms of formation of the need for funds for renewal of the bus fleet and formation of appropriate investments based on formation of a depreciation deduction fund.

Leasing is currently attractive for business entities due to minimisation of value added tax payments. However, leasing has constraints as for its use by road carriers for the following reasons:

• Difficulty in approving a leasing transaction and a rather high cost of financial resources used for primary payments.

• The carrier does not have the right to dispose of the leased asset, since the owner of the rolling stock is the lessor.

• Additional costs associated with conclusion of the lease agreement (one-time commission payments for the transaction and monthly payments during the entire term of the agreement).

International road carriers are not able to widely use leasing and bank lending due to increased rates for provision of borrowed funds because of the low valuation of carriers' own assets, instability of transport organisations in the context of seasonal fluctuations in demand for their services, intense competition in the market of international transportation.

According to the data obtained by JSC NIIAT, the annual renewal of the fleet of trucks (considering their prevailing excessive deterioration) should be about 12 %. In fact, at present, the annual fleet renewal does not exceed 5 % on average [16].

The main problems of attracting investment resources by road carriers include [17]:

• High level of carriers' accounts payable.

• Unsatisfactory financial discipline of carriers, explained by financial shortfalls, which leads to an increase in the loan rates.

• Low level of profitability of road carriers decreasing down to zero.

• The factors of international economic situation and the problems due to COVID-19 coronavirus pandemic have significantly reduced the volume of foreign investment.

Legal Possibilities of State Support for Russian Carriers

Transportation of passengers and goods by road as a type of economic activity refers to services (Chapter 40 «Transportation» of the Civil Code of the Russian Federation (further referred to as CCRF), Federal Law «Charter of road transport and urban land electric transport» No. 259-FZ dated 08.11.2011[6], international agreements on international transportation with the participation of Russia). The economic activity of a carrier in the transport services market is related to entrepreneurial activity.

The legislation limited direct participation of the state in economic activity as of an economic entity since state authorities and administrations are not entities of the kind but exercise the functions of public administration. This rule follows from one of the fundamental postulates of the market economy, according to which the state is an ineffective economic entity. State bodies and local self-government bodies do not have the right to participate on their own behalf in business companies[7], which are corporate commercial organisations with authorised capital divided into shares of founders (participants).

It is advisable to carry out state entrepreneurship exclusively in areas where the obtained useful result does not have a purely economic value, but is aimed at solving other problems (social, environmental, defence-related, etc.), including within the framework of infrastructure projects [21], as well as in the field of natural monopolies. In this regard, direct participation of the state in the activities carried out by entrepreneurs is allowed only in a quality of a participant in contractual relations in the status of an acquirer under a civil law contract. It is in this sense that the state authorities and administrations according to Art. 124 of the CCRF act in relations regulated by civil law, on an equal footing with other participants in such relations, who are economic entities. At the same time, the state can take part in economic activity in other forms (not as an entrepreneur) [18]. Regarding the topic of this article, participation of the state in economic activity can be carried out in the form of:

• Normative legal regulation of the complex of economic relations. The main acts of legislation in this sphere of relations are the Civil Code of the Russian Federation and federal laws and bylaws adopted in accordance with it, regulatory legal acts of legislation on taxes, labour, finances, natural resources, etc., as well as federal laws regulating certain economic relations. We emphasise that in this case the state does not carry out entrepreneurial activity as such but sets its rules.

• Financing the implementation of measures carried out to implement state programs for development of the national economy in accordance with the Federal Law «On Strategic Planning of the Russian Federation» No. 172-FZ dated June 28, 2014, and the corresponding strategies and programs for development of the Russian Federation, its regions and municipalities (only within the framework of the amount of state targeted funding provided for in these documents).

• Founding with the use of state property of legal entities (state commercial organisations) and participation in management of privatised state property. In this regard, it is appropriate to recall that a legal entity is always an independent subject of economic activity, and the state can only have the right to manage its property, but not the right to the legal entity itself. Legal entities created by the state are not liable for the obligations of the public authorities that established them (Article 126, Clause 2 of the CCRF). Accordingly, the state is not responsible for the obligations of the legal entities created by it, except for cases provided for by law (Article 126, Clause 3 of the CCRF). However, this rule does not apply if the state has assumed a guarantee (surety) for the obligations of a legal entity.

• Implementation of projects that are not of commercial interest to private investors (prohibition of private investors to carry out certain activities, as well as economically unprofitable and low-profit projects with a very high degree of risk, which makes it inexpedient to invest private capital, but which are necessary to solve tasks that are mandatory function of the state). Such participation must be legitimised by regulatory legal acts. It can be carried out particularly in the form of a public-private partnership [19].

[6] Hereinafter, normative legal acts are considered, considering the amendments that followed after the entry into force.

[7] Article 66, part 6 of the CCRF.

The analysis of the essence of possible participation of the state in economic activity and of achievement of the goals of providing state support for entities engaged in international road transportation of passengers and goods allows us to indicate the most appropriate forms of such interaction between the state and business:

• Integration of measures of state support in various programs and strategies for development of transport, indicating funding from budget sources and extra-budgetary funds. At the same time, the principles, goals and objectives of such support, indicators for assessing the results achieved should be determined.

• Creation of public joint-stock companies (PJSC) with participation of state capital [20]. The peculiarities of the legal status of joint-stock companies, the shares in the authorised capital of which are owned by the state and are not assigned to state or municipal unitary enterprises, are determined by the CCRF. Considering the possibility of participation of private shareholders in the work of the company and creation of guarantees for safety of invested state funds, it is advisable that state investors retain a control stock in PJSC's capital or own a golden share. In any case, the effective use of funds invested by the state, their return to the state investor and the profitability of the company's activities must be ensured. After achieving sustainable self-reproduction of fixed assets, the state-owned part of the capital of PJSC can be privatised.

Rational Forms of State Support for Russian Road Goods Carriers

Considering the studied legal possibilities of state support for international road goods carriers, the following recommendations are proposed for practical use. Possible urgent measures include:

• Temporary cancellation of the recycling fee, at least for vehicles of ecological class 6, as well as for new semi-trailers and trailers (we can quote an example of the Decree of the President of the Republic of Belarus dated March 20, 2021 No. 123 «On measures to develop international road transportation of goods»).

• Abolition of transport tax. The corresponding budget revenues are already collected in the form of excise taxes on fuel.

• Extension of the procedure for reducing the calculated transport tax by the amounts paid according to the «Platon» system[8] in relation to vehicles engaged in international transportation.

• Reduction of the rate of insurance premiums on the wage fund of small and medium-sized businesses engaged in foreign economic activity (regardless of the tax regime applied by such entities).

• Ensuring the possibility of using a decreasing coefficient when establishing insurance premiums in respect of Motor Third Party Liability Insurance (MTPL) policies for vehicles carrying goods and passengers in international traffic. The reason for this is the high level of en route discipline and qualifications of the crews of the respective vehicles.

• Creation of a mechanism for reimbursing VAT amounts on a reciprocal basis for residents of the EAEU member countries when they purchase goods (works, services) on the territory of other EAEU countries, including for international road carriers when purchasing motor fuel and other goods (services).

The analysis of the experience of the existing mechanisms of subsidising by foreign investors of carriers engaged in export transportation made it possible to establish that these mechanisms are diverse and are constituent elements in the overall package of measures taken to increase the export potential of their countries. Along with measures to support carriers, including subsidising leasing rates for renewal and modernisation of the vehicle fleet, establishment of customs duties, tax incentives, in case of insufficient measures to ensure equality of competitive conditions for national carriers, it is also possible to:

• Limit quotas for issued permits for international transportation.

• Stimulate the competitive party to an unequal exchange of transit permits for transport permits to (from) third countries by restricting transit travel through the territory of a country.

To timely consider the risks of negative imbalance in foreign trade and of reducing export potential, as well as to develop and adopt an exhaustive package of measures to support

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[8] Platon Electronic Toll Collection (ETC) system was introduced to facilitate and process the collection of toll charges offsetting the damage caused to Russian Federal Highways by vehicles exceeding 12 tonnes of gross vehicle weight (HGV N3 sub-category). [Electronic resource]: https://platon.ru/en/about/. – *Translator's note.*

national sectors of the economy, including subsidising international road transportation, public authorities can more actively use automated remote monitoring and control systems based on modern information and communication technologies and intelligent transport systems.

Government programs to support road carriers are often narrowly focused and adopted for a limited time. Since international road carriers miss domestic sources of financing for reproduction of the vehicle fleet, there is a need to create an economic mechanism, as well as scientific and methodological foundations of an integrated approach to solving the scientific and economic problem of renewal of fixed assets. It is necessary to create an economic mechanism to ensure that carriers accumulate their own funds using both public-private partnerships and venture financing for renewal of vehicles used in international traffic [10]. Development and implementation of this mechanism will have a positive impact on the competitiveness of Russian road carriers.

To support organisations engaged in international road goods transportation, JSC NIIAT has developed a methodology that ensures an expanded reproduction of vehicles.

The methodology includes:

• Analysis of the structure of the fleet of organisations carrying out international goods transportation per service life of vehicles.

• Analysis of financial performance of organisations and tariffs for transportation.

• Creation of PJSCs with participation of state capital.

• Government subsidies or interest-free lending to support the initial acquisition of two new vehicles, allowing depreciation to be charged.

• Accrual of depreciation on vehicles according to the sum of the number of years with the mandatory accumulation of accrued funds. The accumulated funds must be placed in reliable banks and bring interest income for carriers for the use of the funds by credit institutions.

• Purchase of the third vehicle at the expense of depreciation deductions from two previously acquired cars at the expense of state support funds at a point in time corresponding to half of the useful life of the first two vehicles.

• Regular purchase of a new vehicle every four years at the expense of accumulated depreciation deductions.

• Assessment of competitiveness of a joint venture based on comprehensive accounting and comparison of economic and environmental performance with other organisations operating in the international freight transport market, according to the recommendations [21].

CONCLUSION

Currently, the competitiveness of Russian international road goods carriers is significantly limited due to significant deterioration of the car fleet of vehicles and their incomplete compliance with environmental requirements and standards. Most carriers do not have their own sources of funds to invest in a timely renewal of the fleet and in expanded reproduction of fixed assets.

The analysis of the known approaches has shown that at present there is no generally accepted methodology for solving the problem of effective renewal of carriers' fixed assets. The use of lending and leasing for these purposes is significantly limited due to the poor paying capacity of carriers and the lack of a clear perspective for their successful development.

Studies have shown that the automotive industry needs government support. To support organisations that perform international road haulage, a set of measures has been proposed to ensure an expanded reproduction of vehicles while implementing private-public partnerships. It is also possible for the state to use organisational and legal forms of support for the road transport business.

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Public Passenger Transport Logistics in the Context of Digital Transformation of Transportation Services Organisation Systems

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ABSTRACT

Transport route specification models are used to analyse the need for combined passenger transportation on popular routes in a large urban agglomeration. The problem of managing the travel chains of passengers using public transport (PT) is revealed with the focus on the complexity of applying the principle of multimodality on the route network used by population due to the mismatch of the schemes of transport and users' routes.

The study of the logistics of passenger transportation with PT introduces the concept of «public transport user (PTU)» which has a variable status relative to the flows of people, pedestrians, passengers, and transport vehicles. The description of the registers of the main parameters of the routes under study serves to create their digital twins.

To manage the travel chains of PTUs, identify related sections of transport routes, it is proposed to highlight within the passenger flow the currents of the same profile which include PTUs that have common transport behaviour.

Models and algorithms of network proximity to transport infrastructure objects, visualisation of digital traces of PTUs and the results of comparing the used and the best route options according to the modelled parameters allow to identify behavioural profiles of PTUs, as well as regulators managing the travel chains.

Keywords: *urban public transport, metro, combined transportation, currents of passenger flows, transport behaviour, complex toutes, long routes.*

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INTRODUCTION

The high rates of development of transport in urban agglomerations towards increase in the length of the transport network, better connectivity of routes of various modes of passenger transport, as well as organisation of speed and high-speed rail routes provide growing transport accessibility and the overall quality of public transport (PT). Along with improvement of this important indicator of efficiency of PT, both passengers and transport organisations face certain difficulties.

For users, the processes of building and choosing an individual route are becoming more and more complex due to an increase in the number of alternative options for moving through the territory of a large urban agglomeration using various routes of one or more modes of transport. As the results of our research have shown, for example, in Moscow urban agglomeration, the share of simple routes (without transfers, using one mode of transport) in trips repeated within a month is about 35 %. With the increase in the distance from the place of residence of travellers to the place of their long stay (4–8 hours), the number of transfers to regular routes of passenger transportation is growing. On «long» routes lasting more than 50 minutes, on average, the active residents make 3 transfers, including transfers to various metro lines.

For carriers, the tasks of «improving quality of transport services for the population» and managing passenger transportation on such routes are becoming more complicated. Difficulties in solving them are due to the lack of transparency of the research results of the population's need for public transport services and passenger transportation on various segments of PT route network, of an integrated transport and logistics system of public transport, as well as of end-to-end technologies for studying traffic flows (of pedestrians, passengers and transport vehicles) required for synchronisation and «coordination of independent processes and participants» in a complex «multi-agent system» [1].

The *objective* of the study is to identify modern tools for analysis and management of passenger travel chains using public transport in urban agglomeration. The task is to describe the approaches to the study of the logistics of passenger transportation by PT, models for specification of connected segments of transport lines on popular, complex (combined) routes used by population within the territorial boundaries of the megalopolis.

LITERATURE REVIEW

Many publications are devoted to analysis and assessment of the demand for passenger transportation in relation to specific types of urban PT, separately to urban land PT, metro and railway transport operating within the urban agglomeration (in city–suburb area). Publications assessing the overall need for public transport services based on sociological and marketing research data dominate. A separate block of scientific papers deals with construction and selection of the optimal route by the user of the mobile application.

The successful international practices of integrating off-street and street transport within the framework of a single system of integrated transport services for the population (SITSP) determine the need to develop solutions related to management of passenger travel chains, logistics of transportation by all types of public transport in the urban agglomeration. Such management becomes possible, as the authors note, based on «logistics integration and cooperation, the principles of multimodality», due to creation of a «centre for urban public transport management to ensure effective coordination of passenger transportation» [2]. The authors proposed «algorithms for constructing optimal routes and statistical analysis of passenger flow», intended «not for a single person, but for the entire population of the city», adapted to the «real transport network with real timetables» of land transport [3].

It should be noted that this algorithm as most of other algorithms published in accessible sources, use volumetric indicators of passenger flows regarding transport routes, certain segments of transport lines obtained through the tools of registering the flow of people at the entrance to the transport system (station), exit from the station, at the places of transfer [4]. They did not consider individual groups of passengers with common transport behaviour. Moreover, the algorithms for optimising the work of public transport were based on average statistical values of the number of trips and generalised characteristics of PT passengers. Accordingly, the total passenger traffic was studied without identifying specific currents consisting of passengers with similar profile.

The characteristics of passengers based on «type of activity and income» often used in marketing research, as the authors of [5] argue, are not directly related to the regularity of travel, and therefore are of little use for identifying routes which are «popular» among the population. The proposal on the need to consider «personal characteristics», «habits» that affect, respectively, the rate of regularity and the transport behaviour of people, was reflected in the work [5].

Quan Liang, Jiancheng Weng, and other co-authors of their research proposed a «travel chain extraction method of individual public transport traveller» and a passenger travel analysis method based on a graph «of individual travel behaviour», which made it possible to get an idea of the «spatial position» of the research object and its real route necessary for further forecasting «the public transport passenger's behaviour choice» [6]. The proposed research technology was based on the information data of transactions of PT smart cards. The authors note that previously the applicability of the proposed characteristics of passengers, their «individual features were not studied adequately» [6].

Most scientific developments (methods, algorithms, models for analysing passenger traffic and optimising routes for groups of travellers) used the «travel time» criterion [7]. Some works were devoted to the study of the influence of the criterion «quality of service» («satisfaction with quality» rate) and the financial affordability of PT services («cost of travel along the route») on the choice of a route option by a traveller.

The work of R. R. Sidorchuk and D. M. Efimova proposed to evaluate the quality of the route through «satisfaction» at the «points of contact» of the passenger with the transport infrastructure [8], and not on the segments of traffic of various flows. The «respondent statuses» selected in this work, i. e., social groups of workers, specialists, students, pensioners, and temporarily unemployed persons, in our opinion, are of little use for determining popular, complex routes of PTUs.

A process approach to the specification of people/vehicles flows on the routes based on the data of automatic recording and image processing (machine vision) was described in [9]. However, its practical use refers more to organising traffic on the existing lines, determining the modes of traffic organised on the transportation route («operating mode profiles» [9]), and not to managing PT passenger travel chains.

An attempt to formalise the transport behaviour of people was an important step towards improving the methods and tools for studying the structured demand for public transport services. The results of these studies were reflected in publications devoted to the urban zoning per transport mobility rates in relation to the socio-economic characteristics of the city's residential areas and transport infrastructure. In particular, the gravity model is an interesting development on specification of the places of origin of passenger flows and on the study of the need for combined transportation on the «long» routes of the population, in which the «intensity of connections» is determined on the basis of the «economic gap» value [10]. The results of these studies can be useful since they allow explaining and predicting the transport behaviour of the population on the territory of economic entities. At the same time, they do not make it possible to determine the regulators for managing the travel chains of the population using PT and to identify the segments of transport routes that are in demand by various behavioural groups of passengers.

RESULTS

Unlike transport routes, for which roads/tracks, places for embarkment and disembarkation of passengers (starting and ending points, stops/stations) and the direction of movement of vehicles are defined, the routes of PTUs have integrated walking sections, on which the population uses the available urban street and road infrastructure. The pedestrian sections of PTUs indicate the lack of connectivity of transport routes in a certain location, as well as the absence of integrated stops and controlled pedestrian crossings included in the list of transport infrastructure objects.

Individuals initiate streams and merge into various streams of street and transport infrastructure. The need for transportation by PT arises for them on those segments of individual (user) routes where they use the services of urban passenger transport.

The probabilistic nature of movement of people across the territory of the city and adjacent settlements complicates the solution of the problem of managing the logistics of passenger transportation by PT. However, some of the trips and the demand for comprehensive public transport services are quite predictable. This applies to mass, regular trips and patterns of commuting of the population on certain days of the week, of months, and during some hours.

To connect the flows of people, pedestrians, passengers, transport vehicles, it is obviously necessary to highlight the key element: the initiator of movement. We have introduced the term «public transport user» (PTU). We mean that he is a person as a part of society and a mobile population, who is at the same time: a pedestrian (participant in/part of movement of the flow of people, of the flow of pedestrians); a passenger (part of the passenger flow) at public transport infrastructure facilities; a driver (participant in/part of the transport flow) when using personal vehicles on segments of the individual route. This solution allowed us to link data about PTUs obtained from different sources, to create a knowledge base about their movements and transport behaviour (using key attributes of smart cards and mobile devices registered with cellular operators), to ink and combine them into flows based on various criteria.

In contrast to the method of «multi-modal planning and assessment» by Todd Litman [9], we propose to use a process, logistic approach to the study of transport routes and management of travel chains, passenger transportation by PT using digital technologies. In our opinion, it is fair to speak about «multimodality» and «multimodal passenger transportation by PT» only in case of complete connectivity of transport routes, coincidence of individual routes and public transport routes in urban agglomeration. In our case, we use the terms «combined» transportation of passengers, «combined» travel of people by public transport.

The classification of sections of transport routes is based on the patterns of transport behaviour of passengers (PTUs) and indicators of «popularity», «predictability» of choice, «insensitivity» to the route parameter. The information base for the analysis of a PTU's preferences is the data on the actually used routes, the conscious or unconscious choice of the route from a variety of alternative route options, which is repeated in the patterns of commuting.

We use a classic set of parameters to describe the combined route chosen by a PTU and to create digital twins of popular routes.

To describe transport routes:

$M_t = \{N_{st}, T_t, F_{tr}, Q_t\}$,

where M_t is metamodel of transport routes;

N_{st} – model of the register «Transport hubs, integrated PT stops»;

T_t – model of the register «Time of movement along the segment of the transport route»;

F_{tr} – model of the register «Cost of travel on a transport route»;

Q_t – model of the register «Quality of public transport in LOS notation».

To describe PTU routes:

$M_{ptu} = \{C_{comb}, T_{ptu}, F_{tr}, Q_{ptu}, U\}$,

where M_{ptu} – metamodel of the characteristics of the combined PTU route;

C_{comb} – model of the register «Complexity of the combined PTU route»;

T_{ptu} – model of the register «Travel time along the segment of PTU route»;

F_{tr} – model of the register «Fare for a combined route of a certain type of PTU»;

Q_{ptu} – model of the register «Quality of public transport on the combined PTU route»;

U – model of the register «Particularly valuable characteristic of the combined route for PTU», includes latent characteristics (U_h), determining the choice of the route.

The route parameter C_{comb} determines the number of transfers and their place in the route pattern. This parameter considers transition from pedestrian sections of the route to a segment travelled through a transport route, transfers from a transport route to another.

The parameters *T, F, Q, U* are determined for each section of PTU route and are combined when describing the complete route.

The similarity in the value attitudes of travellers in relation to the quality of PT on the route makes it possible to single out in the flow of users of public transport separate currents that unite latent groups of people with similar transport behaviour.

The following types of PTU behavioural profiles are suggested:

- behavioural profile «business» (W^B_H) → *T*;
- behavioural profile «economical» (W^E_H) → *F*;
- behavioural profile «demanding» (W^Q_H) → *Q*;
- behavioural profile «rational» (W^O_H) → *F/Q*;
- behavioural profile «special» (W^S_H) → *U*;
- behavioural profile «indifferent»[1] *(*W^I_H*)*.

For the economic substantiation of decisions related to management of passenger flows, it is advisable to single out the types of PTU/passenger:

- H1 – PTU, pays the full travel fare on the segment (s) of the combined transport route;

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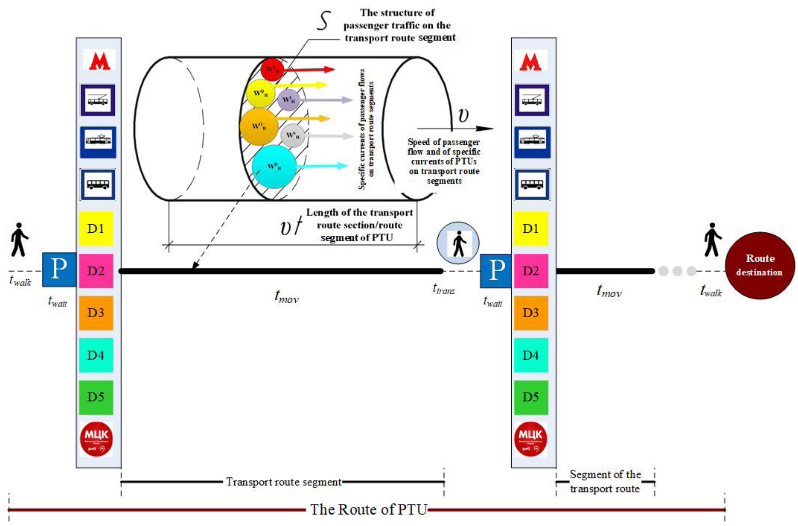
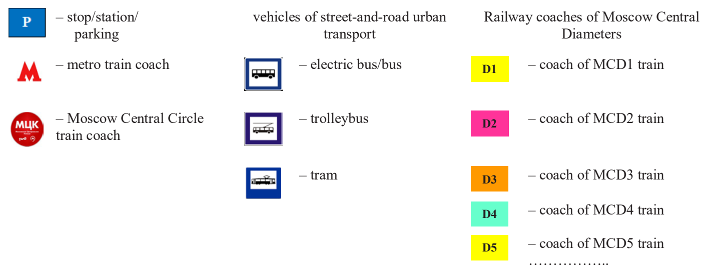
[1] PTUs having this profile use an irrational route due to: 1) lack of available information about the best alternative option; 2) unwillingness to look for the best option due to the difficulty of independently analysing and evaluating alternative options; 3) habits. 1–2 represent managed PTU behaviour; 3 – partially managed PTU behaviour.



Design ations: t_{walk} – time of passage of the walking section of the route; t_{wait} – waiting time of the vehicle; t_{mov} – time of movement of the vehicle along the segment of the transport route; t_{trans} – time of transfer to another transport route.



Pic. 1. Universal model of the structure of PTU route (developed by the authors).

• H2 – PTU, has a social card with the right to travel free of charge by PT;

• H3 – PTU, enjoys fare discount (social card of a school pupil, of a student).

In this case, the structure of PTU route and passenger flow on the segments of transport routes used by a PTU can be represented as the diagram (Pic. 1).

Considering development and widespread adoption of digital technologies in transport sector, it becomes possible to register and identify the selected segment of the transport route not only with various types of PTUs, but also with their behavioural profiles.

The study of the structure of an individual route, of a chain of travels by public transport of a specific type of PTUs widely uses transactions from smart cards of a traveller. Some foreign transport systems possess the complete information about movement of a passenger of the given type (payer status) along the segments of transport routes, since a turnstile system records the entry of people to the PT facility, their transfer to other transport lines and exits. In Russian practices, the number and type of passengers in the framework of the fare payment system is recorded only at the entrance to public transport facilities. The Scientific and Educational Centre «Digital High-Speed Transport Systems» of Russian University of Transport developed «models of network proximity in transport information systems» [11] allowing to visualise the trajectories of travels of people around the city (without linking the data to personal data) based on the information received from cellular operators. This allows us to «see» the process of formation of pedestrian flows, its transformation into a significant volume of passenger flow, as well as movement through city zones with possible linking to road and transport infrastructure facilities without «total tracking» of a specific person. «Distribution of entrances/exits in time» and «zoning of stations» [12] of metro (a frequently used mode of transport) makes possible, in this case, to identify popular, complex users' routes.

The decision to move along a specific route in most cases is made by PTU intuitively, based on experience or on the results of rapid assessment of the route parameters that are significant for the user. And those parameters are not limited exclusively to time and cost of travel. Recently, the level of satisfaction with quality of PT has become significant. The last parameter is characterised by the well-known customer loyalty indices: «Service Quaity Index – SQI (SERVQUAL methods), Customer Satisfaction Index – CSI, American (ACSI) and European (EPSI) indices» that are used for qualitative analysis of the streets, pedestrian zones, including intersections, as well as for classification of the conditions and nature of transport flows organised on the road network.

Obviously, the specific values of the elements of this parameter, which reflects the quality of all PT subsystems on user's individual routes, are of particular importance for PTU. In this regard, the model of the register «Quality of public transport on the combined PTU route» will include the following assessments:

Q = f (Q1, Q2, Q3, Q4, Q5, Q6, Q7),

where *Q1* is assessment of the quality of *the street and road infrastructure* on the pedestrian segment of PTU route *to the public transport infrastructure facility* and of the accessibility of the public transport system in terms of time and regularity of its operation.

The assessment of *Q1* is determined as:

Q1 = f (Q10, Q11, Q12),

where *Q10* is assessment of convenience of parking for personal vehicles, considering the risk of lack of parking spaces in a given time interval on the section of the combined PTU route;

Q11 is assessment of quality of roads intended for pedestrian traffic (including road surface, lighting), as well as schemes for intersections operations, operation of traffic lights used on the initial section of PTU route to the entry point to the object of PT facility;

Q12 is assessment of comfort on the initial segment of PTU route, of convenience of location of stops of land urban transport, railway station, metro station and of the availability of PT in terms of time and regularity of operation.

Q2, which is quality assessment *at the entrance to a public transport infrastructure facility* (railway station, metro station, ground public transport stop) is determined as follows:

Q2 = f (Q21, Q22, Q23, Q24, Q25, Q26, Q27, Q28),

where *Q21* is assessment of the level of quality of work and arrangement of the entrance to the PT facility;

Q22 – assessment of the level of physical comfort (queuing to pass through the entry point to the PT facility, taking into account the risk of malfunction of doors external to the turnstiles);

Q23 – assessment of quality of the atmospheric environment in an enclosed space, regulated (could be managed) by transport organisations (pollution[2], freshness[3] and air temperature, noise, lighting) at the entrance to the transport infrastructure facility;

Q24 – assessment of the level of safety for health and life (systems of protection against undesirable weather phenomena: precipitation, strong wind, heat/cold; means of identifying people with signs of infectious diseases, means of disinfection; systems for counteracting social offenses; security systems and the level of cleanliness of pedestrian areas in front of the entrance to the transport infrastructure object);

Q25 – assessment of the level of aesthetic comfort (design, unobtrusive and useful sound background and visualisation at the entrance to the PT infrastructure facility);

Q26 – assessment of the level of information comfort (navigation systems, personal offers for optimising individual routes using PT);

Q27 – assessment of the quality of public transport personnel at the entrance to the PT facility (availability, professionalism, politeness, efficiency in solving problematic issues);

Q28 – assessment of the quality level of payment systems used by PTU in the context of service methods (purchase of tickets through terminals, cash desks, use of the network of cellular operators, the Internet).

Q3, which is the assessment of the quality level *at the public transport infrastructure facility* (in the lobby, on the escalator, on the platform, at a public transport stop), is determined as follows:

Q3 = f (Q31, Q32, Q33, Q34, Q35, Q36),

where *Q31* – assessment of the quality of the indoor environment, regulated by transport organisations (pollution, freshness, air temperature, noise, lighting) in the lobby, on the escalator, platform, at the land public transport stop;

---

[2] Assessment based on sense impression and measuring of the presence of foreign odours (including toxins, carcinogens, exhaust gases), gases, particulate matters (in the form of dust, soot, pollen, smoke, etc.), infection (in the form of fungus, viruses, bacteria) in an amount exceeding permissible norms.

[3] Assessment based on sense impression and measuring of the level of oxygen saturation necessary for breathing in an enclosed environment (the ratio of carbon dioxide and oxygen).

Q32 – assessment of the level of safety of health and life (protection systems against undesirable weather phenomena: precipitation, strong wind, heat/cold; means of identifying people with signs of infectious diseases, means of disinfection; systems for counteracting social offenses; security systems and cleanliness of pedestrian areas at the facility transport infrastructure) on a platform, at a stop of land urban transport;

Q33 – assessment of the level of aesthetic comfort (design, unobtrusive and useful sound background and visualisation at the PT infrastructure: in the lobby, on the escalator, on the platform, at the stop of land urban transport);

Q34 – assessment of the level of physical comfort at a public transport infrastructure facility (in notation of level of service (LOS, i. e., [13]) it is considered «as a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to manoeuvre, traffic interruptions, and comfort and convenience» [14]), which is adjusted taking into account the risk of slowing down the speed of movement and increasing the density of passenger traffic caused by repetition of cases of malfunction in operation of technical means;

Q35 – assessment of the level of information comfort (information support systems for navigation on PT);

Q36 – assessment of the quality level of public transport personnel in the lobby, at the station (their availability, professionalism, politeness, efficiency in resolving problematic issues) on the section of PTU route.

Q4, which is the assessment of the quality level *in the vehicle interior,* is determined as follows:

Q4 = f (Q41, Q42, Q43, Q44, Q45, Q46),

where *Q41* is assessment of the quality level of physical comfort in the passenger compartment of a vehicle for a PTU of a certain type, taking into account the day of the week, time of day, position of a coach in metro and suburban railway trains (person/m^2);

Q42 – assessment of the quality level of the atmospheric environment in the vehicle interior (pollution, freshness and air temperature, noise, lighting);

Q43 – assessment of the level of safety for health and life (systems for identifying people with signs of infectious diseases, warning systems and counteraction to social offenses; cleanliness in the compartment);

Q44 – assessment of the level of aesthetic comfort of the vehicle interior (design, unobtrusive, useful sound and visual accompaniment during the travel in the passenger compartment, «innovativeness» of technical and constructive solutions, visible for PTU);

Q45 – assessment of the level of information comfort (quality of mobile communication: navigation systems; personal recommendations for prompt adjustment of an individual route, taking into account the delay in information about changes in the parameters of the single system of integrated transport services for the population on the planned segments of the combined PTU route);

Q46 – assessment of the quality level of PT personnel (driver, check-taker, guard, conductor of land public transport) on the segment of PTU route.

Q5, which is the assessment of the quality level *of the interchange hub* (changing to another transport route, line of the route network), is determined as follows:

Q5 = f (Q51, Q52, Q53, Q54, Q55),

where *Q51* is the assessment of the quality level of the interchange, regulated by transport organisations (pollution, freshness, air temperature, noise, lighting);

Q52 – assessment of the level of safety of the interchange for health and life (systems of counteraction to social offenses; cleanliness of passages);

Q53 – assessment of the level of aesthetic comfort of the interchange (design, unobtrusive and useful sound and visual accompaniment at the interchange hub);

Q54 – assessment of the level of physical comfort[4] of the interchange (PT infrastructure object), taking into account the risk of slowing down speed of movement and increasing the density of passenger traffic caused by a malfunction in operation of technical means, imperfection of the system of organising and managing traffic;

Q55 – assessment of the level of information comfort (navigation systems in PT).

Q6, which is the assessment of the quality level *at the exit from the public transport*

[4] The assessment includes an evaluation of the height of steps of stairs, the convenience of moving hand luggage and other oversized objects on wheels, assessment of operation of escalators.

infrastructure facility, is determined as follows:
Q6 = f (Q61, Q62, Q63, Q64, Q65),
where *Q61* is the assessment of the quality level of the exit from the PT infrastructure facility regulated by transport organisations (pollution, freshness, air temperature, noise, lighting);

Q62 – assessment of the health and life safety level of the exit from the PT infrastructure facility (systems for counteracting social offenses; cleanliness of passages);

Q63 – assessment of the level of aesthetic comfort of the exit (design, unobtrusive and useful sound and visual accompaniment at the exit);

Q64 – assessment of the level of physical comfort at the exit from the PT infrastructure facility, taking into account the risk of slowing down speed of movement and increasing density of passenger traffic caused by a malfunction in operation of technical means, imperfection of the system of organising and managing traffic;

Q65 – assessment of the level of information comfort at the exit from the PT infrastructure facility (navigation systems on the final segment of PTU route).

Q7, which is the assessment of the quality of *street and road infrastructure on the pedestrian section of the route from PT infrastructure to PTU destination*:
Q7 = f (Q71, Q72),
where *Q71* is assessment of the quality of roads intended for pedestrian traffic (including road surface, lighting), as well as of schemes intersections, operation of traffic lights used on the final segment of PTU route to the destination;

Q72 – assessment of the level of convenience on the final section of PTU route of the stop point of land urban transport, railway station, metro station.

Besides the above qualitative indicators, it is necessary to consider *Uh* which is the register of special route parameters that are significant for a PTU of a certain type and behavioural profile, and that includes a latent, implicit requirement (condition) from the register «Quality of PT on a combined route».

The difference between our approach and assessment of the «quality» parameter of the route from the one proposed in the work of R. R. Sidorchuk and D. M. Efimova [8] refers to the object of qualitative assessment (section of movement of PTU flow), a set of quality indices and statuses, types, and behavioural profiles of travellers. The structure of the route quality indices includes:

• Index of physical accessibility of a transport infrastructure facility at the initial and final sections of the route, where the city's street and road infrastructure is used.

• Index of life and health safety of PTU.

• Index reflecting the level of risk of slowing down traffic on a section of PTU route or of deterioration in the characteristics of a transport infrastructure object, obtained based on statistical measurements.

• Index of «unique characteristics» (U) from the register of characteristics especially significant for the behavioural profile of a PTU.

To study the routes used by PTU, it is necessary to proceed with a formal description of the admissible set of combined routes according to the key parameters described above. This description becomes possible based on the results of a pairwise comparison of the «actually used» and «best» option for a certain type and behavioural profile of a PTU.

Let's designate the compared options as *i* and *i + 1*, then the parameters of the routes will have the following designation:

N_i, N_{i+1} is the number of transfers (complexity of the combined route), units;

T_i, T_{i+1} – travel time along the combined route (min);

F_i, F_{i+1} – total fare for the combined route (rub.);

Q_i, Q_{i+1} – integrated assessment of the combined route quality;

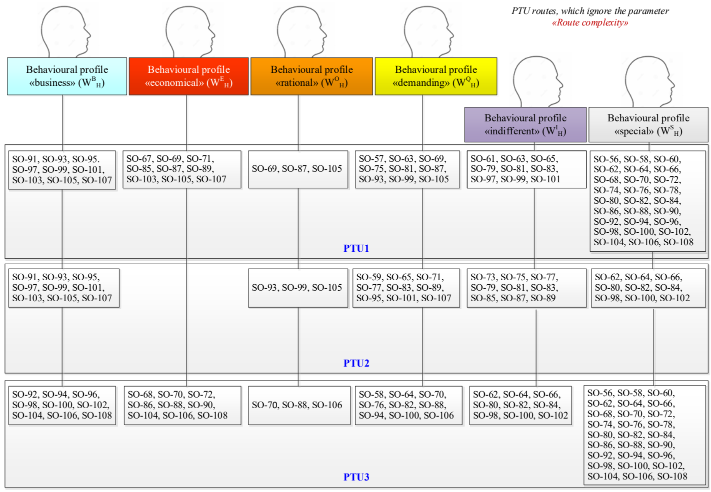
U_i, U_{i+1} – a special service on a combined route, feature valuable for a PTU.

The model for describing the set of PTU routes is as follows:

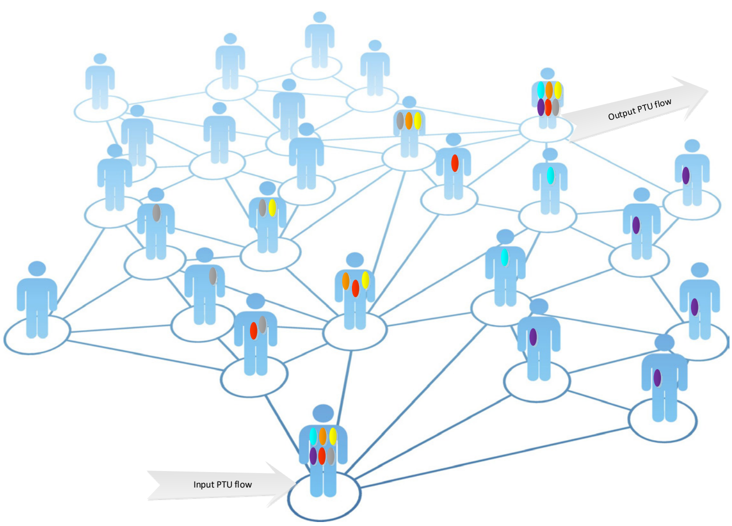
$$SO = \{[(N_i = N_{i+1}) \vee (N_i > N_{i+1}) \vee (N_i < N_{i+1})] \wedge$$
$$[(T_i = T_{i+1}) \vee (T_i > T_{i+1}) \vee (T_i < T_{i+1})] \wedge$$
$$[(F_i = F_{i+1}) \vee (F_i > F_{i+1}) \vee (T_i < T_{i+1})] \wedge$$
$$[((U_i = 0) \wedge (U_{i+1} = 1)) \vee ((U_i = 1) \wedge (U_{i+1} = 0)) \vee ((U_i = 0) \wedge (U_{i+1} = 0))] \vee$$
$$((U_i = 1) \wedge (U_i = 1))]\} .$$

Comparative analysis of the characteristics of the used and alternative PTU routes allowed us to form a description of 162 choice patterns (SO_j) in terms of predictability and sensitivity to certain parameters of the combined route for various behavioural profiles of PTU.

A fragment of the register of this description of PTU behavioural patterns is presented in Table 1.



Pic. 2. Identification of PTU behavioural profiles by route parameters (developed by the authors).



Pic. 3. Route network of PTUs (developed by the authors).

Based on the repetitive usage of the route and knowledge of the route parameters, it is possible to solve the problems of PTU typification and of identification of PTU behavioural profile. The model for identifying the behavioural profiles of PTU based on the used schemes (SO_j) is shown in Pic. 2.

The result of this identification of PTU allows to proceed with the next step focused on identifying specific currents (where the PTUs belong to the same behavioural profile) in the passenger flow on various segments of transport routes and determining the regulators that affect the demand for transport services on a specific section of popular routes.

Pic. 3 schematically shows the routes of movement of the flow of PTUs within the boundaries of an urban agglomeration with labels of behavioural profiles on sections of walking and transport routes.

The chart shows the connected sections of PTU route network and regulators, which are easily determined by the pattern of PTU transport behaviour.

CONCLUSIONS

Comprehensive studies of PTU travel chains and flows of people/pedestrians/passengers/transport vehicles on popular complex routes using «digital traces» of people travelling, algorithms of identifying relevant currents of passenger flows and of linking them to transport infrastructure facilities on sections of transport

Table 1

Fragment of the register describing the patterns of PTU behaviour (compiled by the authors)

Designation of a pattern of conditions for choosing PTU route	Characteristics of PTU behaviour and argumentation in favour of the choice of the combined route based on the results of pairwise comparison of alternative options
SO-1	unpredictable PTU behaviour and route choice
…..	…..
SO-6	predictable PTU behaviour, dependence of choice on availability of a unique service, insensitivity to PT quality on the route
…..	…..
SO-25	irrational PTU behaviour, insensitivity to fare and travel time
…..	…..
SO-38	predictable PTU behaviour, dependence of choice on travel time and availability of a unique service on the route
…..	…..
SO-50	predictable PTU behaviour, dependence of choice on travel time, SOst of travel and availability of a unique service
…..	…..
SO-57	predictable PTU behaviour, dependence of choice on the quality of PT on the route following its complication (increase in the number of transfers)
…..	…..
SO-63	predictable PTU behaviour, dependence of choice on quality of PT, admissibility of route complications, insensitivity to fare
…..	…..
SO-65	irrational PTU behaviour, insensitivity to route complexity, quality of PT on the route and cost of travel
…..	…..
SO-81	predictable PTU behaviour, dependence of choice on quality of PT on the route, insensitivity to route complexity, travel time and cost of travel
…..	…..
SO-88	predictable PTU behaviour, dependence of choice on cost of travel, quality of PT on the route and availability of a unique service, admissibility of route complications, insensitivity to travel time
…..	…..
SO-96	predictable PTU behaviour, dependence of choice on travel time and availability of a unique service, admissibility of route complications, insensitivity to quality of PT on the route
…..	…..
SO-101	predictable PTU behaviour, dependence of choice on travel time, admissibility of route complications, insensitivity to cost of travel and quality of PT on the route
…..	…..
SO-106	predictable, rational PTU behaviour, dependence of choice on travel time, fare, quality of PT and availability of a unique service, admissibility of route complications
…..	…..
SO-120	predictable PTU behaviour, dependence of the choice on complexity of the route and availability of a unique service, insensitivity to cost of travel and quality of PT on the route
…..	…..
SO-149	predictable PTU behaviour, dependence of choice on route complexity (number of transfers), travel time, insensitivity to quality of PT on the route
…..	…..
SO-159	predictable, rational PTU behaviour, dependence of choice on route complexity, travel time, cost of travel and quality of PT on the route
…..	…..
SO-162	predictable PTU behaviour, dependence of the choice on complexity of the route, travel time, cost of travel and availability of a unique service, insensitivity to quality of PT on the route

lines, based on a contactless method of determining parameters that are «ignored» by PTUs when building individual routes, create the necessary conditions not only for improving quality of transport services for the population, but also for effective organisation of PT operations in dynamically growing urban agglomerations.

Depending on the degree of congestion of transport lines, the values of transit and carrying capacity, as well as behavioural structure of passenger traffic within the sections of the transport infrastructure, the «fine tuning» of IT applications of MaaS ecosystem becomes an urgent task. Since the MaaS concept considers «mobility» «as a service», it should consider «the needs of all types of users, user groups should be introduced» [15]. For transport organisations, it is a tool for rational distribution of passenger traffic along PT routes by changing the waiting time and vehicle movement time on the line, LOS parameters, interchange parameters (through organising integrated stops for various transport routes, building new roads, lines, transport interchange hubs), ensuring an increase in the efficiency of the use of transport infrastructure and of transportation companies' operations. For PTU, this means a high-quality integrated public transport service with a higher level of consumer value.

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Frequent Flyer Cost Estimation

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ABSTRACT

The marketing activity of a modern airline is quite diverse. Under the conditions of an oligopoly, airlines develop their business in competition for a passenger.

In modern conditions in Russia, the use of dumping methods of the early 1990s is very ineffective. There are no weak airlines left on the long-distance air transportation market, and in regional markets large companies lose to small regional carriers due to the high cost of performing flights on large-capacity aircrafts of the airline's fleet.

Generally, non-price methods of competition come out on top. Flexible tariff policy, advertising, and high service in servicing passengers remain leading traditional methods of competing for a passenger.

This article is devoted to the study of another marketing method for attracting passengers, or rather retaining passengers on the airline's flights, which is development of bonus programs, frequent flyer programs. PJSC Russian Airlines (Aeroflot) was chosen as the object for the study. The subject of the research is the «Aeroflot Bonus» program.

The objective of the study is to study the cost of the program. For research purposes, this is the value of the frequent flyer program point. The problem proposed to be solved is to determine the amount of expenses for implementation of the bonus program of frequent flyers. When solving the problem in its staging part, the assessment is not limited to direct costs associated with the costs of marketing efforts in the form of costs for organising a special advertising department, issuing bonus cards, software, and wages. The estimation refers also to indirect costs in the form of unreceived proceeds from free bonus tickets. Besides, a rough estimate has been made of the airline's hidden costs due to an unpaid seat on the plane. The study conclusions indicate that hidden costs will be taken into account in calculating the cost of a flight and the bonus program has a right to exist.

Keywords: *civil aviation, airline, passenger, bonus program, frequent flyer program, bonus point, hidden costs.*

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Текст статьи на русском языке публикуется в первой части данного выпуска.

INTRODUCTION

Relevance of Bonus Programs

In 2020, airlines around the world faced big challenges due to the constraints due to the spread of coronavirus infection. Passenger traffic fell on average by 42 %. According to preliminary estimates, the loss of revenue of airlines amounted to more than 400 billion USD. Airlines in North America lost about 32 billion, Europe – about 98 billion, the countries of the Asia-Pacific region up to 86 billion [1].

Russian airlines have reduced passenger traffic by an average of 53 % compared to 2019. The most significant drop was in the volume of traffic for Aeroflot airline, as most of the airline's routes are related to international transportation. Sibir and Pobeda airlines slowed down the least of all in terms of the volume of passenger air traffic. Comparative figures for the volume of passenger air traffic of five largest airlines in the country are shown in Pic. 1.

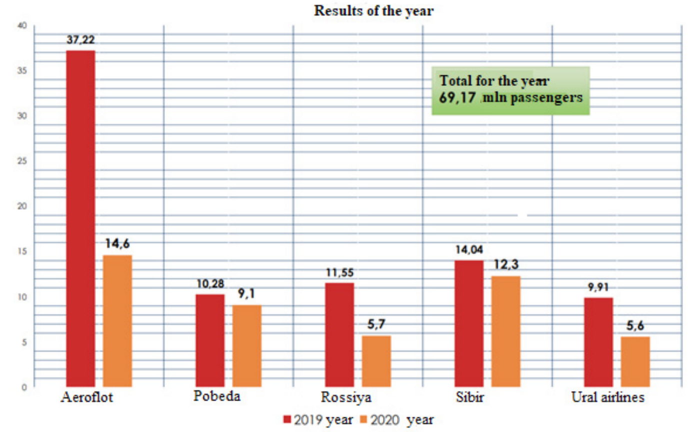
Whether economic conditions are difficult or favourable, airlines are working to attract passengers to their flights. Advertising campaigns, flexible tariff policy, sales, all this is part of marketing techniques to attract passengers. But the overarching goal of airline marketing is passenger retention policy. Organisation of work with passengers as service subscribers is a special policy of the entire range of marketing activities [2]. In this regard, airlines are developing bonus programs that allow them to reward regular customers, «frequent flyers» (FF)[1].

[1] E.g., concerning Russian air companies, see: Terchenko, E. How to earn free ticket [*Kak zarabotat' na besplantyi bilet*]. Vedomosti, August 10, 2018. [Electronic resource]: https://www.vedomosti.ru/finance/articles/2018/08/10/777839zarabotatnaaviabilet. Last accessed 01.05.2021.

Approaches to Definitions and Research Tasks

According to Laurens de Rooij and Zsoka Koczan, «A frequent-flyer program (FFP) is a loyalty program that is offered by a large number of airlines. In most cases, the customers that enrol in a program accumulate frequent-flyer miles, kilometres, points or segments corresponding to the distance travelled with that airline or their partners. Many programs also have other ways to accumulate miles such as through credit-cards, car rentals or hotel stays. In recent years the majority of air miles were awarded for the purchases made with credit and debit cards that offer air miles as a reward for using the card. Some frequent-flyer programs also offer miles through other means, such as purchasing products sold by affiliated companies» [3].

A quote from an article by O. S. Zhuravleva and M. M. Lembrikova illustrates the importance of FFPs: «From a marketing point of view, the airline's bonus program is conceived as an important tool for linking a client to a company. It significantly expands the possibilities for attracting passengers» [4]. According to those authors, «the basis of the programs for frequent flyers is the offer of various incentive schemes for acquiring additional points (options: miles, kilometres) following repeated use of the services of the airline or its marketing partners. At the same time, these marketing partners can be not only airlines, but also firms engaged in other activities, including those directly not related to aviation: these can include chains of hotels, shops, travel agencies, which have a system of receiving bonus discounts based on the customer's award points under the airline's frequent flyer program» [4].



Pic. 1. Volume of passenger transportation by leading airlines of the Russian Federation (compiled by the author).

According to Yi Gao, airline frequent flyer programs have gradually grown into a «multi-billion-dollar business» over the years, and «a fair and up-to-date assessment of the value of frequent flyer program miles has its business implications» for airlines, consumers (frequent flyer program members), airline partners, and investors [5]. This topic was subject to dedicated studies [2], as well as to numerous media publications [3], particularly with regard to COVID-19 pandemics [4].

A question on the profitability of the programs associated with attracting regular passengers to the airline's flights is then quite legitimate. Hence, in contrast with statement of the problem in the field of study the conditions of implementation of those programs, the objective of the research refers to the study of the cost of the programs. Assuming that «a unit of measure is a fundamental, measurable part that creates business value that can be measured» [1], for research purposes a unit of measure is the cost of the frequent flyer program point.

RESULTS

It is evident that the operation of bonus program requires significant expenses. First, these expenses include organisational expenditures referring to creation of a group of specialists to manage development of the program; software costs; communication with passengers by providing them with cards of the participants of FFP; maintaining personal information about program participants and reward points accumulated on their individual accounts; providing services and informing passengers through the existing call centre, or the airline's website.

Besides, there are costs associated directly with the provision of a bonus ticket to the airline passenger. These costs are direct costs of the airline referring to payment of all taxes, insurance, in-flight meals. These costs can be calculated (e.g. [6]): if, for instance, airport taxes for using the airport terminal at a given time were on average of 110 rubles (depending on the airport [5], and the costs must be counted twice (arrival and departure); fare for ground passenger handling was of 300 rubles (again, differentiated by airport); cost of inflight meals (economy class) was of 400 rubles; insurance costs were of 16 rubles, then the total costs could be calculated as 936 rubles.

It is much more difficult to calculate the organisational costs.

Further estimates are basic and conditional ones, and are suggested exclusively to show the methodology, the numerical data extracted from the reports are used only for illustration purposes and are not intended to analyse the activity of an airline.

It is the development of the methods of the unit economics [see, e.g., [7]), when a service within FFP is considered a unit, and cost of attraction of a unit customer is studied. The article does not refer to the data on the programs of airlines and their economic and finance results during pandemics to avoid distortion of calculation results.

Let us first assume that the expense item for maintenance of an airline's frequent flyer program relates to advertising expenses and takes up about 30 % there. If taking this assumption, we consider that, i.e., Aeroflot has spent in 2019 3 528 252 thousand rubles on advertising [6], then the estimated costs of FFP might amount to 1 058 475 thousand rubles. Researchers of effectiveness of bonus programs assume that up to 15 % of transported passengers participate in the programs [5]. Consequently, for Aeroflot it might be accounted as 5,5 million passengers [7].

Then hypothetically it can be assumed that the organisational costs of the program will amount to 192 rubles per passenger.

The cost of a reward point can be calculated using the formula:

$$A = B/C, \quad (1)$$

where A is cost of a bonus point (rubles);

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[2] See, e.g., Special Report – The Price of Loyalty, 2012. [Electronic resource]: https://airlines.iata.org/reports/specialr eportthepriceofloyalty. Last accessed 01.05.2021.

[3] See, e.g., Claire Bushey. US airlines reveal profitability of frequent flyer programmes. *Financial Times*, September 16, 2020. [Electronic resource]: ft.com/content/1bb94ed9–90de4f15aee0–3bf390b0f85e. Last accessed 01.05.2021.

[4] See, e.g., So Yeon Chun, Evert de Boer. How Loyalty Programs Are Saving Airlines. *Harvard Business Review*, April 02, 2021. [Electronic resource]: https://hbr.org/2021/04/howloyaltyp rogramsaresavinga irlines. Last accessed 01.05.2021.

[5] E.g., Airport dues rates and ground handling rates for aircraft of Russian operators at Pulkovo airport; Airport Tax. [Electronic resources]: https://pulkovoairport.ru/partners/airlines/rates/airlines/; https://pulkovoairport.ru/partners/airlines/rates/foreign_airlines/. Last accessed 01.05.2021.

[6] Aeroflot Annual reports [Electronic resource]: https://ir.aeroflot.ru/en/reporting/annual-reports/. Last accessed 01.05.2021.

[7] The specific figure in the report for 2020 is indeed 8 mln persons.

B – the amount of expenses for transportation of a passenger with an award ticket (rubles);

C – sum of points required to receive an award ticket (i.e., 15000).

In the above hypothetical example, the cost of a bonus point might be 0,07 rubles. The amount is insignificant, emphasising high profitability of measures to attract passengers. Nevertheless, there are also hidden costs in the form of unearned revenue from unsold commercial tickets. In this regard, it is possible to make tentative calculations: the total revenue from program participants will be:

$$P = N \bullet T, \quad (2)$$

where *P* is total revenue from program participants (thousand rubles);

N – number of program participants (people);

T – average tariff (thousand rubles);

P = 5 500 000 • 8 = 44 000 000 thousand rubles.

Different airlines use different conditions for earning bonus miles. So, Sibir Airlines [S7 airlines brand name] credit miles for flights on regular flights of the airline as a percentage of the distance and depending on the fare at which transportation is carried out[8]. With the average length of S7 airlines of 2200 km or 1375 miles, it is possible to get from 687 miles when flying in economy class to 3437 when flying in business class.

In Utair, miles are calculated in the range from 3 to 7 % of the ticket price, the percentage level depends on the service class[9].

At Aeroflot, miles in the program are accrued in accordance with the distance in miles between the airports of departure and arrival[6]. Thus, with an average length of the airline's air route of 2670 km, or 1668 miles, the program participant is credited with an average of 2000 miles. An award ticket for this distance will cost at least 15000 miles.

Thus, using the averaged indicators of the distance of transportation and the cost of the ticket, we can conclude that to receive an award ticket, a passenger must use the services of the airline 7 times. With an average ticket price of 8000 rubles, the amount of revenue from one program participant will be 56000 rubles. The aviation mobility ratio of the country's population in 2019 was 87 % approximatively, given that the population of the country in 2019 was 146 820 700 people, and the country's airlines carried 128 127 828 passengers.

Considering travelling rate of frequent flyers, it can be assumed that they use air transport services much more often than an average resident of the country, and despite general background of a relatively low indicator of aviation mobility of the population, it can be assumed that a frequent flyer on average has more air flights during the year. Let's calculate the total number of miles earned by the participants in the bonus program:

$$CM = N \bullet Hm, \quad (3)$$

where *CM* is the sum of miles earned by all program participants;

N – total number of program participants (people);

Hm – average number of miles per ticket for a program member.

In assumed figures, it might be calculated as CM = 5 500 000•2000 = 11 000 000 000 miles.

To obtain one award ticket it is necessary to cumulate 15 000 miles, therefore:

number of bonus flights per year

$$= \frac{11000000000}{15000} = 733333 \text{ tickets.} \quad (4)$$

With an average ticket price of 8 000 rubles, hidden costs due to the fact that these tickets were not available for commercial sale will amount to 5 866 664 thousand rubles, or 1 066 rubles per each program participant.

Then, considering hidden costs, the cost of one bonus point (1) will be:

$$A = \frac{936+192+1066}{15000} = 0{,}14 \text{ rub.} \quad (5)$$

It is possible to continue calculation of the cost of transportation for the awarded program participants borrowing in mind that part of the airline's operating costs will not be paid either. Let us consider the structure of expenses of Aeroflot airline at a given time (Pic. 2) and calculate those of them, that will also affect the cost of one bonus point.

Let's calculate the average cost of transporting one unpaid seat. Let's consider fuel costs, airport taxes and aircraft leasing costs for calculations.

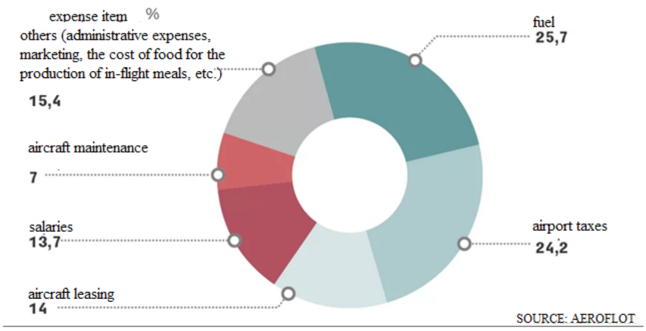
The Aeroflot Group's aircraft fleet numbered at a time 366 aircraft (Table 1).

To determine the cost of transporting an unpaid seat regarding refuelling, it is necessary to calculate the average specific fuel consumption.

$$SFC = \frac{AFC}{AASK}, \quad (6)$$

8 Official website of S7 airlines. [Electronic resource]: https://www.s7.ru/en/. Last accessed 01.05.2021.

9 Official website of Utair airlines. [Electronic resource]: https://www.utair.ru/en/. Last accessed 01.05.2021.



Pic. 2. Structure of the airline's operating costs[6].

where SFC – specific fuel consumption (g/pax-km);

AFC – average fuel consumption per an average distance flight (kg);

$AASK$– average available seat kilometres.

$AASK = L \cdot S\kappa$, (7)

where L is average length of an air line (2670 km);

$S\kappa$ – average number of available seats (221 from Table 1).

$AASK$ = 2670 km • 221k = 589 688,57 pax-km. (8)

When performing a flight with an average distance of 2670 km at an average speed of 720 km/h, it will take 3 hours 40 minutes, the fuel consumption will be:

SRT = 3,7 hour • 3581 kg = 13 278 kg. (9)

Therefore, specific fuel consumption will be:

$$SFC = \frac{13278}{589688{,}57} = 22{,}52\,\frac{\text{gr.}}{\text{pkm}}. \quad (10)$$

That is, to transport one seat or passenger per kilometre, 22,52 grams of aviation fuel will be required, and to transport a passenger over an average distance, 60,12 kilograms of fuel will be needed. The average price of aviation fuel in April 2021 was 49 747 rubles per ton[10]. The unpaid expense would then be 2 990 rubles for each award ticket.

The second expense item is associated with airport dues[11]. Average maximum take-off weight of aircraft, from Table 1 can be estimated at 139,7 tonnes. Airport dues for take-off and landing (for example, at the Sheremetyevo airport) were 467,55 rubles per ton of maximum take-off weight, dues related to ensuring aviation security at the same airport were of 23,01 rubles per ton of maximum take-off weight. Then the unpaid expenses for ensuring take-off and landing and aviation security will be:

139,7•490,56 = 68 531,23/221 = 310,09 rubles per each award ticket.

The third item of expenses[6] selected for determining the value of the bonus point is aircraft leasing. It is difficult to estimate the exact costs in view of the wide variety of aircraft types, their service life, but if we focus on the average prices of the lease cost per a seat, then it will be 2000 USD per seat per month, therefore 24 000 per year. If the average flight lasts 3,7 hours, then considering necessary stoppings of flights to perform routine maintenance, the aircraft can perform about 100 flights per month. Consequently, the cost per seat of an award ticket will be 20 USD or 1 500 rubles.

The total cost of one bonus point will be:

$$A = \frac{936 + 192 + 1066 + 2990 + 310{,}09 + 1500}{15000} = 0{,}46\,\text{rubles}. \quad (11)$$

It turns out that the airline bears indirect and hidden costs in the amount of 46 kopecks per each point of the award ticket, or 6 900 rubles per a ticket. In total, in 2019, according to the above author's calculations, we can estimate the number of issued award tickets as 733 333, therefore, indirect losses might be 5 059 997,70 thousand rubles. These losses, in principle, exist speculatively, since they are reimbursed by the cost of tickets, at the expense of calculating the cost of a flight, considering the seat occupancy rate within 72–75 %, that is, empty and premium seats are paid for by passengers.

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[10] Official website of FAVT (Federal Agency for Air Transport). [Electronic resource]: https://favt.gov.ru/?snm. Last accessed 01.05.2021.

[11] Order of the Ministry of Transport of the Russian Federation of July 17, 2012 No. 241 «On air navigation and airport dues, tariffs for servicing aircraft at airports and in the airspace of the Russian Federation». [Electronic resource]: https://base.garant.ru/70212130/. Last accessed 01.05.2021.

Table 1

The composition of the aircraft fleet of Aeroflot airline

Aircraft type	Number of aircrafts	Number of seats	Hourly fuel consumption (kg)	Specific fuel consumption (g/pax-km)	Maximum take-off weight (tonnes)
A330-200	5	235	5600	30,74	233
A330-300	17	292	5600	26,64	233
B777-300	5	550	6800	17,17	299
B777-300ER	22	402	7800	26,95	351
B747-400	9	660	10300	21,68	397
A319	35	156	2350	20,92	75,5
A320	85	158	2500	21,98	78
A321	37	183	2740	20,80	93,5
B737-800	87	158	2480	21,80	79
DHC6-400	3	39	480	33,33	5,6
DHC8-200	2	39	540	19,23	16,4
DHC8-300	4	56	560	13,89	19,5
DHC8-400	5	78	680	12,11	29
SSJ100	50	87	1700	27,14	45,9
Total	366	3092	50130	314,37	1955,4
Average value		221	3581	22,45	139,7

It can be assumed that eliminating the cost per unit of measure of the loyalty program could lead to a decrease in the cost of tickets, which will increase the number of sales. But FF programs are aimed at increasing airline brand loyalty. This factor can be proved by the positive dynamics of the number of program participants, while the influence of other factors on the increase in the volume of transportation is more complicated.

BRIEF CONCLUSION

As a conclusion, we can quote: «Modern methods of marketing communications, using the additional points for the most important customers of the airline (for example, rewarding passengers of high service classes with points calculated with a ratio exceeding economy class by one and a half or two times for the same flight) are generally recognised factors that result in an increase in passenger turnover and airline customer retention rate» [6].

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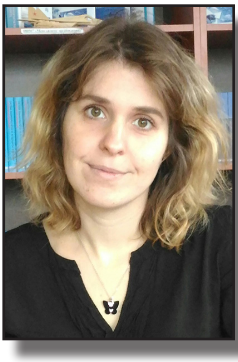
Transport System of the Republic of Sakha (Yakutia): Analysis of the State and Development Challenges



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ABSTRACT

The transport accessibility of the Arctic zone is of strategic interest for Russia from the point of view of the possibility of mineral exploration and ensuring further systemic development of this part of the national territory.

The objective of the study is to carry out a spatial analysis of the transport system of the Republic of Sakha (Yakutia), to identify its topological properties and restrictions that impede providing sufficient logistics services. Based on the method of spatial analysis, the conducted study of the state of the transport system of the Republic of Sakha (Yakutia) allowed to assess transport provision within its territory for three types of transportation: transport provision of internal regional (local) transportation, transport provision of accessibility (entry and exit) of the territory of the region, and transport provision of transit transportation across the region.

The study showed that air transport is the main mode for passenger transportation, while seasonal water and winter road transportation are the main modes of freight haulage.

The regions of Yakutia with access to traffic arteries and isolated from them have been identified. Calculations based on the Engel's coefficient allowed to proceed with a mathematical assessment of the transport system of the region, which indicates its insufficient development due to the lack of year-round transportation routes in the areas of the Far North and the Arctic zone. The transport infrastructure of this part of the region are represented by seasonal winter roads and waterways, which prevents from assessing their general year-round potential. For its assessment, it is necessary to consider seasonal availability of each individual section of the network.

Keywords: *transport system, Republic of Sakha (Yakutia), airport network, water transport, Arctic zone, winter road, transport provision of the territory.*

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The text of the article originally written in Russian is published in the first part of the issue.
Текст статьи на русском языке публикуется в первой части данного выпуска.

INTRODUCTION

The Republic of Sakha (Yakutia) is not only the largest administrative territorial entity of the Russian Federation, but also the largest subnational administrative territorial entity in the world. Its total area, including the continental and insular parts, is 3,1 mln sq. km. More than 50 % of the Republic's territory is located beyond the Arctic Circle (about 1,63 million sq. km). The Arctic zone of the Republic of Sakha (Yakutia) exceeds the area of the Arctic zone of Canada [1].

According to the decree of the President of the Russian Federation[1], the land territory of the Arctic zone of the Republic of Sakha (Yakutia) includes the territories of 13 districts (ulus): Abyysky ulus, Allaikhovsky ulus, Anabarsky national (Dolgan-Evenk) ulus, Bulun ulus, Verkhnekolymsky ulus, Verkhoyansky ulus, Zhigansky national Evenk ulus, Momsky ulus, Nizhnekolymsky ulus, Oleneksky Evenk national ulus, Srednekolymsky ulus, Ust-Yansky ulus, and Even-Bytantaysky national ulus.

With such a large area, the population of the region is only 981 971 people (0,32 people per sq. km) according to Rosstat [Federal State Statistics Service] data as of January 1, 2021.The share of the urban population was 66,1 %, the share of the rural population was 33,9 %. Most of the population of Yakutia lives in the central part of the region (about 500 thousand people). The largest cities are Yakutsk, the Republic's administrative centre, Neryungri, Aldan, Lensk, Mirny, Vilyuisk, Aikhal, and Udachny. The uneven settlement is explained by the difficult natural and climatic conditions of the northern part of the region, which complicates development of the transport system and ensuring transport accessibility of all remote sparsely populated areas [2–4].

At the same time, the Republic of Sakha (Yakutia) is of great economic interest from the point of view of exploration of the richest mineral deposits. The territory of the Republic englobes 82 % of the country's diamond reserves, 17 % of gold, 61 % of uranium, 82 % of antimony, 6,2 % of iron ore, 40 % of coal, 28 % of tin and 8 % of mercury[2], as well as the reserves of rare earth elements. The diamond mining industry is widely developed, while the region is gradually developing the extraction of oil and gas resources.

The development of the mineral industry requires a reliable transport infrastructure necessary for delivery of production resources (building materials, fuel, equipment), transporting specialists, and the export of mining products [5]. However, the large area of the territory, natural and climatic conditions, the presence of permafrost, terrain features, a dispersive settlement system determine the high construction cost of transport roads. According to the Government of the Republic of Sakha, in terms of transport, Yakutia is one of the most isolated and hard-to-reach regions in the world, since 90 % of its territory does not have year-round transport links[3]. When allocating the budget, priority is given to transport projects aimed at developing economically and socially justified ties, which are predominantly of interregional and country significance to the detriment of internal and local ties [6]. The peculiarities of the transport system of the Republic of Sakha (Yakutia) are: absence of alternative to the existing transport delivery schemes, consisting of several links, including seasonal routes, and limited interchangeability of modes of transport and transportation routes, which lead to increased travel time, transport monopolisation and increased costs (high tariffs) [7].

The *objective* of the study is to conduct a spatial analysis of the transport system of the Republic of Sakha (Yakutia), to identify its topological properties and constraints that impede sufficient transport provision of the territory.

RESEARCH METHODS

The study of the state of the transport system of the Republic of Sakha (Yakutia) was carried out at the first stage based on a spatial analysis of the location and topological structure of the existing networks of water, rail, and road transport. The analysis of the topological

[1] Decree of the President of the Russian Federation of May 2, 2014 No. 296 «On the land territories of the Arctic zone of the Russian Federation» (with amendments and additions introduced by the decree No. 220 of May 13, 2019). [Electronic resource]: https://www.garant.ru/products/ipo/prime/doc/70547984/. Last accessed 07.07.2021.

[2] Mining industry. Ministry of Industry and Geology of the Republic of Sakha (Yakutia) official website. [Electronic resource]: https://minprom.sakha.gov.ru/gornorudnaja-promyshlennost/gornorudnaja-promyshlennost-gorno. Last accessed 07.07.2021.

[3] The Republic of Sakha (Yakutia). Federation Council of the Federal Assembly of the Russian Federation. [Electronic resource]: http://council.gov.ru/structure/regions/SA/. Last accessed 07.07.2021.

structure of the transport network was carried out according to the methodology of S. A. Tarkhov [8; 9]. Among the main topological properties of transport networks, he singles out: spatial connectivity and isolation, mutual ranking of elements (their mutual arrangement), neighbourhood relation, cyclicity and branching of linear network elements. The assessment of the topological structure of the transport system of the Republic of Sakha (Yakutia) was based on the results of studies of imperfections in transport networks in the regions of Siberia and the Far East [7; 10].

Further, the analysis of the transport provision of the region was carried out in terms of ensuring transportation for three types of transportation: transport provision of internal regional (local) transportation, transport provision of access (entry and exit) to the territory of the region, and transport provision of transit through the territory of the region. The division of the indicator of transport provision into three components is necessary since the effective functioning of the Arctic transport system cannot be achieved without ensuring high-quality transport trunk and feeder lines [11]. The conducted analysis allowed to identify areas that have access to transport trunk lines and those which are isolated from them. Further, based on statistical data of the Ministry of Transport and Roads of the Republic of Sakha (Yakutia), it was possible to calculate indicators of the length of transport routes per 1000 sq. km of territory and per 10 000 inhabitants, the performance indicators of each mode of transport, and their respective place in the structure of passenger transportation and cargo turnover in the region.

For a mathematical assessment of the level of development of the transport system of the Republic of Sakha (Yakutia), Engel's coefficients were used considering the length of the year-round main lines of road and rail transport [12–14]. The complexity of assessing the transport provision of the Republic of Sakha (Yakutia) refers to many seasonal transportation links, which does not allow assessing their year-round potential [15–17].

RESULTS. SPATIAL ANALYSIS OF THE LOCATION AND PERFORMANCE INDICATORS OF THE TRANSPORT NETWORK OF THE REPUBLIC OF SAKHA (YAKUTIA)

Historically, due to the large area of the territory, natural and climatic features, and the presence of the largest river artery in the Republic of Sakha (Yakutia), *river transport* is the cheapest and most popular. The length of the operated waterways in the Republic of Sakha (Yakutia) is 21,8 thousand km, of which 13,6 thousand km are serviced, and guaranteed depths are provided at 9,2 thousand km (Pic. 1). The water transport network of Yakutia consists of the channels of six rivers: the Lena (4440 km), Anabar (939 km), Olenek (2292 km), Yana (872 km), Indigirka (1726 km), and Kolyma (2129 km) with their tributaries, as well as of a section of the Northern Sea Route (NSR). The main waterway of the Republic is the Lena with tributaries Aldan (2273 km) and Vilyui (2650 km) [18]. The Lena is the third river in Russia in terms of basin area after the Ob and Yenisei. Besides, it is the largest river in the world that flows through permafrost area. The length of the sea coastline of Yakutia is 4,5 thousand km. The analysis showed that the Republic's river routes provide cargo delivery to 17 out of 34 districts (ulus) and the city of Yakutsk, including 11 out of 13 ulus located in the Arctic zone (except for Oleneksky and Eveno-Bytantaysky districts). Delivery of goods to the territory of the region is carried out, as a rule, from the upper river Lena after the opening of navigation. Further, the cargo is awaiting the opening of navigation at the upper reaches of the river and on the NSR. Along the NSR, cargo is delivered by river-sea vessels to the channels of the northern rivers and along them to district centres. In district centres, cargoes are deposited in warehouses and in winter they are transported by road to settlements by winter roads. Delivery of goods under this scheme takes about a year on average. The navigation period on the rivers varies from 45 to 130 days, depending on the navigation area, climatic conditions, water level, volume and quality of survey and dredging works. On the Lena, Yana, Indigirka, Kolyma rivers, navigation starts in late May – early June. On the bars of these rivers, on the Olenekskaya creek, the Olenek River and along coastal sea routes, navigation starts in late July and early August. Navigation on offshore sections is limited to 40–70 days from July 15 to October 7. The port of Tiksi is shallow and is not capable of receiving large sea vessels. The maximum allowable draft is 5,6 m; therefore, unloading is carried out in the roadstead, and due to September storms, the navigation period is reduced to 30–40 days [19]. In these conditions, there is an acute issue of deepening the water area of the seaport

Pic. 1. A schematic diagram of the network of water transport of the Republic of Sakha (Yakutia)[4].

Table 1

Length of waterways and dynamics of production indicators of water transport in the Republic of Sakha (Yakutia)*

Indicators	2013	2014	2015	2016	2017	2018	2019
Length of river waterways, thousand km	16 520	16 522	16 522	16 522	16 522	16 522	16 522
Total transported, thousand tonnes	2 757,5	2 942,3	2 709,4	2 731,8	2 745,8	2 411,8	2 798,0
Including: PJSC LORP	1 124,0	1 305,0	1 315,0	1 167,0	1 416,0	1 280,0	1 241,0
Others	1 633,5	1 637,3	1 394,4	1 564,8	1 329,8	1 131,8	1 557,0
Total cargo turnover, mln tkm	2 471,1	2 721,1	2 484,2	2 248,9	2 236,7	2 160,6	2 276,0
Passengers transported, thousand people	252,9	354,6	310,4	337,4	312,0	312,0	no data
Passenger turnover, million pkm	22,6	26,1	22,3	27,4	28,6	27,7	no data

* Compiled by the author based on the data of the Ministry of Transport and Roads of the Republic of Sakha (Yakutia).

of Tiksi, through which the region is connected with the Northern Sea Route. Without solving this problem, it is impossible to fully use the potential of the Northern Sea Route.

Besides, in the summer months, the rivers of Yakutia become shallow, which requires introduction of restraints on the draft of ships, leading to a loss of the carrying capacity of the fleet. According to the data of the Lena United River Shipping Company in 2020, during the period of shallow water in the sections of the river Yana fleet was operated with a load of only 30–50 %, and in the sections of the river Indigirka with a loading of 50 %. In 2020, the situation was aggravated by forest fires in the Lena, Vilyui, Aldan, Kolyma basins, which provoked almost zero visibility. As a result, from 5 to 12 August, a ban was imposed on navigation downstream of the Aldan River[5]. The dynamics of production indicators of water transport and the length of waterways are presented in Table 1.

Restrictions associated with river shallowing and a reduction in the commercial load of river vessels lead to a decrease in the cargo turnover of river transport.

The railway transport of Yakutia is represented by the single Amur-Yakutsk main line, connecting the Trans-Siberian and Baikal-Amur main lines with the bank of the Lena opposite Yakutsk, 10 km from the village of Nizhny Bestyakh. Its length is 767 km, Pic. 2.

The absence of a bridge across the Lena River does not allow laying a railway line to the regional capital, Yakutsk. As a result, the goods delivered by rail are transloaded to river vessels or deposited in warehouses in the village of Nizhniy Bestyakh, and in winter they are delivered to Yakutsk via an ice crossing by road. The construction of the road bridge, which began in 2021, will partially solve this problem by

[4] Delivery of goods by water transport to the territory of the Republic of Sakha (Yakutia). A-Service. Delivery of goods to hard-to-reach regions. [Electronic resource]: https://as-sib.com/uslugi/rechnyie-perevozki/lena. Last accessed 07.07.2021.

[5] Lena United River Shipping Company. Annual report on the results of work for 2020. Yakutsk, 2021, 37 p.

Pic. 2. Amur-Yakutsk railway line.
(Amur-Yakutsk railway main line. Russia 24. [Electronic resource]: https://www.youtube.com/watch?v=MFJS1sQGrHs. Last accessed 07.07.2021).

organising year-round road transportation of passengers and goods to the opposite bank of the Lena River.

The main categories of cargo delivered by rail are coal, construction materials and oil products, containerised cargo, food products, and timber. Passenger traffic is carried out daily. The length of the railway line and performance indicators are presented in Table 2.

According to the Ministry of Transport and Roads of the Republic of Sakha (Yakutia), the increase in the volume of transportation of goods by rail is associated with an increase in the volume of transportation of foodstuffs following entering into force of a single lower tariff of JSC Russian Railways within the price list 10–01 since the beginning of 2018, as well as of transportation of coal by coal mining enterprises.

Since extensive network of railway transport misses, *road transport* in the Republic of Sakha (Yakutia) is the only available land mode of transport. However, the road network is also poorly developed, has seasonal operation, and individual road sections and territorially isolated. The location of the network of federal and regional highways and of local roads, including winter roads, across the territory of the Republic of Sakha (Yakutia) is shown schematically in Pic. 3.

There are three federal highways running on the territory of the Republic. The A-360 «Lena» highway with a length of 1157 km connects the R-297 «Amur» highway and the settlement of Nizhny Bestyakh. The highway does not reach Yakutsk since there is no bridge across the river Lena. In summer, the crossing is carried out by ferry, in winter using the ice bridge (from December to April), during the period of ice drift and freezing-over by hovercraft [20]. In Nizhniy Bestyakh, the highway joins the R-504 Kolyma highway. The federal highway «Kolyma» has a length of 2032 km, connects Nizhny Bestyakh to Magadan and goes to the Pacific Ocean coast. A federal highway A-331 «Vilyui» is under construction, which will have to connect Tulun of Irkutsk region through Bratsk, Ust-Kut, Mirny, to Yakutsk. On the territory of Yakutia, there exists a section from Mirny to Yakutsk, on the territory of Irkutsk region there is a segment from Tulun to Ust-Kut, the rest of the sections are connected by winter roads. In the northern and Arctic areas of the Republic, the length of highways with year-round operation is extremely insignificant. More than 92 % of the roads of the Republic of Sakha (Yakutia) are seasonal roads (winter roads).

The length of the roads and the performance indicators of road transport in the Republic of Sakha (Yakutia) are presented in Table 3.

Cargo turnover of road transport has been showing positive dynamics from 2017 till now since this type of transportation is the only one available for settlements located far from river arteries.

The total length of the road network in the Republic is 38 998,7 km, however, more than half of the roads are seasonal and winter roads. The total length of paved roads is 12 205,9 km

Pic. 3. Location of the year-round and seasonal road network of the Republic of Sakha (Yakutia) (winter roads are marked in green, darker colour; currently not-maintained winter roads are shown with a dotted line).
(How to lay a winter road a month earlier? Round table in the Public Chamber of the Republic of Sakha (Yakutia). [Electronic resource]: https://dnevniki.ykt.ru/nikbara/1114992?mobile=true https. Last accessed 07.07.2021).

Table 2

Length and indicators of activity of railway transport in the Republic of Sakha (Yakutia)*

Indicators	2014	2015	2016	2017	2018	2019	2020
Length, km	525	525	525	525	525	525	525
Volume of cargo transportation, thousand tonnes	2 158,2	2 928,1	4 015,5	4 681,6	5 501,8	6 683,6	6 067,7
Cargo turnover, million tkm	337,2	410,1	519,8	581,7	615,8	1 047,4	1 628,4
Passengers transported, thousand people	88,8	75,6	74,9	79,6	83,6	93,1	81,7
Passenger turnover, million pkm	26,5	22,9	34,4	35,3	37,1	49,4	39,5

*Compiled by the author based on the data of the Ministry of Transport and Roads of the Republic of Sakha (Yakutia).

(31,3 %). Federal roads' length is 3 586,2 km, of which 3 313,6 km (92,4 %) are hard surfaced. Regional roads are 13 152,7 km long, of which 3 545,3 km are hard-surface roads (27,0 %). Local roads are 22 259,8 km long, of which 5 347,0 km (24,0 %)[6] have hard surface.

The period of operation of winter roads is directly related to the weather conditions and freeze-up on the rivers. On average, the working period of winter roads does not exceed four months: from the end of December to the end of April (25.12–25.04). An increase in the efficiency of their use can be achieved by increasing the accuracy of forecasting ice phenomena for all water areas of the region. One of the methods for specifying the forecast accuracy was proposed in the works of N. A. Filippova [21].

Air transport is the only one mode of transport within the transport system of the Republic of Sakha (Yakutia), capable of providing year-round transport accessibility of all districts and settlements. Airports are its main nodes of the civil aviation, interconnected by the route network of airlines and land modes of transport. On the territory of the Republic of Sakha (Yakutia), according to the Federal Air Transport Agency as of May 28, 2021, there are 31 airports[7]. 16 airports in Yakutsk and district centres will have been reconstructed till 2024[8]. The airport network of the Republic is served by four organisations: 28 airports are under the jurisdiction of the Federal State Enterprise «Airports of the North». «Airport Yakutsk» which is of federal importance, is operated by JSC «Airport Yakutsk». Talakan airport is operated by JSC «Airport Surgut», «Mirny» airport, operated by the Mirny Aviation Enterprise

[6] Government decree of the Republic of Sakha (Yakutia) No. 146 of 27.03.2010 (as amended on 17.05.2021).

[7] State register of aerodromes and heliports of civil aviation of the Russian Federation as of 28.05.2021.

[8] Tayursky, V. Runway [*Polosa razgona*]. Rossijskaya gazeta, 11.02.2021. [Electronic resource]: https://rg.ru/2021/02/11/reg-dfo/v-iakutii-nachinaetsia-massovaia-rekonstrukciia-aeroportov.html. Last accessed 07.07.2021.

Table 3

Length of highways and roads and performance indicators of motor transport in the Republic of Sakha (Yakutia)*

Indicators	2014	2015	2016	2017	2018	2019
Public roads with hard surface, km	11 367	11 714	11 766	11 900	12 047	12 205
Cargo transported, thousand tonnes	14 401,4	26 057,3	26 396,0	20 696,0	21 316,4	22 612,0
Cargo turnover, mln tkm	1 643,2	2 279,0	2 304,1	2 185,2	2 333,8	2 651,0
Passengers transported, million people	92,5	96,2	no data	96,6	94,7	no data
Passenger turnover, mln pkm	447,0	483,6	no data	475,4	456,4	no data

* Compiled by the author based on the data of the Ministry of Transport and Roads of the Republic of Sakha (Yakutia).

Table 4

Air transport performance

Indicators	2014	2015	2016	2017	2018	2019*
Cargo and mail loaded and unloaded, tonnes	31 672,46	28 253,74	32 772,26	32 361,40	27 348,40	22 575,61
Cargo turnover, million tkm	82,3	69,9	73,3	67,7	48,9	52,1
Passengers embarked and disembarked, people	1 567 655	1 624 624	1 675 180	1 757 327	1 760 858	1 849 467

* Compiled based on the data of the Ministry of Transport and Roads of the Republic of Sakha (Yakutia) for 2014–2018, data for 2019 are provided by the airport management and does not include data from Talakan airport and mail processing at Yakutsk and Mirny airports.

of PJSC ALROSA. The indicators of their activities are presented in Table 4.

The volume of cargo transportation by air in the Republic of Sakha (Yakutia) is insignificant and is formed mainly with perishable and pharmaceutical products delivered to provide remote areas. The decrease in passenger air transportation is due to the increase in fuel prices and consequently in ticket costs. On the territory of the Arctic area of the Republic, there are 14 airports (airfields) and one aviation site in the village of Nizhneyansk, which are under the jurisdiction of the Federal State Enterprise «Airports of the North». Flights to these airports are carried out from the administrative centre with a frequency of one or two flights per week. Flights on local routes are operated by AN-24 aircrafts with a capacity of 48 seats and Let L-410 Turbolet with a capacity of 19 seats with an average load of 30 to 70 %, which is economically ineffective. Therefore, airlines are reducing the frequency of flights to increase the load factor [7; 22].

Spatial location of airports and air routes in the Arctic area are shown in Pic. 4.

The calculations carried out by the author showed that in 2019 the main volume of transport work in the region fell on road transport and amounted to 2 651,0 million tkm (40 %), the cargo turnover of river transport decreased and amounted to 2 276,0 million tkm (34 %), the cargo turnover of railway transport increased and amounted to 1 628,4 million tkm (25 %), the cargo turnover of air transport amounted to 52,1 million tkm (less than 1 %). The changes took place in connection with the increased role of railway transport due to reception of some cargo flows on Ust-Kut–Nizhny Bestyakh section redirected from water transport. Road transport is most demanded when organising passenger suburban transportation, and air transport is most used for intercity intraregional traffic.

Table 5 shows the calculation of indicators of transport development of the territory of the Republic of Sakha (Yakutia), however, these indicators do not take into account the constraints of seasonal availability of water transport. The length of winter roads was not considered in the calculation of the indicators.

The Republic of Sakha (Yakutia) has an extremely low density of hard surface roads since they are absent in the northern part of the region. The length of the railway is also very small in relation to the total area of the region. As a result, the Engel's coefficient in Republic is only about 0,01. For comparison, the average value of the Engel's coefficient for the Far Eastern Federal District of the Russian Federation is 0,37, and for the Siberian Federal District it is of 0,53, but these calculations do not consider seasonality of the waterways used. In general, for the Russian Federation, the Engel's coefficient is 0,6. If, when calculating the Engel's coefficient for the Republic of Sakha (Yakutia), we consider the length of waterways and winter roads without taking into account their seasonal use, then its

Pic. 4. A schematic diagram of the airport network of the Republic of Sakha (Yakutia) and the operating route network of regular air transportation in the Arctic area. Compiled by the author based on the analysis of flight schedules of Polar Airlines and Yakutia Airlines.

Table 5

Indicators characterizing the level of transport provision of the territory of the Republic of Sakha (Yakutia)*

Indicators	2014	2015	2016	2017	2018	2019
Density of hard surface roads per 1000 sq. km of territory, km	3,69	3,80	3,82	3,86	3,91	3,96
Density of railways per 1000 sq. km of territory, km	0,17	0,17	0,17	0,17	0,17	0,17
Density of hard surface roads per 10 000 inhabitants, km	118,79	122,06	122,20	123,40	124,58	125,57
Density of railways per 10 000 inhabitants, km	5,49	5,47	5,45	5,44	5,43	5,40
Engel's coefficient	0,01	0,01	0,01	0,01	0,01	0,01

* Calculated by the author based on the data of the Ministry of Transport and Roads of the Republic of Sakha (Yakutia).

value will be of 0,03. The complexity of considering seasonality of the use of waterways and road transport routes is associated with the different periods of operation of different sections of the network and requires a detailed mathematical analysis.

CONCLUSIONS

Spatial analysis of the transport system of the Republic of Sakha (Yakutia) has allowed to draw several conclusions.

Seasonal networks of winter roads and river routes, especially outside the southern and central parts of the region, are of predominant importance in organising cargo transportation throughout the region. Transportation by rivers and road haulage are carried out in the meridional direction and do not have sufficient connections with each other.

The main role in organising local passenger transportation between municipal districts is played by air transport, the airport network of which is poorly developed and connects only the administrative and regional centres of the region. High tariffs for transportation reduce affordability of intraregional air transportation. The high role of air transport is an objective necessity and is confirmed by the experience of many countries [23–26].

Regarding transport provision of access (entry and exit) to the territory of the Republic of Sakha (Yakutia), one can speak of its semi-isolated position, since the northern regions have no connection between the hard-surface road network and federal highways; and railway transportation is carried out only to the Ust-Kut village and does not connect the capital of the region with the federal railway main line.

Several spatial forms of transport provision have been formed on the territory of the Republic of Sakha (Yakutia) [7; 27–29]:

• Central transport hub: the city of Yakutsk, located at the intersection of three federal highways («Lena», «Kolyma», «Vilyui»), the Berkakit–Tommot–Nizhny Bestyakh railway and Ust-Kut–Lensk–Yakutsk–Tiksi waterway along the Lena River [28], while its year-round connectivity with federal highways is hampered by the absence of a bridge across the river Lena.

• Southern transit transport hub: the city of Neryungri (Yakutsk–Aldan–Neryungri), serving Yakutsk all year round [28] with limited traffic during periods of autumn freeze-up and spring floods, with access to «Lena» federal highway and Amur-Yakutsk railway. Through it, the entrance from and the exit to the national-wide transport network is carried out [23].

• Western transport hub: the city of Mirny, which arose due to development of the diamond mining industry (Ust-Kut–Lensk–Mirny–Udachny–Olenek – Saskylakh).

• Eastern transit transport axis (Yakutsk–Khandyga–Ust-Nera) with an additionally forming haul through winter roads to the industrial Arctic areas with the destination points of Deputatsky and Zyryanka [28].

• The Arctic transport axis (Yakutsk–Tiksi and Arctic rivers), in combination with a system of winter roads, provides the Northern Delivery [seasonal delivery of goods to the northern areas], but its operation is hampered by the shallow water of the seaport of Tiksi, which limits the possibilities of servicing sea cargo vessels.

The evolution of the designated development zones of the transport system of the Republic of Sakha (Yakutia) is due to development of the resource-extracting industry in the region and does not provide year-round transport accessibility to sparsely populated northern settlements. All this impedes social and economic development of the region. In the author's opinion, development of the air transport network and expansion of the number of local air routes could be the main direction towards growing transport capacity of the Republic of Sakha (Yakutia). A more accurate mathematical assessment of the transport provision of territories requires a deep analysis of the seasonal period of use of all sections of the network and introduction of relevant data into the formula for calculating the Engel's coefficient [30].

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Problems of Decision-Making in Implementation of Technological Innovations in Transport Industry

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ABSTRACT

The article considers the features of transport as an object of technological innovation, due, on the one hand, to the service nature of the main activity and the specifics of innovative processes during provision of transport and logistics services, and, on the other hand, to the high capital intensity and technological complexity of the infrastructure transport complex, which is the focus point of technological innovation.

The objective of the article is to substantiate the initial prerequisites for developing an alternative approach to making strategic decisions on development of transport organisations based on technological innovations, which, besides the traditional justification of economic efficiency, considers several non-economic factors. The method of substantiation is a systemic strategic analysis, which allows to study the features of the transport complex in the context of the factors of external environment and their dynamics.

Regarding the Russian Federation, the scale of the national territory, natural and climatic diversity and uneven territorial distribution of the resource and production base determine the special role and place of transport in the national economy, which quite often leads to the need to make decisions on development of the transport complex based on predominantly non-economic factors (such as security, reliability, environmental friendliness, etc.) and on scientific, technical, political and socio-economic forecasts. At the same time, private enterprises (with or without participation of the state) dominate currently almost all transport sectors where they operate on the principles of profitability, investment attractiveness and competitiveness, which leads to inconsistency of internal decision-making criteria in the field of technological strategies.

The ongoing change in the technological paradigm is an additional and significant factor determining trends in transport developments. It is based on the processes of digitalisation and digital transformation of the transport and logistics business. The problems of decision-making in implementation of technological innovations in transport industry, arising from its peculiarities, necessitate a revision of approaches since economic assessments of efficiency are not always able to reflect the real needs and feasibility of choosing mainstream trends in technological development of the transport system.

The analysis of the features of the transport and logistics industry based on universal experience and cases in Russian practices in the context of formation of a new technological paradigm makes it possible to substantiate the methodology for making strategic decisions on implementation of technological innovations.

Keywords: transport, transport services, technological innovation, digitalisation and digital transformation of transport, the process of making strategic decisions, trends in the technological development of the transport complex.

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INTRODUCTION

Improvement of approaches to substantiating the choice of a strategy for technological modernisation of the transport complex is among inherent aspects of the problem of making decisions on development of transport.

In the Russian Federation, transport plays an important role in ensuring sustainable economic development of the country and its national security due to the territorial scale, uneven distribution of the resource and production base, climatic and geographical differences between the regions of the country. The main task of transport is to ensure integrity, unity, and connectivity of the territory of the Russian Federation based on reliable circulation of freight and passenger flows as a condition for effective functioning of the country's economy [1]. Insufficient attention to the problems of transport development can lead to a threat to national security (in a broad sense): from the rupture of production and logistics chains and termination of trade and economic relations with other countries to destruction of connectivity and disruption of life support systems of individual regions and territories.

Even though currently the transport industry in Russia and other countries has developed and uses methodological provisions for assessing the effectiveness of innovative technological solutions, which serve as a rationale for development of technological strategies, practices show that the results of assessment do not always reflect real consequences of the implemented innovative projects since non-economic factors and decision-making criteria are not sufficiently considered. In this regard, it becomes necessary to clarify the approach to substantiating decisions on implementation of innovations in transport, considering a wider set of factors and criteria, as well as industry's specifics. For this, it is necessary to highlight key prerequisites for development of an alternative approach to making strategic decisions on development of transport organisations based on technological innovations, which is the *objective* of this study. This objective is achieved by *analysing* the specifics of transport as of an object of innovation through highlighting non-economic aspects of decisions made that then become separate research and analytical tasks.

RESULTS

Transport, being a complex organisational and technical system, has a characteristic specificity due to its belonging to the service sectors of the economy: the main result of functioning of transport is provision of transportation and logistics services. According to the classical approach developed within operations management [2], a feature of the technological process of providing services is that the client (consumer) is directly involved in the process of providing services, and the operator is in constant contact with the client, therefore, one of the main indicators of functioning of service-providing organisations is «customer focus» [1].

Based on the principle of customer focus, it is possible to clearly draw the boundary between main and auxiliary technological and business processes in the transport industry:

• *Main* processes include those technological and business processes that have value and are important (significant) for the client, serve as the basis for making decisions on obtaining a service and determine technological competitiveness of a transport organisation.

• *Auxiliary* technological and business processes meet only the needs of the service-providing organisation itself, while remaining outside the customer value system and having significance, first of all, either for the transport organisation itself, or for creating conditions and the possibility for sustainable implementation of the main technological and business processes.

But for transport, which is a high-tech industry, it is the auxiliary components and processes of transport systems that are the most resource-intensive and complex (infrastructure, vehicles or rolling stock, etc). As a result, the bulk of innovations in transport are implemented precisely in auxiliary components and processes, almost imperceptibly for the client, which forms negative customer assessment of the level of innovative activity of transport organisations. For example, the transition to automated train driving, which is a breakthrough technological innovation, is almost invisible to the passenger of an unmanned train. At the same time, marketing innovation, such as changes in design of the train, is obvious, but not always positively perceived as a necessary and useful innovation.

Another consequence of dominance of auxiliary processes and components in innovations in transport systems is low productivity of one of the traditional methods of initiating innovations based on new or projected market needs (*market pull*), which are not always associated with auxiliary or supporting processes. Moreover, in the main activities of transport organisations, new services that can become innovations appear quite rarely: transportation of goods and passengers, as well as cargo handling services or services before travel and along the route have changed little in their essence over the past 100–200 years. Mainly the technologies of their provision were subject to changes: the level of mechanisation and automation was growing, new transport equipment was mastered, the transport infrastructure was modernised, etc. [3]. Therefore, the innovative activity of transport is mainly concentrated in the field of technological process innovations. Consequently, the problems of making strategic decisions in the field of technological process innovations acquire special significance for transport.

If we study the example of Russia, it is necessary to consider other factors as well. The territorial and geographical position of Russia and, consequently, of its transport system are a prerequisite for creation of international transport corridors and organisation of transit of passenger and freight traffic along Europe-Asia axis [4]. The growth in the volume of transit traffic by land transport requires not only modernisation of the track infrastructure, but also expansion of the range of additional services that ensure competitiveness of Russian transit in the global transportation market. However, it should be noted that most of the innovations in this field of transportation, despite their scale and high resource intensity, are also out of sight of customers: passengers and shippers/consignees. Thus, straightening of curved sections in the eastern mountainous part of Trans-Siberian Railway to ensure heavy and faster train traffic [5], most likely, will be invisible to passengers and shippers, although we are talking not only about new technologies for construction of railways, but also about fundamentally new technical solutions for traffic organisation and control, including the unmanned driving of trains.

The high capital intensity of the transport business inevitably leads to an increase in the size of companies up to formation or maintenance of natural monopolies or formation of oligopolies. In Russia, e.g., this feature is typical for all modes of transport: in civil aviation, there are practically no medium and small airlines left with unconditional dominance of Aeroflot PJSC, small private taxi fleets are forced to merge on the platforms of the aggregators *Uber, Gett* and *Yandex*, the natural monopoly of JSC Russian Railways remains on the railways. Similar trends can be traced abroad. Due to the monopoly on the market, transport companies have a lower propensity to innovate, they are more conservative in their decisions on implementation of atypical technologies and technical solutions that differ significantly from the used technologies. When deciding on the purchase of new transport equipment, large companies prefer established technological solutions with minimal risks for operational activities, therefore, as a rule, they buy not innovative, but mass-produced products, that is, those products which are no longer innovative for their manufacturer. At the same time, transport organisations themselves turn out to be «innovatively active», or «carrying out innovative activities», since, according to the definitions of statistical bodies [1,2], we can talk about the first three years of implementation of new equipment and technology in an organisation, regardless of the innovativeness of the latter[1].

Due to high capital intensity, the period of transition to a new technological basis in transport organisations turns out to be quite long and can reach several decades, going beyond the normative definition of the innovation period up to three years[1]. From this point of view, the decision to introduce new technological solutions in transport industry should be made taking into account the long period of operation of equipment and the use of technologies, where an erroneous decision will have a negative impact on efficiency of the transport business for many years. Thus, the decision to electrify railways turns out to be effective only with cheap electricity, while a change in the price ratio between electricity and hydrocarbon fuel can lead to permanent

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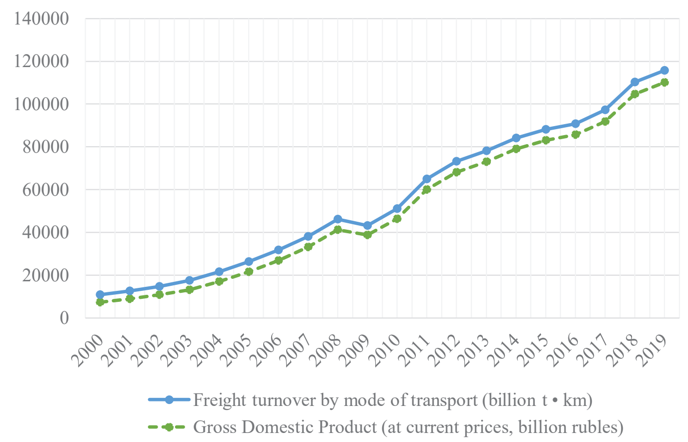
[1] Instructions for filling out the federal statistical observation form N 4-innovation. Information about the organisation's innovative activity. ConsultantPlus website, 1997–2021. [Electronic resource]: http://www.consultant.ru/document/cons_doc_LAW_359374/. Last accessed 20.01.2021.

[2] OECD/Eurostat, Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation, 4th Edition, The Measurement of Scientific, Technological and Innovation Activities, OECD Publishing, Paris/Eurostat, Luxembourg, 2018. [Electronic resource]: https://www.oecd-ilibrary.org/docserver/9789264304604-en.pdf?expires=1604869291&id=id&accname=guest&checksum=B2ED06AD817A6F8922255CA9BF2A9D34. Last accessed 28.01.2021. DOI: https://doi.org/10.1787/9789264304604-en.



Pic. 1. Dynamics (accumulated) of GDP and freight turnover per modes of transport in the Russian Federation (accumulated), 2000–2020 [built by the authors based on Rosstat [Federal State Statistics Service] data][3, 4, 5].

losses during transportation due to the use of more expensive energy resources. As a result, when making decisions on technological modernisation, it is necessary to consider the long-term and difficult-to-predict context of the decisions made.

Another features are that the service could not be «stored up» to reduce peak loads in future, and that there is a high dependence on the economic activity of other sectors of the economy. In fact, the economic activity of transport is a derivative of the situation prevailing in a country's economy: in case of a general economic downturn, the demand for transportation and logistics operations decreases proportionally, regardless of the level of technological readiness of transport, its capacity and special marketing measures (Pic. 1).

Hence, innovations in transport industry should be more resistant to unfavourable economic situation. At the same time, for making innovative decisions and setting targets for transport development, the use of indicators related to freight and passenger turnover (for example, the amount of revenue or operating profit) or calculated on their basis (for example, labour productivity) turns out to be unproductive. Real indicators can significantly differ from the calculated ones for reasons beyond the control of a transport organisation. For the same reasons, such indicators should not be considered when deciding on implementation of innovations in transport organisations. Nevertheless, such indicators as «labour productivity» and «revenue growth rates» are set as targets and are planned by the government when developing and implementing innovative development programs for such large Russian transport organisations [with public capital] as PJSC Aeroflot[6] and JSC Russian Railways[7].

Also, a feature of service-providing industries, in general, and of transport, in particular, is their special role in the high-tech market, where they must act as consumers or customers, creating a demand for innovation. At the same time, transport organisations should not independently develop new generation transport equipment, since they are not manufacturers, but operators. In this regard, the innovative activity of transport organisations is determined by technological capabilities of manufacturers of this equipment. Of course, a transport company can actively participate in design of technical specifications, but when purchasing new equipment, it will be limited in choosing between only those solutions

[3] Federal State Statistics Service (Rosstat). Gross Domestic Product, annual data (at current prices). [Electronic resource]: https://www.gks.ru/storage/mediabank/tab1(2).htm. Last accessed 20.01.2021.

[4] Federal State Statistics Service (Rosstat). Freight turnover by mode of transport in the Russian Federation. [Electrnic resource]: https://www.gks.ru/folder/23455. Last accessed 20.01.2021.

[5] Federal State Statistics Service (Rosstat). Information on the socio-economic situation in Russia, 2019. [Electronic resource]: https://gks.ru/storage/mediabank/oper-12–2019.pdf. Last accessed 20.01.2021.

[6] Passport of the Innovative Development Program of Aeroflot Group 2020. Aeroflot Airlines 2008–2021. [Electronic resource]: https://www.aeroflot.ru/media/aflfiles/media/strategy/pasport_programmy_innovatsionnogo_razvitiia.pdf. Last accessed 23.01.2021.

[7] Long-term development program of JSC Russian Railways until 2025, approved by the order of the Government of the Russian Federation of 19.03.2019, No. 466-r. ConsultantPlus, 1997–2021 [Electronic resource]: http://www.consultant.ru/document/cons_doc_LAW_320741/. Last accessed 21.01.2021.

Source: Russian Railways: https://company.rzd.ru/ru/9407/page/68650?id=20454.

that are on the market. And the possibilities of its development can be limited by the technological backwardness of suppliers. For example, the metallurgical industry may not have existing new technologies and production facilities for production of advanced grades of steel and its products. As a result, modernisation of the track can be based only on those materials and components of the track superstructure that are available on the market, which leads to a decrease in the innovative potential and in the organisational and technical level of technological processes ensuring transportation.

On the other hand, due to the scale of the railway infrastructure and the associated large volumes of purchases of railway equipment, railways are among main players in the innovation market, shaping the demand and trends in technological development of the industry, that, in case of Russia, is confirmed by the data of the investment program of JSC Russian Railways, which during the period from 2015 for 2019 ranged from 365,5 to 690,0 billion rubles[8], or on average about 3 % of the total budget of the Russian Federation. Russian transport organisations annually acquire new equipment, not only stimulating its production, but also taking an active part in its development and modernisation, which is not typical for transport organisations in some other countries, where transport companies can choose equipment from a sufficiently large number of really competing suppliers seeking to bypass each other in terms of the technological characteristics of new equipment. Abroad, transport companies and the state only determine the requirements and adopt technical regulations for operation of new equipment (for example, noise level, energy efficiency class, railway track width, runway length, etc.), and the whole R&D process is carried out by companies manufacturing transport equipment. This is largely due to the closed nature of the Russian market of transport equipment since manufacturers focus on the internal needs of Russian transport companies as the export or expansion of new players to the market is associated with complex procedures of certification of products and production, confirmation of qualifications, and possession of competencies and technologies necessary to participate in electronic trading, and many other constraints in this area. Constraints linked to entering the domestic Russian market of transport equipment, on the one hand, allow to rule out unscrupulous suppliers, but, on the other hand, prevent the emergence of innovatively active players developing alternative competitive and technologically promising solutions. As a result, the inflow of new technological solutions to the transport equipment market is significantly depleted, and the quality of supply decreases.

An additional factor affecting quality of transport equipment offered by suppliers is alienation in favour of the customer of intellectual property rights arising from creation of new transport equipment ordered by a transport organisation. The requirement to transfer all

[8] JSC Russian Railways. Investment activity. [Electronic resource]: https://old-ir.rzd.ru/static/public/ru?STRUCTURE_ID=35. Last accessed 21.01.2021.

rights to the result of intellectual activity[9] to the customer which is a transport organisation, clearly turns out to be illogical and ineffective from all points of view: transport organisations pay the cost of creating IP, increasing their research and development costs and at the same time having neither the capabilities nor the intention to further commercialise those results outside their own business, since they are not manufacturers of railway equipment. At the same time, organisations that have performed R&D resulted in creation of objects of intellectual property (OIP) lose the possibility of using OIP in other developments, which reduces the interest of developers in a high scientific and technical level of the obtained results of intellectual activity[10].

At the same time, the experience of international companies shows that even in the conditions of a monopoly or an oligopoly of transport organisations, the developed technologies and samples of equipment can be successfully promoted outside the national markets, and competition in world markets encourages developers and manufacturers of transport equipment to increase the level of developments brought to the market. For comparison: Deutsche Bahn, the largest German railway carrier, has only a few patents on its balance sheet: for logos and branding, while their suppliers, in particular, Siemens AG, owns intellectual property rights and promotes their transport equipment not only in Germany, but around the world.

Nevertheless, at present, making decisions on implementation of innovations in large transport companies with state participation, according to the established requirements, should be built considering how many intellectual property objects will be on the balance sheet. The number of patents and licenses that a transport organisation possesses, becomes one of the key development indicators. Reporting on innovative development programs includes indicators of obtained patents.

A feature of transport is the strong influence of regulators on the main and auxiliary technological processes: from tariff regulation to requirements for safety and environmental performance, which leads to a high share of economically ineffective innovations. Thus, the requirement established by the legislator to enter passport data in travel tickets and their obligatory checking during embarkation and disembarkation of passengers, led to an increase in complexity of processing travel documents and increased the time required to service passengers at stops. This, on the one hand, reduced the customer satisfaction index, and on the other, led to an increase in costs for transport organisations. Nevertheless, this economically ineffective innovation has been implemented in almost all modes of long-distance passenger transport. Innovations in the field of ecology and safety are not characterised by a real (reflected in the financial and economic indicators of transport organisations) economic effect, but nevertheless they are invariably included in the programs of innovative development of transport organisations[11, 12, 13].

Another feature of transport is its heterogeneity. The transport system of Russia is formed by various modes of transport. At the same time, railway transport plays a system-forming role in the country's economy: its share in freight turnover in 2018 reached almost half (46 %) of cargo transportation by all modes of transport and over 87 % excluding pipelines. The volume of freight turnover of railway transport in 2018 amounted to 2 598 billion tkm[14]. The importance of railways as the main component of the Russian transport system is emphasised in the Transport Strategy of the Russian Federation until 2030: «Railway transport is one of the key

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[9] The term RIA in Russian laws is generally equal to intellectual property protected in law. – *Translator's note.*

[10] Standard STO RZD 08.014–2011 «Innovation activities in JSC Russian Railways. Requirements for procurement of innovative technical products». [Electronic resource]: https://files.stroyinf.ru/Data2/1/4293731/4293731375.pdf. Last accessed 21.01.2021.

[11] A comprehensive program for innovative development of Russian Railways holding company for the period up to 2025, approved by the Board of Directors of JSC Russian Railways on February 26, 2020. Single window of innovation. [Electronic resource]: https://eoi.rzd.ru/front/media/1022/266-%D1%80-%D0%BE%D1%82–11022021.pdf. Last accessed 20.01.2021.

[12] The strategy for development of innovative activities of the Federal Road Agency for the period 2016–2020, approved by the order of Rosavtodor dated 28.03.2016, No. 461-r. Accounts Chamber of the Russian Federation. [Electronic resource]: https://ach.gov.ru/upload/iblock/67d/ap67p4spuhjz179h0jbnjtb66pvlptlc.pdf. Last accessed 21.01.2021.

[13] Passport of the Innovative Development Program of Aeroflot Group 2020. Aeroflot Airlines 2008–2021. [Electronic resource]: https://www.aeroflot.ru/media/aflfiles/media/strategy/pasport_programmy_innovatsionnogo_razvitiia.pdf. Last accessed 23.01.2021.

[14] Russia in figures. 2019: Brief statistical collection of Rosstat. Federal State Statistics Service, Moscow, 2019, P. 371. [Electronic resource]: https://www.gks.ru/free_doc/doc_2019/rusfig/rus19.pdf. Last accessed 25.01.2021.

Source: Russian Railways: https://company.rzd.ru/ru/9407/page/68650?id=23436.

components of the single transport system in Russia, it is called to timely and efficiently meet the needs of the population, business and the state in transportation, to help create conditions for development of the economy and ensure the connectivity of territories and a single economic space»[15].

According to experts' forecasts [7–10], railway transport in the long term will remain the main mode of transport in Russia. This is due to the fact that among land modes of transport, the railway transport is most easily transferred to the remote-control mode, and subsequently to automatic (unmanned) control, since the train trajectory is linear with a limited number of degrees of freedom. For example, in many international airports and in some foreign metro systems trains run without drivers [11], and traffic control is carried out through a single remote-control centre.

In addition, for several regions of the country (for example, Western Siberia), railways remain the only means of transportation throughout the year due to wetlands and undeveloped territory.

In the context of formation of a new technological paradigm (Industry 4.0), railway transport is characterised by a higher readiness to integrate new intelligent control technologies, being one of the most ready for automation of operational activities and adoption of unmanned technologies, which was especially pronounced in the context of the COVID-19 pandemic. The volume of traffic during the period of quarantine measures in most countries fell sharply, and at the peak of the epidemic, the drop in passenger traffic was from 70 to 100 %[16]. The pandemic almost completely paralyzed air traffic around the world, the largest international hub airports, which provided links between regions and continents, were closed.

In a pandemic, railway transport has proven to be the most flexible and adaptable to new realities. Several strategic decisions were made to improve transport safety. For example, in long-distance passenger trains, it is possible to provide an isolated passage of passengers by installing additional filters in the compartment ventilation system, ensuring embarkation and disembarkation of passengers at a safe distance with an increase in the parking time at intermediate stations, a decrease in the occupancy rate[17] of a compartment to a single passenger or to

[15] Transport strategy of the Russian Federation for the period up to 2030. Order of the Government of the Russian Federation of November 22, 2008 No. 1734-r. [Electronic resource]: http://static.government.ru/media/files/41d4e8c21a5c70008ae9.pdf. Last accessed 20.01.2021.

[16] Report of the Analytical Center for the Government of the Russian Federation. Countering the impact of the COVID-19 pandemic on railway transport in the world. Russian Railways. Working reports, Iss. 24, p. 5. [Electronic resource]: https://ac.gov.ru/uploads/2-Publications/RZD_june2020.pdf. Last accessed 23.01.2021.

[17] Regulatory documents on countering the spread of coronavirus infection in the Russian Federation: electronic operational collection (as of June 25, 2020) in 3 parts. Moscow, NMITs FPI, 2020, Part 1. [Electronic resource]: https://edu.rosminzdrav.ru/fileadmin/user_upload/specialists/COVID-19/dop-materials/250620/Sbornik_CH.2_25_ijunja.pdf. Last accessed 30.01.2021.

a family with an increase in length of trains, which is significantly cheaper in comparison with re-equipment of the aircraft cabin, where a complete rearrangement of the cabin must be carried out with creation of autonomous passenger seats.

In several cases, freight railway transport remains uncontested: for example, transportation of coal and ensuring its export, i.e., from Russia to China, is possible only by rail, since all other modes of transport are unable to provide reliable and relatively cheap transportation of such significant volumes of cargo. With the permafrost melting, operation of pipelines in the Arctic is becoming unreliable and carries risks of environmental disasters, like the catastrophic diesel spill in 2020 in the Arctic. Transportation of produced hydrocarbons in railway tanks, on the one hand, allows monitoring the condition of the track and rolling stock, and, on the other hand, allows reducing the likelihood of a spill and localising possible leaks.

However, at present, the trend of development of transport as of a multimodal system has emerged and is strengthening, which is the result of development of information and communication technologies, which make it possible to unite management of various modes of transport within a single technological platform. Initially, multimodal transportation emerged in transnational companies, global operators of transport services for transportation of goods, based on the integration (mergers and acquisitions) of companies (for example, Maersk Seeland) related to various modes of transport. However, at present, alliances and partnerships of various transport companies are increasingly spread, together with the emergence of independent logistics operators that form multimodal transport chains. Also, at present, multimodal transportation is increasingly being developed at the domestic national or regional level, primarily in the segment of passenger transportation [10].

The transition from a multi-agent model of transportation, in which a shipper or a consignee had to conclude several contracts with carriers related to different modes of transport, to multimodal transportation which is provision of services for transportation of goods with a single contract with at least two different modes of transport under the control of a single carrier, as a model of a multimodal transport network and its elements is confirmed by domestic research [11; 12]. When deciding on introduction of multimodal cargo transportation, as a rule, the main attention is focused on cost indicators or time of delivery of goods or passenger travel. In addition, it is necessary to consider the total travel time, the risks of loss of goods by various modes of transport, the costs of concluding contracts, taxes, etc.

In passenger transport, multimodal transportation is often due to social reasons. For example, multimodal commuter train-bus service initiated by JSC Russian Railways carrier company makes it possible to reduce the costs of transportation on ineffective routes while maintaining transport mobility of the population, as well as unload highways at the exits from large settlements and megacities.

In development of multimodal freight transportation, railways also dominate, as they are capable of providing transportation of large volumes of goods with minimal costs and have ready-made points for sorting and transshipment of goods, including for further transportation by other modes of transport. Therefore, as a rule, namely railways become the initiators of multimodal transportation.

An example demonstrating the leading role of railway transport in development of multimodal freight and passenger transportation refers to organisation of piggyback transportation with participation of JSC Russian Railways on Yekaterinburg–Moscow route: in February 2020, a new piggyback platform was serially manufactured and launched onto the line [18], allowing to minimise time parameters of loading and unloading operations and to organise seamless shipment and delivery of goods to customers located far from railways.

Nevertheless, development of multimodal transportation requires modernisation of the transport infrastructure. The expansion of the volume of multimodal transportation leads to the need to create hubs, large logistics complexes that provide a seamless connection of various modes of transport within the optimal route. And the very first task in this area faces the need to determine the optimal location for a multimodal transport hub, its capacity, technological equipment, etc.

It should be borne in mind that decision-making in this area is based on forecast data on

[18] Heavyweight piggyback. *Gudok*, Iss. 32 (26881) 25.02.2020. [Electronic resource]: https://www.gudok.ru/newspaper/?ID=1494810&archive=2020.02.25. Last accessed 29.01.2021.

freight and passenger traffic for many years to come, which does not guarantee either accuracy or even the minimum adequacy of the forecasts. Regarding strategic perspective, in recent years, more and more people are talking about «strategic surprises» («black swans» [13]), which are not considered by any forecast.

Change in the technological paradigm, which not only changes the structure of technologies and equipment, but also significantly alters traffic flows adds additional complexity to decision-making in development of infrastructure and construction of hubs, as well as in their design. So, according to one of the forecasts [14], development of additive technologies and full automation of production will lead to the phenomenon that instead of production and subsequent transportation to the place of consumption of technological products, with emergence of automated factories, instead, only information about the technological process of manufacturing «on site» and «from local resources» will be transmitted, that is, the pre-existing need for transportation will disappear or at least decrease. In these conditions, a new, just laid railway line or an expensive and high-performance hub may turn out to be unclaimed, and the costs of their creation may be irrational.

Preserving and strengthening the role of transport in the country's economy requires a significant increase in innovative activity, aimed primarily at modernising and significantly renewing vehicles and infrastructure. However, in accordance with F. Janszen's TAMO[19] model [15], the success of innovations is achieved only with an integrated, balanced approach that considers all aspects of the organisation's activities. Therefore, along with technological process innovations in accordance with Oslo Manual 2018, organisational, marketing, technological product innovations and innovations in business processes are no less important for transport organisations, and when designing technological changes, it is necessary to make changes along the entire chain of innovation activity.

Decisions on development of transport are currently based mainly on economic assessments, which are based on a comparison of expected effects and costs of modernisation and reconstruction of both transport equipment and transport infrastructure. It has already been shown above that, as a rule, transport forecasts, which often represent an extrapolation of the current situation into the future, in certain situations turns out to be incorrect, and, therefore, the result of purely economic estimates turns out to be incorrect. Besides, the above-described features of transport as a capital-intensive service-providing sector of the economy with long-term fixed assets are not sufficiently considered. From an economic point of view, wear of these assets is reflected in depreciation, however, obsolescence of equipment remains currently outside the scope of economic assessments and feasibility studies. However, acceleration of the technological process, a change in the technological paradigm, require considering obsolescence when making decisions on the development of transport infrastructure, and ignoring it inevitably leads to errors and losses. In this regard, it is necessary to change the approach to making strategic decisions on development of transport, complementing economic assessments by considering technological trends both in the field of transport technology and in the transport services market.

CONCLUSIONS

When making decisions on implementation of innovations in transport industry, it is necessary to use an alternative approach to existing methodologies, based mainly on traditional economic models.

The prerequisites for this are the provisions that have been substantiated above and now are summarised below.

When making decisions on technological development of transport, one should focus on non-economic factors, which primarily include the need to ensure sustainable development of the country and national security in a broad sense.

Decisions made in the field of technological development are not always justified by market needs, but at the same time, for transport, as a service-providing industry, customer focus is becoming one of the most important factors of competitiveness, that is, a conflict arises that requires its resolution in the decision-making methodology.

When making decisions, it is necessary to take into account heterogeneity of transport both by modes and by the operated technological components (vehicles, infrastructure, etc.).

[19] Technology, Applications, Markets or customers groups, Organisation.

However, at the same time, multimodal transportation, digitalisation, and digital transformation processes, as well as global natural, economic, socio-demographic and political processes are widely spread, which gives rise to a large number of options for implementation of transport and logistics services and increases the level of uncertainty in decision-making.

Development of the transport complex is characterised by high capital intensity and long service life, which, on the one hand, leads to an increase in the cost of an error in decision-making and, on the other hand, increases uncertainty in predicting functioning of the industry as a whole and of individual transport organisations in particular.

Based on these prerequisites, it becomes obvious that there is the need to develop an alternative approach to substantiating decisions on implementation of innovations in transport industry, based on the methods of multi-criteria parametric optimisation and considering non-economic criteria and indicators.

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Assessment of Drivers and Deterrents of Development of High-Speed Passenger Railway Transportation




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ABSTRACT

Reduction in travel time is one of the eloquent trends in transport developments. It is consistent with the desire of leading transport companies to create conditions to increase traffic speeds.

The objective of the article is to analyse prospects and drivers for development of high-speed rail transportation as of a priority transport segment characterised by best safety rates and environmental friendliness as compared to other types of transportation.

The review of core parameters of HSR is suggested to show features of its global development.

Ecological friendliness, encouragement of labour and other mobility of people, of innovative technology development of railways and interconnected industries are most relevant as universal drivers of HSR development.

Constraints due to substantial investment needs, long payback period, necessity to implement additional side projects to develop interrelated transport infrastructure to obtain more tangible economic and social effects, to provide for sufficient passenger flow at the initial or further stages of HSR operation were considered as main deterrents.

The factors, their parameters, assessment of their priority ranking when making decisions on construction or development of HSR are determined in each country by transport development strategies, current economic conditions, and a set of other factors.

Keywords: *railways, HSR, speed transportation, HSR rolling stock.*

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INTRODUCTION

The growing mobility of the world population has a significant impact on development of the transportation network, engendering challenges such as increasing travel speed and growing comfort. Similar trends are observed on railways as well: during the period 2010–2019 passenger turnover increased by 927,1 billion passenger-kilometres (28,8 %) [1].

The increase in population mobility determines the need to modernise existing transport systems that supposes adoption of advanced developments and technologies, improvement of infrastructure facilities, integration of various systems to obtain a synergistic effect (development of multimodal transportation) [2]. The development and expansion of urban agglomerations, widespread urbanisation form the trends towards growing demand for development of the transport system.

The railway industry, in turn, is one of constituent parts of the entire transport industry, providing necessary and sufficient conditions for functioning of urban agglomerations. One of the priority trends in development of the railway network in the context of an increase in migration flows is development of high-speed railway passenger transportation.

In accordance with the definition of the International Union of Railways, a high-speed rail (hereinafter referred to as HSR) combines many different elements which constitute a «whole, integrated system». The most critical, from the point of view of HSR operation, elements [3] of this system are:

• an infrastructure (two types of infrastructure are distinguished):

a) new lines designed for speeds of 250 km/h and above;

b) upgraded existing lines for speeds of up to 200 or even 220 km/h;

• rolling stock, especially designed specifically for train sets;

• telecommunications;

• signalling, equipment, etc.

In the Russian Federation, traditionally, HSR means a specialised dedicated (purpose-built) railway line that ensures movement of trains at a speed of more than 250 km/h. The provision of passenger railway transportation services at a speed from 160 km/h to 220 (250) km/h corresponds to higher-speed [1] traffic. The mixed type of traffic is also widespread: high-speed trains operate on lines intended for conventional trains.

The mixed type of train traffic has the advantages associated with the absence of the need for a complete reshaping of a railway or construction of new tracks. However, operation of trains with different features, properties and responding to divers technical requirements on the same railway tracks leads to additional costs associated with the need for constant maintenance and repair [4], as well as gaps in the timetable associated with overlapping tracks for conventional trains during the passage of high-speed trains [5].

HSR development in the Russian Federation and in the world is determined by various factors. The *objective* of the article is to analyse prospects and drivers of development of HSR as of a priority transport segment owing better safety rates and environmental friendliness as compared with other types of transportation.

RESULTS

Drivers of Development

Improved environmental requirements

Tighter requirements towards CO_2 emissions encourage development of the whole railway industry: transportation by rail has a lower environmental footprint compared to civil aviation, water and road transport.

According to the information of the International Union of Railways [6], the advantages of railway transportation and, in particular, of HSR are determined by:

• land allotment for HSR is 2–3 times less than the area of highways;

• emissions of carbon dioxide per passenger-kilometer on railways is four times less than that of air transport, and 3,5 times less than that of cars;

• energy consumption of rolling stock per passenger is four times less than that of cars, and eight times less than that of aircraft.

The ecological superiority of railway transport stimulates not only its overall development, but also contributes to acceleration of introduction of HSR in environmentally responsible countries.

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[1] The original term in Russian can be translated literally as «fast» or «rapid». – *Translator's note*.

Implementation of the newest technology

The introduction of «end-to-end» digital technologies allows both the use of advanced developments in production of specialised trains and development of infrastructure facilities, for example, to use digital simulation systems [7], which optimise the processes of rolling stock operation through algorithms for processing big data, and intelligent systems operating on the principles of the industrial Internet, in the processes of monitoring the state of rolling stock and infrastructure facilities [8; 9].

Development of urban agglomerations

The expansion of urban areas allows for the transition from an increase in building density to development of suburban areas and formation of urban agglomerations. Such dynamics of urban development requires modernisation of the transport network, including improvement of suburban transportation and its connection to urban transport. On the contrary, the existing problems of territorial connectivity, the solution of which is identified as the priority of the scientific and technological development of the Russian Federation [10], negatively affect the conditions for development of human capital and formation of economic innovation clusters.

The development of HSR and of speed of intercity transportation constitute a certain safety margin for further development of the boundaries of urban areas, providing comfortable intercity connectivity and acting as a locomotive of development of multimodal transportation.

Development of non-energy economy

Global digitalisation of all sectors of the economy not only contributes to development of new technologies, but also creates conditions for their implementation. For instance, development of tourism and of the service-providing sector, as well as expansion of urban agglomerations, create a demand for more comfortable modes of transport, characterised, among other things, by higher speeds. The development of end-to-end digital technologies such as big data, artificial intelligence and robotics contributes to production and maintenance of the newest transport systems and provision of a decent level of customer service.

The development of a non-resource economy, stimulating competition in the labour market and redistribution of human resources between various sectors of the economy, acts as a transmission mechanism that immediately results in a significant increase in the volume of commuting and development of urban agglomerations.

Constraints

Despite the presence of important drivers, due to various socio-economic and technological reasons, mass construction and development of HSR is complicated by the presence of a number of barriers.

Long payback periods

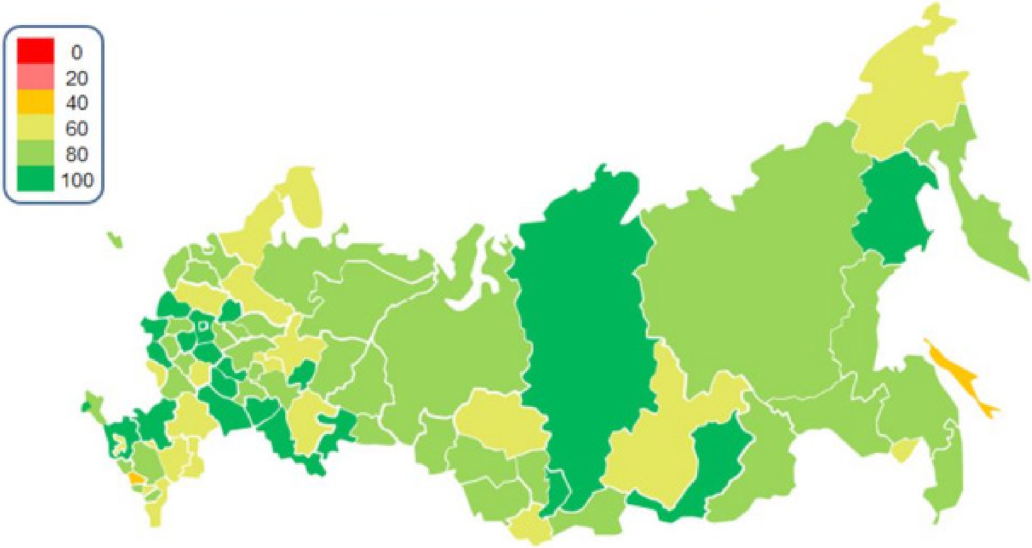
The implementation of HSR infrastructure projects is associated with high investment and capital costs associated, among other things, with the high cost of developing and implementing innovations, as well as with the need to invest significant funds in construction of new infrastructure or in modernisation of the existing one. Such projects can be carried out for 5–10 years, which implies the presence of various force majeure circumstances, comprising, for example, the need to implement previously unplanned solutions due to improvement of technological characteristics, development of fundamentally new technologies/solutions, or tightening of technical requirements.

These circumstances negatively affect the increase in the estimate and in the required investments, which, in turn, determines the high level of the cost of travelling with high-speed railway for end users. The payback of such infrastructure projects depends directly on demand, which is determined by both the level of the population's payment capacity and the presence of significant economic ties between cities or regions. On the contrary, under the conditions of stagnation of the economy, a decrease in the number of business ties and a decrease in real incomes of the population, this barrier has a significant impact on the prospects for development of HSR.

Insufficient passenger turnover

The increase in migration flows, encouraging HSR development, is characterised by a relative impact, since the current level of passenger turnover is not sufficient in terms of the investment return on projects for construction of HSR.

In the Russian Federation, this situation is exacerbated by the presence of weak economic ties between regions, especially those lying



Pic. 1. Index of economic activity in the constituent entities of the Russian Federation in June 2021. (Source: Institute «Development Centre» of National Research University Higher School of Economics, official website. [Electronic resource]: https://www.hse.ru/data/2021/08/16/1410149399/ci_rea_2021–06.pdf. Last accessed 15.08.2021).

outside the central federal district. Economic activity in constituent entities of the Russian Federation is distributed extremely unevenly (Pic. 1).

Complexity of integration into already existed transport structures

The construction of HSR is fraught with various difficulties in the field of determining the optimal routes that allow reaching high speeds on the route, as well as in the field of integrating new dedicated lines into the established transport ecosystem of urban agglomerations, linking them with existing transport interchanges and stations.

Nevertheless, the impact of the above barriers is not critical, which is confirmed by the presence of existing and planned projects related to construction of HSR. The construction of HSR makes it possible to achieve such socio-economic effects as development of urban agglomerations, unloading of existing transport systems, stimulation of economic activity in regions and of tourism, and more even regional development of economic sectors. It is assumed that the greatest degree of attractiveness of high-speed railway transportation will be observed on routes with a length of up to 700–800 km. The transportation itself is safe and environmentally friendly [11].

The need for construction and development of HSR within the national transport system of Russia is explained through possible achievement of several socio-economic benefits, including:

• increased mobility of all groups of the population;

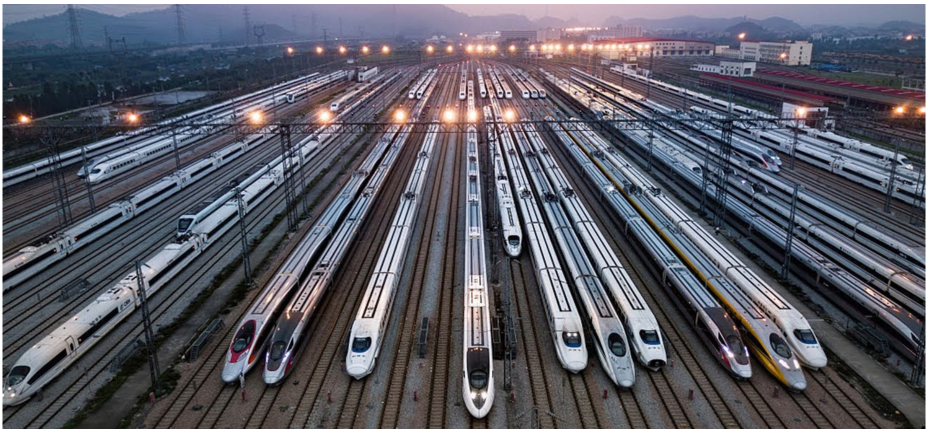
• increase in tourist flows within the country;

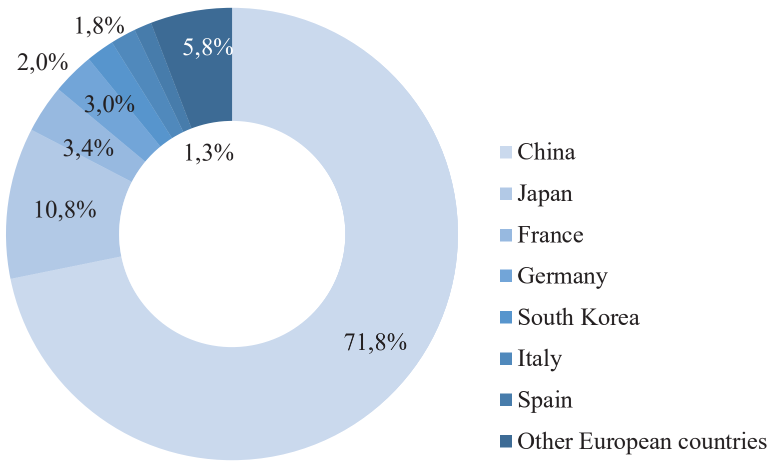
• ensuring complex synergistic interaction of various modes of transport in the field of passenger transportation.

Today, the Russian Federation is lagging behind foreign partners in development of high-speed railway transportation. According to the data of the International Union of Railways, China, Japan, France, Germany, South Korea, Italy, and Spain are the leading countries regarding HSR development in terms of total HSR passenger traffic (Pic. 2).

China is an absolute leader with the longest HSR lines in the world: as of the end of 2020, the total length of HSR in China was more than 38 200 km [12], which is more than 2/3 of the total length of HSR in the world. China's investments in development of high-speed rail projects amounted to more than 110 billion US dollars. Pic. 3 shows a comparison of investments of several leading countries in development of HSR at the end of 2018.

China, France, and Germany are actively involved in the process of expanding national HSR systems, even despite the existing developed network of routes. Activity in the field of transport in France and Germany is guided by the current policy of the European Union to create a single pan-European transport network TEN-T, which includes highways and railways, inland waterways and airways [13].





Pic. 2. Leading countries in terms of HSR passenger traffic in 2019.
(Source: International Union of Railways, official website. [Electronic resource]: https://uic.org/statistics. Last accessed 10.08.2021).

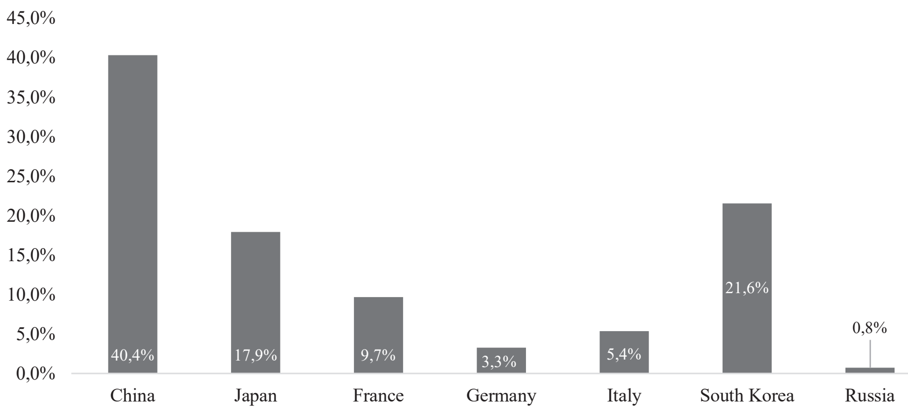
China's leadership is also observed in terms of the share of HSR in the total operating length of the railway network which is now of 40,4 % (Pic. 4).

The high share of HSR in the operational length of the railway network in China is reflected in the wide network of high-speed passenger railway transportation routes. The leaders in terms of the number of routes are China, Korea, and Germany (Table 1).

Despite the absolute leadership of China in terms of the total passenger traffic in highspeed passenger transportation, the largest share of HSR and high-speed passenger transportation in passenger traffic in 2019 was observed in Korea and France (Pic. 5).

The accelerated pace of HSR development in China can be clearly traced due to current investment projects, as well as the clear scope for increasing the share of HSR passenger

Pic. 3. Analysis of investments in construction of HSR in 2018 per countries, bln US dollars.
(Source: Information agency RZD-Partner, official website. [Electronic resource]: http://www.rzd-partner.ru/zhd-transport/news/kitay-narashchivaet-investitsii-v-zheleznye-dorogi/. Last accessed 10.08.2021).



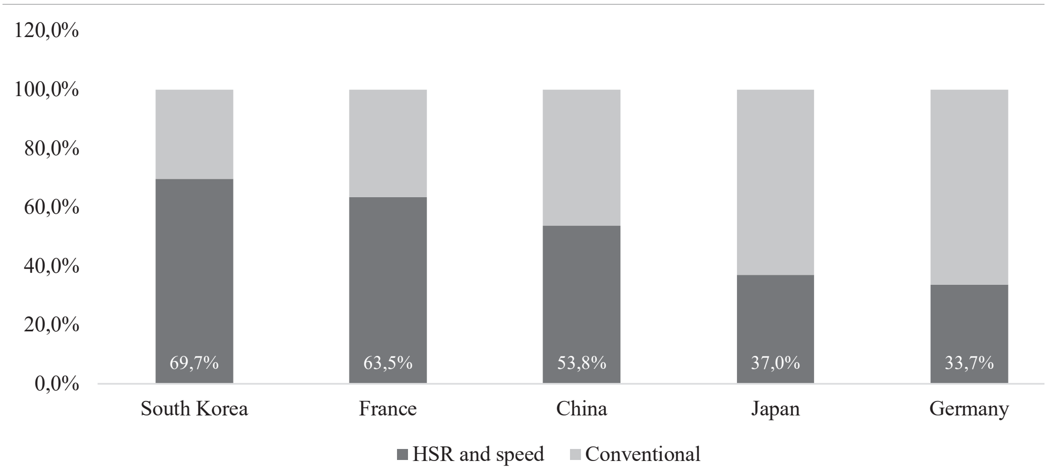
Pic. 4. The share of HSR in the total length of railway networks per countries.
(Source: International Union of Railways: official website. [Electronic resource]: https://uic-stats.uic.org/. Last accessed 10.08.2021) .

Table 1

Selected routes of high-speed railway transportation in some countries

Country	Routes
China Railway (China)	Beijing–Shanghai, Wuhan–Changsha–Guangzhou, Shanghai–Hangzhou, Shanghai–Nanjing, Beijing–Tianjin, Zhengzhou–Xian, Ningbo–Taizhou–Wenzhou, Wenzhou–Fuzhou, Shijiazhuang–Taiyuan, Fuzhou–Xiamenjin, Shijuang–Taiyuan, Fuzhou–Xiamen, Nanchang–Jiujiang, Hefei–Wuhan, Qingdao–Jinan, Hefei–Nanjing, Chengdu–Ganksian, Changchun–Jilin, Haikou–Sanya, Guangzhou–Zhuhai, Guangzhou–Xinhui
Renfe Operadora (Spain)	Madrid–Seville–Malaga, Madrid–Barcelona
Japan Railways (Japan)	Shin Osaka–Hakata, Tokyo–Niigata, Tokyo–Shin Osaka, Tokyo–Kanazawa, Tokyo–Shin Aomori–Shin Hakodate
SNCF (France)	Rennes–Paris, Calais–Paris, Strasbourg–Paris, Avignon–Lyon–Paris, Bordeaux–Tours–Paris
Deutsche Bahn (Germany)	Frankfurt–Hamburg, Frankfurt–Munich, Frankfurt–Cologne, Frankfurt–Stuttgart, Hamburg–Munich, Berlin–Hamburg, Berlin–Frankfurt, Berlin–Munich, Cologne–Berlin, Frankfurt–Aachen, Frankfurt–Brussels, Hamburg–Copenhagen, Cologne–Brussels, Frankfurt–Paris, Frankfurt–Basel, Frankfurt–Amsterdam, Nuremberg–Vienna
FS Italiane (Italy)	Naples–Bari, Palermo–Catania–Messina, Turin–Milan–Reggio Emilia–Bologna–Florence–Rome–Naples–Salerno, Venice–Padua–Bologna–Florence–Rome–Naples–Salerno, Udine–Venice–Padua–Vicenza–Verona–Brescia–Milan–Turin
Korail (South Korea)	Seoul–Dongdaegu, Dongdaegu–Busan, Osong (Cheongju)–Gnangju, Suseo (Seoul)–Pyeongtaek, Seoul–Gangneung

Sources: UIC and official annual reports of the respective railway companies.



Pic. 5. Distribution of countries by the share of HSR in the total passenger turnover in 2019, %. (Source: International Union of Railways: official website. [Electronic resource]: https://uic-stats.uic.org/. Last accessed 12.08.2021).

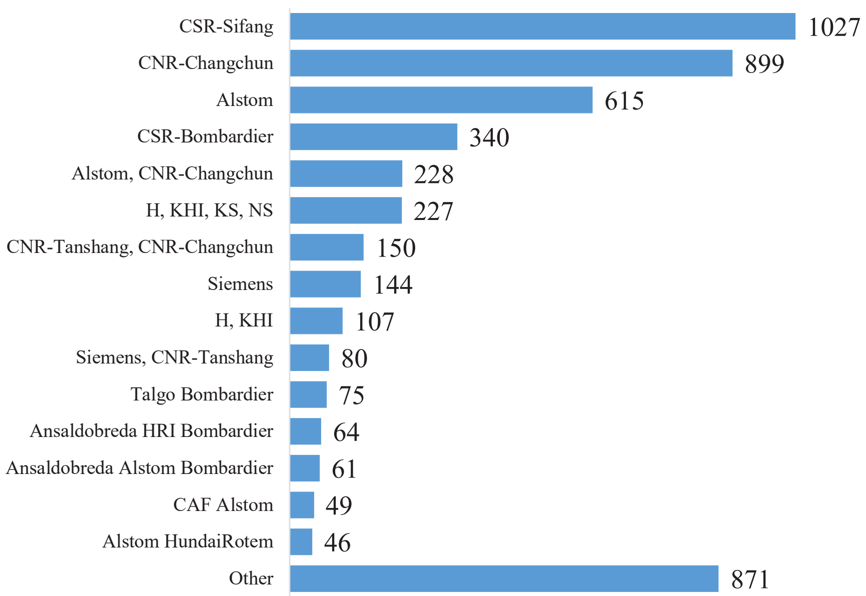
turnover in the total passenger turnover. The predominance of China in development of HSR is also observed in the production of specialised trains (Pic. 6).

One of the most common high-speed train models is CSR-Sifang. Other common models include CNR-Changchun, Alstom, and Bombardier.

The prevalence of Chinese manufacturers is explained by the increased demand associated with current and future projects of China regarding HSR development. France also plans to increase the number of high-speed passenger routes, focusing on decentralisation of Paris in the national HSR network and on increasing the share of regional HS infrastructure.

SHORT CONCLUSION

Development of HSR is determined by several universal drivers. They include ecological friendliness, encouragement of labour and other mobility of people, of innovative technology



Pic. 6. Ranking of manufacturers of high-speed rolling stock. Compiled based on the data source of the International Union of Railways: official website. [Electronic resource]: https://uic.org/IMG/pdf/202100801_high_speed_rolling_stock.pdf. Last accessed 12.08.2021.

development of railways and interconnected industries.

Deterrents and constraints to HSR development are due to substantial investment needs, long payback period, necessity to implement additional side projects to develop interrelated transport infrastructure to obtain more tangible economic and social effects, to provide for sufficient passenger flow at the initial or further stages of HSR operation. These factors, their parameters, assessment of their priority ranking when making decisions on construction or development of HSR are determined in each country by transport development strategies, current economic conditions, and a set of other factors.

In the Russian Federation, the need to develop HSR is considered as sufficiently high, and various plans for development of HSR are being discussed.

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Improving Information Interaction between the Metallurgical Plant and Rail Operators




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ABSTRACT

The current situation of development of the world economy presupposes intense competition in both external and internal markets. Under these conditions, it becomes more and more obvious that the growth of profits and, accordingly, further development of companies will be carried out not so much through expansion, but through improved service for customers, an increase in the range of goods and services offered, a better product quality and a decrease in production costs.

The main role in optimisation of technological processes is currently played by digital transformation of production. The introduction of advanced information technologies is of great importance for all global companies, since the enhanced development of information systems results in improvement of business processes, better safety, and environmental friendliness.

International studies show that the use of modern information technologies in transport industry is necessary to improve traffic safety, reduce environmental impact, increase the efficiency of the transportation process.

The Russian mining and metallurgical sector, along with the oil and gas industry, makes a significant contribution to development of the country. Complex production technology, a large volume of traffic, hazardous and dangerous working conditions for personnel necessitate development of a digital environment to increase labour productivity and the volume of products.

The objective of the research is to study the possibility of using information control and forecasting systems for solving technical, technological, and organisational problems of industrial railways of metallurgical plants.

Based on comparative analysis, general scientific and mathematical research methods and the study of the role of information systems in digital transformation of production process, the authors suggest a methodology for creating a stochastic model for predicting the arrival of unit trains at an enterprise, and consider development trends in digital transformation of industrial transport.

Keywords: railway transport, stochastic modelling, metallurgical enterprise, information systems.

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INTRODUCTION

The results of international studies advocating positive role of modern information technology in the transport sector increasing safety, reducing environmental impact, and raising efficiency of transportation [1, p.12; 2, p. 36; 3, p. 692] can be fully applied to analyse the operations of the industrial transport, namely, to industrial railways.

Today, almost every industrial enterprise has its own developed logistics system, the efficiency of which influences the productivity of its productive capacity, vehicle turnover and company costs.

The cost of production of metallurgical plants depends on a correctly built strategy for delivery of raw materials from mining sites to the workshops of the main production site, and then to the consumer. Reducing the cost of transportation and storage of goods, increasing monthly and annual turnover of products have a positive effect on the efficiency of the production process.

Therefore, the systemic development, optimisation and improvement of all logistics supply and sales chains are important since future development of an industrial enterprise depends on them.

The main role and task of logistics is procurement, supply, marketing, transportation, and storage of commodities and material assets.

The research paper offers the results of a study conducted with an *objective* to analyse and forecast of promising forms of interaction of an industrial enterprise of a full production cycle (metallurgical plant) with operators that own rail rolling stock [4, p. 299]. In general terms, this can be represented as interaction of mainline railway transport and non-public transport. At different stages of the study, a forecasting method was based on statistical mathematical stochastic model with elements of the probability theory.

Transport logistics is a complex planning process based on an analysis of demand for finished products in accordance with the needs of consumers. Knowing final parameters in terms of production volumes, specialists choose the required type of rolling stock, its required quantity, plan the volumes and routes of transportation, considering conditions for minimising transport costs, and prepare necessary transport documents. The work results in satisfaction of the demand for finished products and provision of production workshops with raw materials.

Logistics can be divided into two types:

1) internal logistics, which provides transport services for workshops within the production site (for example, transportation of hot pig iron from a blast furnace workshop to a converter workshop);

2) external logistics, the purpose of which is interaction between various enterprises, namely, suppliers and consumers, in the field of transportation of raw materials, finished products, equipment and other goods by means of mainline transport.

Logistics in the activities of an enterprise is the main connecting link between all stages of production, and at this stage of technology development followed by sophistication of supply chains, it is impossible to effectively manage production and commercial activities of the enterprise without the use of powerful information decision support systems.

RESULTS

Predicting the Arrival of Wagon Flows

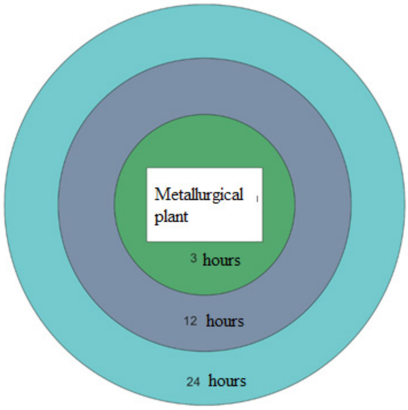
When building a forecasting model for arrival of wagons at the enterprise, it is necessary to determine the boundaries of the forecasting period, or the planning horizon. It is exactly this model that will be the basis for functioning of the information system for monitoring and forecasting work of the railway of a metallurgical plant.

It should be borne in mind here that the forecasting horizon should be optimal from both technical and economic points of view. With an increase in planning periods, uncertainty also grows due to the fact that the number of factors affecting movement of rolling stock through the network increases, therefore, the forecast accuracy decreases. The planning horizon is conventionally divided by the authors into three tiers of forecasting (Pic. 1):

1) operational: a three-hour period;
2) shift: twelve hours;
3) daily: twenty-four hours.

After determining the planning horizon, it is required to develop a model for predicting arrival of wagons at the metallurgical plant. This will improve the technological interaction of industrial and mainline railway transport at the interchange stations by improving the quality of planning of train work for exchange of trains, which will lead to a reduction in turnover of wagons, an increase in performance rates of locomotives that move trains to and from interchange points and a decrease in occupancy of elements of the track infrastructure.

Currently, there are several forecasting methods [5, p. 120; 6, p. 74; 7, p. 320; 8, p. 129]:



Pic. 1. Tiers of wagon traffic forecasting (compiled by the authors).

1) Intuitive methods that are based on findings of experts in the field of study;

2) Mathematical methods, which are based on the mathematical apparatus and are subdivided into:

- domain models;
- time series models:
  – statistical models;
  – structural models.

In this study, to predict arrival of unit trains, the authors propose to apply a statistical mathematical stochastic model using elements of the theory of probability. For this, the travel time through the network from the departure station to the destination station of each train will be taken as a probabilistic experiment for the following reasons: for the metallurgical industry, trains with raw materials are sent regularly and daily, the trains are of the same type and the route is similar. Besides, arrival of the train at the facility at the *i*-th moment of time is a random event since an infinite number of factors act on the unit train during the journey, which cannot be fully considered. For example, they may comprise a breakdown of a locomotive, hitting a technological traffic interval, detection of a wagon defect with subsequent uncoupling, the effect of human factor in the actions of locomotive crews, train dispatchers, station attendants, etc. Thus, the travel time of the train is a random variable.

The predicted time of arrival of the train at the station is generally defined as:

$$t = t_{i\ ship} + t_{i\ travel}(P), \qquad (1)$$

where t_{iship} – time of shipment, h (days);

$t_{i\ travel}(P)$ – a function of travel time to the destination station, depending on the probability P, h (days).

This shows that the value of the predicted arrival time is probabilistic, and the function itself is probabilistic.

As an example, the authors consider a sample of 100 values of the travel time of trains with dry-quenched blast-furnace coke in the summer period from Zarinskaya station to Novolipetsk station in days. All calculations of numerical characteristics of a random variable were made by the team of authors using *mathematical methods* in the Statsoft Statistica program. The resulting histogram of the distribution of values in comparison with the Gaussian distribution curve is shown in Pic. 2.

Application of the *method of comparative analysis* shows a significant deviation of the histogram to the left from the normal distribution curve, an elongation of the right «tail» and a pronounced peak. Checking the specified distribution for normality is carried out using the Kolmogorov–Smirnov and Shapiro–Wilk tests.

Research by the Kolmogorov–Smirnov method [9, p. 60]:

$$D_n = \sup_x |F_n(x) - F(x)|, \qquad (2)$$

where $\sup_x$ – exact upper bound of the set;

$F_n(x)$ – distribution function of the studied population;

F(x) – normal distribution function.

The allowed value of the significance level is more than 0,05. Otherwise, the hypothesis of normality is rejected.

Checking according to the modified Shapiro–Wilk criterion is carried out according to the formula [10, p. 605]:

$$W = \frac{[\sum_{i=1}^{n} a_{n-i-1}(x_{n-i-1} - x_i)]^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}, \qquad (3)$$

where *i* – ordinal number of the element in the studied row;

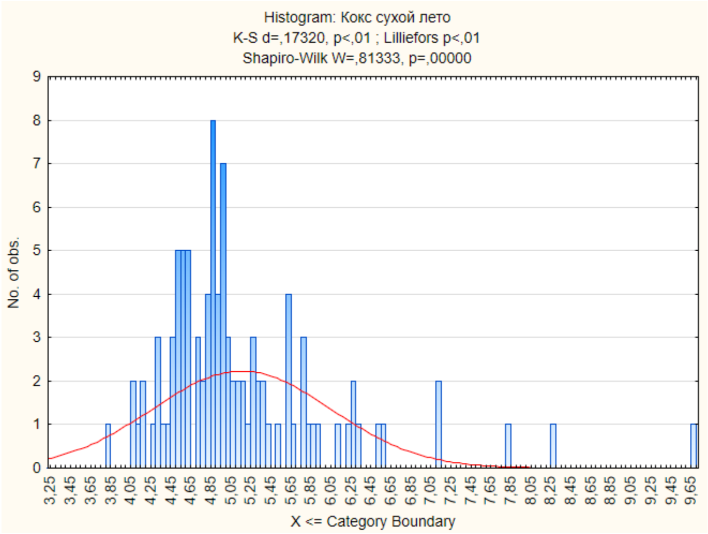
n – volume of the population;

– arithmetic mean value;

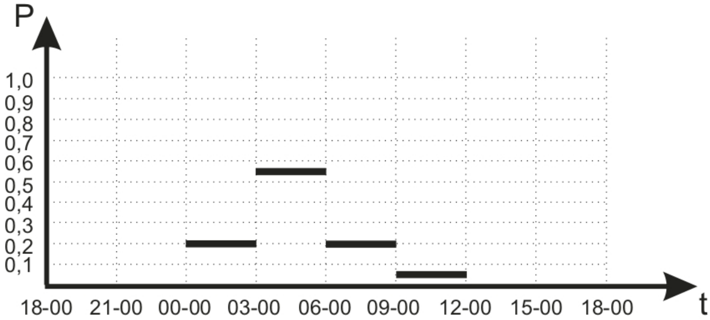
a_{n-i-1} – tabular coefficient.

Checking according to the specified criteria using the Statistica software package shows a discrepancy between the studied distribution and the normal one. According to the results of the study in the Statistica program, the authors determined the numerical characteristics, which are given in Table 1, and built a graph of the predicted arrival time for a daily period with three-hour intervals in general form for the dry quenching coke train (Pic. 3).

The constructed schedule of the planned arrival is automatically transmitted to the internal information system [11, p. 231].



Pic. 2. Histogram of distribution of travel time of the trains (compiled by the authors).



Pic. 3. The graph of the probability of arrival of a train within a three-hour interval (compiled by the authors).

Automated System for Monitoring the Position of Rolling Stock on Railway Tracks of an Industrial Enterprise

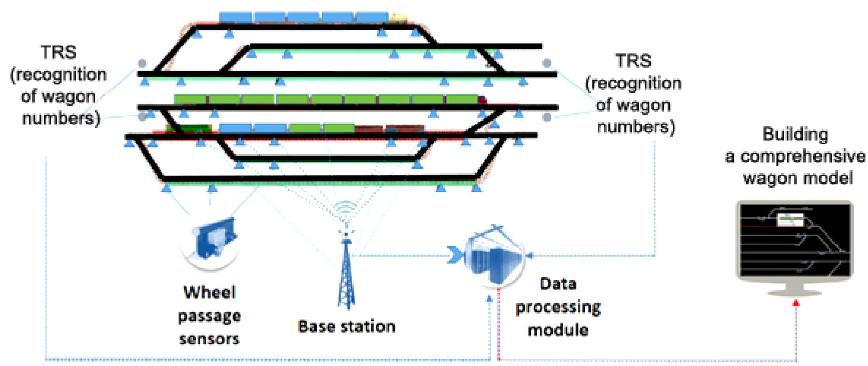
An in-depth study of the issue of logistic interaction between an industrial enterprise and rail operating companies shows that this process is trilateral: production workshops, industrial transport system and main transportation lines are inextricably linked [12, p. 636].

The development of a single information field will allow all participants in the logistics process to monitor the relevant performance indicators of the transport system, to cover by planning and permanent control the entire logistics chain from the moment of inception of the traffic flow to its consumption, and to build a strategy for further development [13, p. 265].

After adoption of a single automated system for monitoring the positioning of rolling stock at the enterprise, all processes through which the wagon passes at the industrial site will be visualised. The concept of the system's operation for an industrial railway station of a metallurgical enterprise proposed by the authors is shown in Pic. 4.

This system controls movement of wagons on the production site and the time of technical and commercial processing of trains, increases speed of acceptance and dispatch of goods and of related document flow operations, and minimises the influence of the human factor. In the future, it is planned to introduce elements of artificial intelligence, the algorithm of which will allow calculating the most optimal shunting routes to reduce transport costs and risks.

Recognition of the inventory wagon numbers (with the help of TRS, technical registration system) is made with a probability of at least 95 % (for clean, well-readable numbers that meet the numbering requirements of the freight fleet of 1520 mm gauge railways) under any weather conditions and varying degrees of illumination.



Pic. 4. The concept of the system for monitoring movement of wagons and locomotives in real time (compiled by the authors).

A screenshot of the software program running at the railway station of the metallurgical enterprise is shown in Pic. 5.

Thus, the information system makes it possible to fully automate the process of documentary registration of passage of trains through the controlled area, providing inspection functions in technical and commercial terms. The data obtained can be used both for recording and accounting purposes and as an evidence base in the event of disputable situations with counterparties [14, p. 55].

With the help of the system for monitoring the position of rolling stock, each participant in the transportation process can monitor in real time specific performance indicators.

Using a comparative analysis, it is possible to highlight the advantages of the automated rolling stock positioning monitoring system:

1)For production workshops:

• control of movement of wagons with raw materials both on the external and internal sites;

• control over supply of empty rolling stock for loading finished products;

• data correction and input of additional information for other participants;

Table 1

Numerical characteristics of a random variable (compiled by the authors)

Name of the characteristics	Designation	Value
1	2	3
Mathematical expectation	M	5,159
Median	Med	4,942
Standard deviation	σ	0,798
Asymmetry coefficient	β_1	2,237
Coefficient of kurtosis	β_2	7,333
Confidence interval, 95 %	–	(3,378; 6,940)

• optimisation of interaction between the main production facilities and the industrial transport system that serves it [15, p. 66].

2)For non-public transport:

• control over movement of loaded and empty rolling stock both on the backbone network and at the production site;

• coordination of interaction between production departments and mainline transport, considering parameters entered by other participants in the transportation process;

• reduction of transport costs, subject to implementation of best routing;

• control of movement of locomotives, which will increase the efficiency of using traction rolling stock on non-public tracks [16, p. 53].

3)For companies of operators, owners of wagons of the external fleet:

• visualisation of the entire logistics process, which allows predicting time of delivery of rolling stock to the network.

• planning of dispatched wagon flows.

The Economic Component of the Project

The economic component of the project for an industrial enterprise, provided that an automated system for predicting arrival and monitoring the position of rolling stock on non-public railway tracks at the production site is put into operation, will be assessed in the form of an annual economic effect and a payback period:

$$T = C/(E – M), \quad (4)$$

where T – payback period of the project, years;

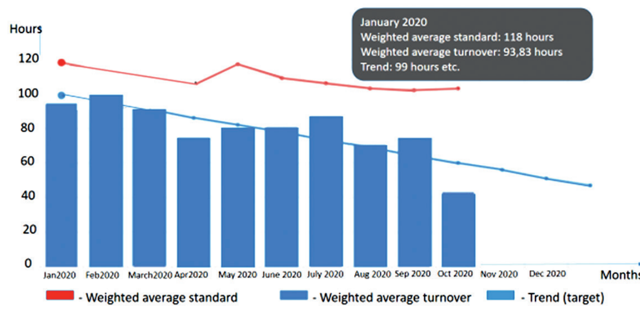
C – capital expenditures for implementation of the project, rubles;

M – additional annual costs of maintaining the system, rubles;

E – economic effect of the project, rubles:

$$E = (\tau_2 – \tau_1)\cdot W\cdot R, \quad (5)$$

Pic. 5. An example of the system's operation to control movement of rolling stock (compiled by the authors).



Pic. 6. Monthly weighted average turnover of wagons at the industrial site before and after introduction of the system (compiled by the authors).

where τ_2, τ_1 – average time spent by wagons on the industrial site before and after introduction of the system, h;

W – annual number of wagons arriving at the enterprise, wagons;

R – rate of attraction of rolling stock per unit of time, rubles/wagon-hour.

The team of authors determined the monthly weighted average turnover of a wagon at the site according to data for 2020 (Pic. 6).

All the calculated economic data given in the article are indicated according to expert estimates.

Capital expenditures C for introduction of this project will amount to 31 million rubles.

Annual operating costs M after introduction of the system will amount to 1,9 million rubles/year.

The positive forecast for reduction of the indicator of the turnover time of wagons within the industrial site gives reason to believe that an economic effect will be achieved due to [17, p. 187]:

• optimisation of labour costs for control of incoming and outgoing wagons – 4,8 million rubles/year;

• monitoring compliance with the carrier's requirements – 2,4 million rubles/year;

• reducing the cost of document management regarding wagons – 2,5 million rubles/year.

Thus, the total economic effect following the adoption of the system should be about 9,7 million rubles per year. Consequently, the payback period of the project will be 4 years.

CONCLUSION

Improving the information interaction of all participants in the transportation process will bring an economic effect by improving quality of operational work, reducing labour costs, turnover of wagons both on the siding track of the enterprise and on the external network [18, p. 183].

The predictive mathematical apparatus will allow planning a uniform arrival of trains at the interchange stations, while the automated control system of rolling stock on the siding track will make an optimal plan for shunting operations with arriving rolling stock. Improving the algorithm of the system's operation, as well as its further training, for example, based on artificial neural networks, will provide an even greater technical and, therefore, economic effect.

High prices for metals in foreign and domestic markets, together with an increase in production volumes, cause an increase in the volume of transportation of ferrous metallurgy goods. If this trend continues, the economic effect will be higher than the predicted one.

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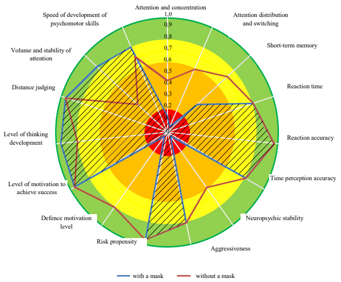
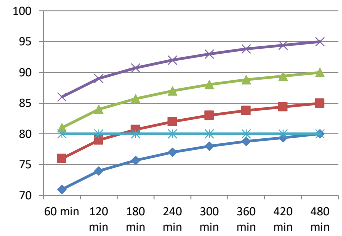
SAFETY, SUSTAINABILITY, ENVIRONMENTAL PROTECTION

Face masks in the cars. The study of their impact on psychophysiological qualities and behaviour of drivers.



Russian practices, current legislation and applied studies confirming the safety of work of railway track operatives in vicinity of railway mainlines with intensive traffic. Universal conclusions and unsolved problems.



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Face Masks as a Factor in Eventuality of Changes in Driving Safety

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ABSTRACT

During the COVID-19, pandemics or worsening virus situation, taxi and regular-route bus drivers are recommended to work in medical masks. However, the quantitative and qualitative influence of wearing protective face masks on safety of driving vehicles has not been previously studied. Therefore, this became the objective of preliminary studies to determine the specifics of the influence of a face protective mask on the change in psychophysiological qualities of a car driver as a factor in safety eventuality under urban traffic conditions.

The method of an open-ended survey of 108 healthy adult drivers was used to obtain a quantitative subjective assessment of the effect of face masks on changing driving safety conditions and a comfortable emotional state while driving. A qualitative analysis of assessment of the level of psychophysiological qualities of drivers wearing and not wearing a face mask was carried out using Meleti hardware-software complex.

A sharp decrease in neuropsychic functions with a simultaneous increase in quality of thinking and visual analysis of the traffic situation was revealed regarding the drivers wearing a face protective mask compared to those driving without a mask while the level of psychomotor reaction remains unchanged regardless of the gender of the driver.

The subjective assessment of survey participants of the effect of a face mask on professionally important, psychophysiological characteristics of drivers revealed a significant (41,7 %) or insignificant (20,4 %) decrease in reaction, while 38 % of drivers did not notice significant changes in driving because of the effect of the mask.

Based on these results, it is assumed that the face mask may serve as a predictor of a road pre-accident situation.

To assess the effect of the face mask on the driver, a coefficient of eventuality of reducing road safety is proposed. It is recommended to use it as an additional factor in a situational pandemic environment when developing recommendations for the use of face masks for car and bus drivers, and when analysing the causes of road accidents.

Keywords: *face protection mask, driver, road safety, psychophysiological qualities, external factors, eventuality coefficient, road traffic accidents.*

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INTRODUCTION

Following the outbreak of the SARS-CoV2 pandemic, the use of face masks is widely recommended by international[1], national[2] and local authorities[3]. The purpose of new sanitary and hygienic requirements is to reduce the release of droplets from the respiratory tract of persons with pre-symptomatic and asymptomatic infectious respiratory conditions [1, p. 4].

Depending on the type, masks can either be used to protect healthy people or to prevent further spreading of infection (source control). WHO continues to recommend that anyone with suspected or confirmed COVID-19 who is awaiting laboratory test results wears a medical mask in public (this does not apply to those waiting for a test before travelling). Any type of mask requires proper use, storage, and cleaning or disposal to ensure maximum effectiveness and avoid an increased risk of infection transmission.

The current recommendation to wear a mask when in contact with other people affects millions of civilians, not just medical employees, who must wear masks during all labour hours. So, taxi and regular-route bus drivers are advised to work in medical masks during pandemics and outbreak of viral diseases. However, the quantitative and qualitative influence of protective and medical masks on the safety of driving vehicles has not been previously studied. An example is the case in the United States, where the first serious car accident involving COVID-19 personal protective equipment occurred. « The driver is «believed» to have passed out behind the wheel after wearing an N-95 mask for too long, police said. As a result, vehicle careened, front bumper first, into a wooden pole. The driver suffered non-life-threatening injuries; accident scene investigation did not reveal that the driver was not under the influence of drugs or alcohol»[4, 5]. As it is known, respirators with this protection class filter about 95 % of the air, and they are usually worn only by medical employees who are constantly in contact with infectious patients. According to law enforcement officers, the victim had not taken off the mask for several hours and, most likely passed out behind the wheel due to insufficient oxygen intake.

The data of foreign studies evaluating the effect of physical exercises performed by a person with a face shield on cardiopulmonary load capacity, give unequivocal results regarding the negative impact on such parameters as maximum voluntary ventilation that a person can exhale (MVV) and maximal oxygen consumption (VO_{2max}/kg), affecting breathing and ventilation of air in the lungs. Masks significantly reduce pulmonary parameters at rest and during maximum exercise. In addition, wearing masks was perceived as very uncomfortable and significantly affected subjective breathing resistance with the mask. «Wearing the FFP2/N95 mask resulted in a reduction of VO2max by 13 % and of ventilation by 23 %» [2]. These changes are consistent with increased nasal and breathing resistance (e.g., [3, p. 920]). Studies that have tested the increased obstruction of the upper airways caused by additional resistance in the mouth report a similar effect on the parameter of lung function followed by increased breathing resistance [4, p. 1374]. The decrease in ventilation was the result of a lower respiratory rate with corresponding changes in inspiratory and expiratory times and a decrease in tidal volume. This is consistent with the effects of respiratory protective devices or additional external resistance to breathing [5, p. 279]. In particular, breathing resistance, warmth, oppression and general discomfort when wearing masks are factors that are perceived as subjectively disturbing and are accompanied by increased perception of stress [6, p. 509]. Obviously, masks have a negative effect on the dynamics of perception, especially at the limit of exercise tolerance and indicate the associated discomfort

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[1] Mask use in the context of COVID-19: interim guidance, 1 December 2020. The World Health Organization (WHO). [Electronic resource]: https://apps.who.int/iris/handle/10665/337199. Last accessed 29.04.2021.

[2] Methodological recommendations for prevention of coronavirus infection (COVID-19). Ministry of Health of the Republic of Belarus, 2020.

[3] Rules of conduct that are binding on citizens and organisations when a high alert or emergency regime is introduced. Decree of the Government of the Russian Federation of April 2, 2020, No. 417.

[4] The driver got into an accident due to a protective mask. [Electronic resource]: https://germania-one.turbopages.org/germania.one/s/voditel-popal-v-dtp-iz-za-zashhitnoj-maski/. [In Russian]. Last accessed 29.04.2021.

[5] Source in English, e.g., Carrega, C. Driver in crash may have passed out from wearing N95 mask too long: Police. ABC news. [Electronic resource]: https://abcnews.go.com/US/driver-crash-passed-wearing-n95-mask-long-police/story?id=70346532. – *Translator's note*.

as the second important cause of the observed deterioration in physical performance [7, p. 950].

The mask wearing in many countries is introduced as partially or completely mandatory measures, depending on the situation [8, p. 152]. And if pedestrians, while observing the social distance, must wear masks in public places and follow the rules for wearing masks [9, p. 1985], then for car drivers, such norms remain controversial. The cases when the driver must wear a mask, and when it is permissible to be without it are not stipulated. Traffic rules do not specifically regulate wearing of medical masks and, therefore, this can be considered as the absence of a ban on wearing them while driving. Therefore, it is relevant to conduct research to determine the causes and consequences of wearing face protection masks as a factor in eventuality of changes in safety of driving and road traffic.

The *objective* of this work is aimed at a randomised study of the effect of a face mask on the change in psychophysiological qualities of a driver as a factor in eventuality of driving safety in urban traffic environment during the COVID-19 pandemic period.

RESEARCH METHODS

The total pooled study sample included 108 healthy participants in a randomised order. In this group, the effects of driving in a protective mask and without it as for men (75 %) and women (25 %) (age 22–48 ± 2,2 years) were quantified. The response to traffic was monitored using a video recorder. After driving with and without a face protection mask (FPM), ten areas of driver comfort/discomfort were assessed using a questionnaire generated in the open web resource Google Forms https://docs.google.com/forms/.

For qualitative assessment of the influence of FPM on the psycho-emotional state of the driver and the degree of its influence on driving safety, about 10 % of drivers were examined using the Meleti hardware and software complex, designed to test, evaluate, and develop the psychophysiological qualities of vehicle drivers. Meleti software issues an automated conclusion without participation of a professional psychologist and allows to assess the level of psychophysiological qualities necessary for safe driving. The respondents were tested twice: with and without a mask. The tests were carried out at the same time of the day, but on different days with an interval of at least 48 hours, to ensure the same experimental environment.

The paper assumes that the type of FPM (medical or tissue) does not affect the passing of the test, because the choice of a mask was offered to the test takers, and the study authors could not control it closely.

Cars and passenger buses were used as vehicles.

All test participants recorded their permission at the end of the survey to use their answers in this research work, since it will not harm the participants and the institutions where they study or work, and all results obtained are confidential and will be presented in general form.

The test takers were not aware of the results of the respective tests to avoid bias in passing the tests. Statistical analysis was performed by an independent investigator who was not involved in the tests.

THE RESULTS OBTAINED

The first part of the research

The first part of the research was dedicated to a statistical analysis of a quantitative subjective assessment by healthy adult drivers of the influence of FPM on changes in safe driving conditions and a comfortable and emotional state while driving. The data obtained in the course of the research obey the law of normal distribution, due to which parametric statistical procedures are applied to them.

The study involved 108 people, most of the subjects (75 %) were males. The age of the respondents is from 18 to 55 years old, and more than half of them are from 20 to 35 years old. Driving experience was from one to 25 years.

The following distribution of respondents per time of driving in FPM was established: 61,1 % of the study participants were driving a car for about 15 minutes, 33,3 % of the subjects drove a car for 30 minutes or more. The rest drove for about 20 minutes.

The respondents' assessment of the influence of FPM on comfort while driving showed that the study participants experienced constant (56,5 %) or noticeable (40,7 %) discomfort when using masks, especially during strenuous driving and at night.

The distribution of respondents per degree of influence of FPM on respiratory function showed that more than half of the study participants (54,6 %) experienced constant difficulty in breathing when using a mask while driving, another 22,2 % experienced discomfort sometimes, and only slightly less than a quarter (23,1 %) did not experience any inconvenience.

The study of distribution of cases of allergic reactions to wearing a mask while driving using FPM revealed that 51 % of drivers had various allergic reactions (itching, redness) each time, 16,7 % had such consequences sometimes, and only 32,3 % never had any.

The overwhelming majority of drivers (75,9 %) felt sometimes a desire to take off their masks, and three quarters of drivers felt it all the time.

Also, about 60 % of respondents felt a high degree of fatigue from wearing FPM all the time, 17,6 % – sometimes, and only 23,1 % of respondents did not suffer a negative effect of masks.

At the same time, more than half of the respondents noted a deterioration (38,9 % – significant, and 12,0 % – insignificant) in perception of information from the dashboard of a car when driving wearing a FPM. A narrowing of the viewing angle and some inconvenience in using side mirrors were also noted. This correlates with the results on decrease in accuracy of the use of controls while wearing a mask, since more than half of drivers (53,7 %) noted some inhibition in their control reactions. Similar responses were received to the question about the effect of a face mask on concentration. Thus, for 38 % of drivers, the mask significantly reduced concentration of attention, for 27,8 % the reduction was insignificant, and 34,3 % of respondents did not notice any negative influence of FPM on this characteristic.

The results of studies on subjective assessment of the effect of a protective mask on professionally important, psychophysiological characteristics of drivers revealed the following: about two-thirds of drivers reported a significant (41,7 %) or insignificant (20,4 %) decrease in reaction, while 38 % did not notice significant deviations because of the mask to the response to driving. Since the mask is an additional factor in inattention and physiological fatigue of drivers, this can become one of the causes of a traffic accident.

Thus, it is obvious that in a situation where the risk of infection is minimal, there is no objective need to drive a car in FPM, and a driver without passengers in the car can work without a mask. It is also necessary to clarify that in the summer season, the mask will only complicate breathing and worsen the driver's well-being, and the presence of a mask on the face in summer while wearing sunglasses will lead to fogging when exhaling, which is another negative factor in driving safety.

The second part of the research

The second part of the research was dedicated to a qualitative analysis of assessment of the level of psychophysiological qualities of drivers in FPM and without it using the Meleti hardware-software complex [6] having the necessary certificates of conformity. 11 people, or 10 % of the total number of those tested, passed the testing with Meleti. The testing lasted from 70 to 100 minutes. The personality traits were assessed, such as:

• Psychophysiological traits: parameters of attention (volume, stability, concentration, distribution of attention), parameters of short-term memory, reaction time and accuracy, time perception accuracy, etc.

• Individual traits: risk propensity, aggressiveness, properties of the nervous system and temperament, motivation for safe driving, etc.

As a system for evaluating test results, marks from high to low were taken. Data processing was carried out using statistical analysis tools in MS Excel spreadsheets, the boundary value of each specific coefficient was calculated as the average of the test results from 0,1 to 1.0 (Table 1).

So, the presence of a mask on the driver's face provokes a decrease in the level of professionally important qualities from «high» to «average», the overall assessment of psychophysiological selection from «good» to «satisfactory», a deterioration in the forecast of the success in driver profession from «favourable» to «indefinite». Besides, when wording the final opinion on admissibility of a candidate to work as a driver as «apt», drivers in a mask were assigned to the category of respondents for whom this activity is «not contraindicated» with remark of «conditionally apt».

A parametric model, a radial diagram, which allows to visually evaluate the fields and areas of permissible values was chosen as the main toolkit for identifying the conditionally influencing values of the coefficients on the

[6] Testing of psychophysiological qualities. [Electronic resource]: https://anonmc.ru/deyatelnost/testirovanie/. Last accessed 29.04.2021.

Table 1

The results of assessment of professionally important qualities of the driver in a protection mask and without it (compiled by the authors)

Professionally important qualities of a driver	Indicators			
	with a mask		without a mask	
	rel. units	points	rel. units	points
Concentration and attention	0,14	2	0,45	3
Attention distribution and switching	0,047	2	0,6	3
Short-term memory	0,36	3	0,72	4
Reaction time	0,81	4	0,81	4
Reaction accuracy	0,96	5	0,96	5
Time perception accuracy	0,81	4	0,81	4
Neuropsychic stability	0,047	2	0,6	3
Aggressiveness	0,81	4	0,81	4
Risk propensity	0,96	5	0,96	5
Defence motivation level	0,047	2	0,81	4
Level of motivation to achieve success	0,96	5	0,96	5
Thinking development level	0,96	5	0,81	4
Distance judging	0,96	5	0,96	5
Volume and stability of attention	0,85	5	0,36	3
Speed of formation of psychomotor skills	0,81	4	0,72	4
Total	9,531	3	11,34	4

general psychophysiological state of the driver in FPM.

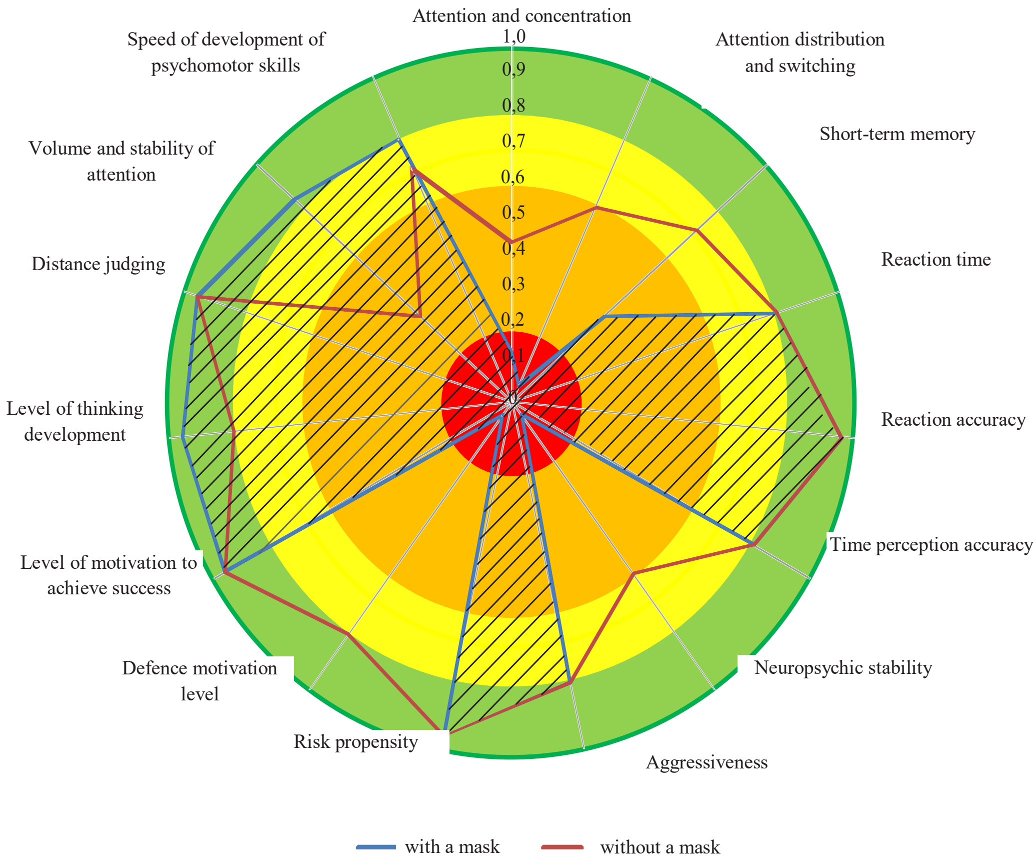
Pic. 1 shows the generalised test data for determining the level of psychophysiological qualities and the established parameters of the studied group of drivers with and without FPM. Each evaluated parameter in the diagram corresponds to a separate ray. Depending on the importance, the diagram is conventionally divided into four zones: threshold – from 0 to 0.19, satisfactory – from 0,2 to 0,59, good – from 0,6 to 0,79, and excellent – from 0,8 to 1,0.

Analysing the generalised results of an automated psychophysiological examination, it was found that the psychophysiological qualities of drivers wearing the masks showed lower values for certain professionally important qualities in comparison with the results of the same test passed by them without a mask, namely:

• The level of concentration and attention is reduced by 69 %. The driver is not able to concentrate on important elements of road traffic and vehicle controls for a long time (on instrument readings, road signs and markings, traffic signals, etc.). He is often distracted by extraneous factors and irritants (by his own thoughts not related to driving a vehicle, which reduce safety of driving a vehicle, by the environment, by using gadgets, by sounds and emotional conversations). He cannot concentrate in difficult road situations (driving during peak hours, difficult road, and weather conditions).

• The indicator of attention switching is reduced by 92 %. The driver is not attentive to road signs and instrument readings, misses road landmarks, is often unable to evaluate combinations of road signs, regularly demonstrates a slow reaction to switching attention from the traffic situation to external stimuli, is constantly distracted. He demonstrates confusion, a tendency to create emergency situations due to the slowed down ability to adequately assess them and the delayed control decision-making (especially in an unfamiliar road situation or terrain).

• The indicator of short-term memory is reduced by 50 %. The driver is not always able to retain operational information in his memory: road signs with prolonged action, for example, speed limits, stop bans, signs of settlements, etc. Sometimes he can forget routes, addresses, nature of road surface. He is not always able to stably maintain his behavioural motives when driving through a known road, depending on its load at



Pic. 1. The influence of the mask on the level of psychological qualities of drivers (compiled by the authors).

the time of day, on days of the week, when conditions of insufficient visibility occur. He may find it difficult to navigate the terrain. Because of the above, it can sometimes unknowingly violate traffic rules, create emergency situations.

• The level of neuropsychic stability decreases by 92 %, which indicates the occurrence of the likelihood of neuropsychic breakdowns directed at fellow travellers and (or) at the «culprits» who caused such a reaction. The driver is quick-tempered and unbalanced, behaves inappropriately while driving, often violates traffic rules, both involuntarily and intentionally. The driver is advised to consult a neuropsychiatrist.

• The level of motivation to avoid failure increases by 94 %. Such a driver has reduced skills for safe driving, which are a consequence of his inattention and low concentration, of low indicators of visual-motor reaction, inability to correctly assess the road situation. The foregoing often leads the driver to an extremely low self-esteem and level of aspirations, to a chronic fear of failures (unwillingness to get into an accident), which increases as the motivation for a high level of failure avoidance grows, and often increases their occurrence like an avalanche.

• The level of thinking development increases by 19 %. Such a driver is always reliable in controlling his vehicle, movement of other vehicles in the stream and the entire traffic situation in general, is able to qualitatively predict development of the traffic situation. He ensures high safety of vehicle control, adheres to a safe driving style with minimal risks.

• The level of monotony increases by 136 %. The driver in uniform, boring and monotonous traffic conditions gets tired, loses reaction speed, ability to control the traffic situation, may even fall asleep, which from time to time provokes an emergency.

A person as a link in the «driver–car–road–environment» (DCRE) system is not only basic, but also the most unstable element [10, p. 113]. By his nature, a person is characterised by inconstancy, the ability to change, and therefore, the problem of the driver's reliability when driving a car is complicated by its versatility [11, p. 14].

https://rozetked.me/images/uploads/eOGOhivqLbwc.jpg

When all the links of the system are balanced, the probability of a road traffic accident is insignificant [12, p. 9; 13, p. 60]. But the imbalance of at least one link leads to an imbalance of the entire system and an increase in the likelihood of a road traffic accident. The reliability of a driver in the «driver–car–road–environment» system is determined by a very complex set of interrelated factors. Performance, knowledge, abilities, skills, motives are most important factors, which intensity is due to individual characteristics, the nature and health of the driver, as well as his driving style [14, p. 87].

The peculiarities of the driver's activity should also include external unfavourable factors affecting him: heat and cold, high air humidity, unsatisfactory road conditions (ice, snow, mud, etc.), noise and vibration, uncomfortable working posture, etc. [15, p. 770]. With absent-mindedness, irritability, decreased attention, drowsiness and other complaints affecting the level of performance, the likelihood of a traffic accident increases sharply (by 1,5–1,8 times) [16, p. 178]. Therefore, the requirement to drive a vehicle wearing a protective mask is another negative external irritant that negatively affects performance.

Thus, the mask is considered as an eventual environmental factor affecting the accident rate. The degree of influence is proposed to be estimated by the coefficient of eventuality of reducing road safety determined as the ratio of the area of the radar diagram, built according to the values of the indicators of the level of the professionally important qualities of the driver in the mask, to the area of the diagram obtained during testing without it.

$$k_{ev} = \frac{S_{\text{m}}}{S_{\text{no.m}}} = \frac{\sum_{1}^{n} k_{\text{piq, m}}}{\sum_{1}^{n} k_{\text{piq, no.m}}}. \qquad (1)$$

The coefficient shows a quantitative assessment of the influence of the use of a protective mask in the process of driving a car on the level of psychophysiological qualities and personality traits of the driver, which in turn affect safety of driving. In the studied case $k_{ev} = \frac{9,531}{11,340} = 0,84.$

The need to consider the eventuality coefficient arises when investigating a traffic accident, when there are assumptions about the presence of a causal relationship between wearing a protective mask and the emergence of a traffic conflict and emergency situations.

CONCLUSION

The results obtained indicate that the use of a face mask by the driver while driving leads to a significant increase in the level of mental activity, the volume and stability of the driver's attention. However, psychological overstrain and discomfort from wearing the face mask result in a decrease in such important psychophysiological qualities of the driver as concentration and attention (by more than three times), the distribution of attention switching between static (road signs, traffic lights, markings, etc.) and dynamic (moving vehicles and pedestrians) objects on the road (by more than ten times).

To assess the effect of a face mask on a driver, a coefficient of eventuality of reducing road safety was proposed, which can be taken into account when developing recommendations on the use of face masks for drivers of cars and buses and when analysing the causes of road accidents in a situational pandemic situation.

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Noise as a Criterion for Designating Sanitary Protection Zones of Traffic Arteries

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ABSTRACT

The article is devoted to the study of a possibility of designating the boundaries of sanitary zones (distancing) for traffic arteries outside settlements within the right-of-way.

The study was conducted regarding the current Russian laws, projects of possible changes in legislation and draft amendments. It offers definitions of the right-of-way and of sanitary zone and highlights topics that have not yet been regulated.

At the same time, the research methods are of universal character and after introducing other regulatory parameters may be applied for similar research in other countries as well.

Calculations and field studies allowed to find that within the railway right-of-way and with the existing train traffic intensity, equivalent continuous sound pressure level in aggregate does not exceed the established maximum permissible level of 80dBA for personnel performing their labour functions within the railway right-of-way.

A growth in the Leq/LAeq on the right-of-way from 80,0 to 95,0 dBA may lead to an increase in the hazard class (subclass).

An analysis of the actual results of a special assessment of working conditions at JSC Russian Railways showed in the vast majority of cases the acceptability of working conditions evaluated according to noise factor measured at the workplaces of employees working during full or part-time shift on the right-of-way. Hazardous working conditions at the level of some subclasses for certain professions (operator of track measurement, railway track worker) arise rather due to indicators of severity of the labour process.

Keywords: *railway, sanitary protection zone, sanitary distancing, right-of-way, noise, special assessment of working conditions.*

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INTRODUCTION

Sanitary protection zones (SPZ) are established around various production facilities that are a source of negative impact on the environment, employees, and the population. SPZ are designed to localise and reduce the negative impact to the values determined by hygienic standards.

Sanitary protection zones in the Russian Federation are established, changed and ceased to function by adopting relevant legislation regarding capital development facilities if:

• these facilities are sources of chemical, physical and biological impact (*CPBF, where F mean factors*);

• the impact affects directly the human habitats;

• the impact exceeds the values established by sanitary and epidemiological requirements outside the boundaries of capital development facilities[1].

The human habitats are understood to be urban and rural settlements[2].

Sanitary and epidemiological requirements are adopted by the state bodies separately for the population and for organisations of various forms of ownership.

The Rules[1] adopted by the Government of the Russian Federation do not contain instructions governing the establishment of sanitary zones for transport routes.

Sanitary and epidemiological rules and norms (further referred to as SanPiN) 2.2.1/2.2.2.1200–03 require the establishment for hazardous transport infrastructure facilities (road, rail, air, pipeline facilities, etc.) of sanitary distancing up to the boundaries where the effect of CPBF will be reduced to the level or will be below the hygienic standards[3].

Standard requirements for sanitary distancing have not been developed, although such a need exists and is justified [1].

Industrial site according to[3] is a land plot on which an industrial facility is located which legally owns this land plot. The right-of-way, by its very nature and purpose, is an industrial site for transport road facilities[4].

From all the described above, it can be concluded that, according to the current Rules, SPZ (sanitary distancing) for traffic arteries are designated in case of exceeding the sanitary and epidemiological requirements (not specified which ones) and include a right-of-way. According to the project [2] SPZ are established in case of chemical, physical and (or) biological impact that exceeds the sanitary and epidemiological requirements and must be located outside the boundaries of land plots legalised according to established procedures and intended for economic activity by capital development and other facilities in accordance with the classification, established by sanitary and epidemiological requirements.

Most of traffic arteries in the Russian Federation pass outside the settlements, hence impossibility of the impact of CPBF in this case on the population. For the same reason, it is impossible to use hygienic standards stipulated for residential areas both inside the right-of-way and outside it [3].

Based on the foregoing, according to the current legislation, SPZ (sanitary distancing) outside the settlements can be established only within the right-of-way, and according to the legislative project, it should not exist at all.

In case of establishing the boundaries of SPZ (distancing) along the boundary of the right-of-way, it is important to determine the choice of sanitary and epidemiological requirements. Currently, various standards are applied for industrial sites and for residential areas. Since the right-of-way is not intended for habitation, the choice of these requirements for settlements will be incorrect. The only and correct choice of sanitary and epidemiological requirements for the production environment, since the right-of-way is one of the working areas of personnel serving transportation and maintaining transport facilities located on it [3].

The solution to the issue of establishing SPZ outside settlements can be found, as an example, based on an assessment of the impact of noise emanated from roads as part of a special assessment of working conditions of personnel who are permanently or temporarily working on the right-of-way land plot.

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[1] Decree of the Government of the Russian Federation dated 03.03.2018 No. 222 «On adoption of the Rules of designating sanitary protection zones and of the use of land plots situated within the boundaries of sanitary protection zones». [Electronic resource]: https://base.garant.ru/71892700/. Last accessed 03.06.2021.

[2] Federal law No. 52-FZ «On sanitary and epidemiological wellness of the population» dated 30.03.1999. [Electronic resource]: http://www.consultant.ru/document/cons_doc_LAW_22481/. Last accessed 03.06.2021.

[3] SanPiN 2.2.1/2.1.1.1200-03. Sanitary protection zones and sanitary classification of enterprises, facilities and other objects. [Electronic resource]: https://docs.cntd.ru/document/902065388. Last accessed 03.06.2021.

[4] Since the topic does not refer to the issues of ownership of the right-of-way or nonpossessory rights (e.g., easement), it does not consider here and further in the article either legal aspects or relevant regulatory features of Russian and international legislation. – *Ed. note.*

For railways, noise within the right-of-way outside settlements is generated mainly by train traffic. There are three main groups of noise production:

• rolling noise (prevails in the speed range of 60–300 km/h);

• equipment noise (50–60 km/h);

• aerodynamic noise (over 300 km/h) [4].

Specific noise figures depend on the types of trains. Thus, passenger trains at a speed of 30–120 km/h generate noise in the range of 78–88 dBA, electric trains at a speed of 40–120 km/h create the noise of 76–90 dBA, and higher-speed trains of Sapsan series at a speed of 100–220 km/h generate noise of 68–86 dBA [4–7].

The noise intensity depends on the speed of the train. The higher is the speed, the higher is the noise intensity [4–6].

The maximum permissible noise level for workplaces, regardless of job positions and duties, is standardised at Leq/LAeq of 80 dBA[5]. It serves as one of the criteria for establishing a hazardous class (subclass) in the process of conducting a special assessment of working conditions[6].

The relevance of the study is determined by the need to develop criteria for establishing SPZ (sanitary distancing).

The *objective* is to reduce the cost of designating a SPZ. The task is to study the possibility of using the results of a special assessment of working conditions as per noise factor as a criterion for designating the boundaries of SPZ.

RESEARCH METHODS

The measurements were carried out with the «Assistant» Total + noise and vibration analyser, serial number 231716, verification certificate No. SP 2791442, the date of expiration of the verification period was November 21, 2020.

Direct single measurements were carried out in May 2020 in accordance with the instruction manual for the device. The measurement time fully covered the interval of train movement. The results of three measurements at the single point did not differ by more than ±3 dB. The main axis of the measuring device was directed perpendicular to the track. There were no foreign objects between the microphone and the noise source. The height of the microphone position was 1,5–1,8 m.

The device was calibrated at the beginning and at the end of the measurements with an acoustic calibrator «Zashchita-K», serial number 124416, verification certificate No. SP 2662786, the date of expiration of the verification period was May 26, 2020.

The object of research is the railway right-of-way on Moscow–Khimki section of Oktyabrskaya railway[7].

RESEARCH RESULTS

Traffic noise affecting an employee within the right-of-way has its own characteristics. First, it is intermittent (non-constant) noise, which implies the use of specific techniques when measuring noise.

Outside settlements, the train speed is higher and generates noise up to 95 dBA. Within the right-of-way and up to 50 m, it decreases slightly, by about 0,5–1,5 dBA.

The negative impact of train noise on an employee depends not only on the noise emitted by an individual train, but also on the duration of exposure to this factor during the shift. To clarify the dependence of the actual level of exposure to noise on the employee and to establish the dependence of the hazard degree on the level of sound generated by a vehicle, the appropriate calculations were made for the most significant range of 80–95 dBA with a step of 5 dBA (Table 1).

The data obtained clearly show that the degree of negative impact of noise depends on the time of an employee's exposure to it («protection by time»). Working conditions refer to hazard class 2 with any time of exposure to an LAeq up to 80,0 dBA inclusive and up to a full work shift. A sound level of 85 dBA does not have a negative effect for at least 2 hours, at 90 dBA – for at least 0,5 hours.

At all other time intervals, hazard class 3 is recorded (subclasses 3.1 and 3.2).

The presented hazardous working conditions are located on the graph above the MPL (maximum permissible level) line (Pic. 1).

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[5] Order of the Ministry of Labour of the Russian Federation dated 24.01.2014 No. 33n (version of 27.04.2020) «On approval of the Methodology of conducting special assessment of working conditions, of the Classifier of hazardous and (or) dangerous industrial factors, of the form of the report on the special assessment of working conditions and of guide to fill it». [Electronic resource]: http://www.consultant.ru/document/cons_doc_LAW_158398/. Last accessed 03.06.2021.

[6] Federal Law dated 28.12.2013 No. 426-FZ «On special assessment of working conditions». [Electronic resource]: http://www.consultant.ru/document/cons_doc_LAW_156555/. Last accessed 03.06.2021.

[7] Oktyabrskaya or October railway, a subsidiary to Russian Railways JSC. – *Translator's note*.

Table 1

Equivalent continuous sound pressure level and hazard level for personnel depending on the exposure time (compiled by the author)

Indicators	Exposure time, hour								
	0,5	1	2	3	4	5	6	7	8
Noise, dBA	68,0	71,0	74,0	75,7	77,0	78,0	78,8	79,4	80,0
Class (subclass)	2	2	2	2	2	2	2	2	2
Noise, dBA	-	76,0	79,0	80,7	82,0	83,0	83,8	84,4	85,0
Class (subclass)	-	2	2	3.1	3.1	3.1	3.1	3.1	3.1
Noise, dBA	78,0	81,0	84,4	85,7	87,0	88,0	88,8	89,4	90,0
Class (subclass)	2	3.1	3.1	3.2	3.2	3.2	3.2	3.2	3.2
Noise, dBA	83,0	86,0	89,0	90,7	92,0	93,0	93,8	94,4	95,0
Class (subclass)	3.1	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2

Table 2

Ranges of noise measurement at workplaces of personnel employed at the facilities within the right-of-way [8; 9]

The name of the workplace (profession, position)	Noise, dBA	Class (subclass) of working conditions as per noise	
		when protected by time	based on actual measurements
Outdoor cleaning operative	58–73	2	2
Foreman (main occupation) of current track maintenance and repair works	65–81	2	2
Trackwalker	65–81	2	2
Operator of track measurement	65–81	2	2–3.1
Roadmaster	65–81	2	2
Railway track worker	70–80	2	2–3.2
Bridge and structure maintenance worker	74–94	2	2–3.2
Tractor driver (Belarus-922)	60–75	2	2

The same trend persists for contractors performing maintenance works on land plots of the right-of-way and in protection zones, fighting against unwanted vegetation and collecting garbage.

To find out the reasons for reduction of the noise hazard class, the time of the exposure to the noise of passing trains was calculated using the example of Moscow–Khimki section during the day of May 19, 2020.

The number of passenger trains passing in both directions per day was 268.

The duration of traffic was 20 hours 57 minutes or 1257 minutes.

The time of continuous passage of all trains relative to one point, constituted in total 4,27 %.

With an eight-hour working day, this will be 20,5 minutes, and considering the increase in train traffic during peak hours (+ 30 %) this will be up to 26,7 minutes.

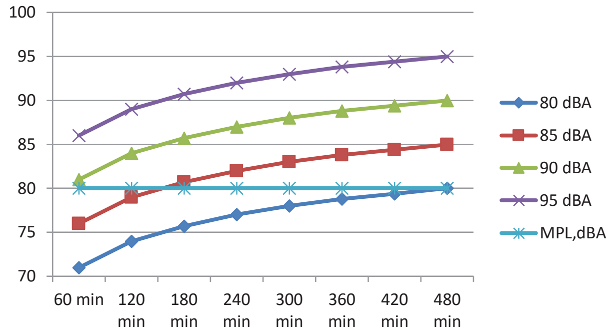
Comparing the obtained data with the Table 1 and the picture, we can conclude that for a given train traffic intensity, the noise up to 90 dBA inclusive generated during by train movement does not go beyond the boundaries of hygienic standards[8] and corresponds to the hazard class 2.

The analysis of actual results of a special assessment of working conditions at JSC Russian Railways showed that in the vast majority of cases, at the workplaces of workers who spend full or part-time shift on the right-of-way, working conditions are established as per noise factor as permissible ones, i.e., belonging to hazard class 2. The final class (subclass) is formed mainly due to the «severity» indicator and corresponds to subclass 3.1. of class 3 and extremely rarely to subclass 3.2 of class 3 (Table 2) [8; 9].

The measured and calculated values of the equivalent sound level in the right-of-way have shown that they are within the ranges established by sanitary and hygienic requirements for personnel working in this area[3].

The application of other standards limiting the noise level on the right-of-way outside the

[8] SanPiN 1.2.3685-21. 21. Hygienic norms and requirements for ensuring safe and (or) hazardless human habitat factors. [Electronic resource]: https://docs.cntd.ru/document/573500115. Last accessed 03.06.2021.



Pic. 1. Working conditions depending on the value of the LAeq and the time of its exposure (nomogram compiled by the author).

settlements is impossible due to the lack of appropriate regulatory legal acts in this field.

Establishing the boundaries of SPZ according to the proposed draft changes to the Rules for establishing SPZ [2] is impossible because the measured and calculated values are lower than MPL standard[8].

CONCLUSION

With an increase in the equivalent sound level from 80,0 to 95,0 dBA, the degree of hazard for employees working on the right-of-way increases proportionally from hazard class 2 to class 3 of subclasses 3.1 and 3.2.

Reducing the time of exposure to noise (time protection) exceeding hygienic standards allows the calculated value to be reduced to a safe level.

Designation of SPZ (sanitary distancing) for railway mainlines outside settlements, according to the current legislation, is possible in terms of the noise indicator within the boundaries of the right-of-way.

The noise indicator cannot serve as a basis for establishing SPZ following the logic of the draft [2], since the measured and calculated values are below MPL standard according to[8].

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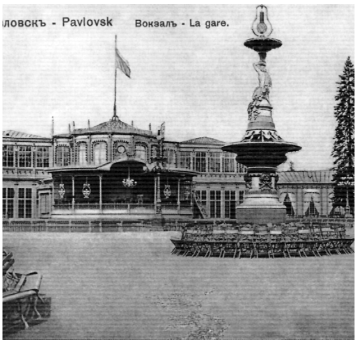
HISTORY WHEEL



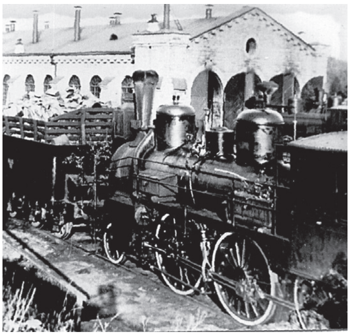
RAILWAY STATIONS 288

History of railway stations… One could return infinitely to the issue. This time, the topic refers to the history of railway stations built on first Russian railways in Tsarskoye Selo, St. Petersburg and Moscow.


Желѣзнодорожное Дѣло
ЖУРНАЛЪ
издаваемый VIII Отдѣломъ ИМПЕРАТОРСКАГО Русскаго Техническаго Общества
№ № 17-18-19. Годъ XXX. 1911 г.

RAILWAYS 304

In 1911, Russian railways celebrated their 75th anniversary. It was an excellent occasion to sum up some results of their developments and to compare them with foreign railroads. Probably, not in exactly modern terms, but the stated idea to ensure the connectivity of the country was quite sound.



REVIEW ARTICLE
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Russian Metropolitan Railway Stations as Historical Architectural Masterpieces

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ABSTRACT

According to the author of the article, the appearance of the first railway stations immediately became the most striking image of the time. The history of the architecture of Russian railway stations begins at the same time when the first railway in Russia was built connecting St. Petersburg to Pavlovsk. Previously existing post stations and the so-called road imperial palaces served prototypes for railway stations.

The railway station is, first, a story in which both the most interesting architectural and social plots collide. The railway station offers passengers the most vivid images of our time. The architects who designed the first railway stations had to solve problems that no one had ever encountered before: to cover train sheds by a roof, to design platforms, lighting, ventilation, acoustics... All this made the railway station the most technically enriched architectural genre of its time. And in this sense, the railway station architecture is a very interesting plot, in which everything changes very quickly and where all human relations are very aggravated. Therefore, the railway station is a condensed replica of society. Therefore, at the railway station, you can always very clearly see how society is organised. For example, at imperial railway stations, division of passengers per travel classes was obvious and inherent in the architectural program itself. The imperial pavilions, the imperial rooms also make part of the story... The railway station is, first, an image of modernity, mobility and a history of boundaries between the country and the city. This is especially interesting in the case of metropolitan railway stations.

Keywords: *railway station, railway tracks, train shed, cable-stayed train shed, platform, station architecture, water tower, truss arch.*

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Текст статьи на русском языке публикуется в первой части данного выпуска.

INTRODUCTION

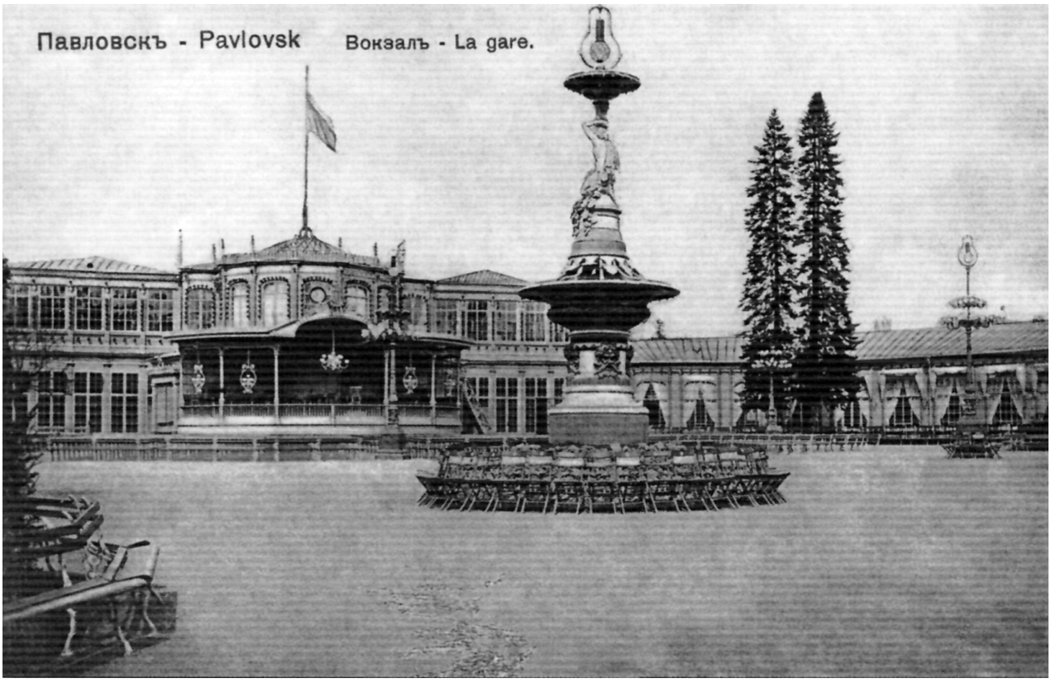
The first railway stations[1] in all countries appeared immediately with th emergence of the first railways and became an integral part of large cities, and often their attractions. Railway station buildings [in Russia] were created by many famous architects: I. I. Strukov, N. I. Orlov, R. N. Kuzmin, K. A. Ton, A. V. Shchusev, F. O. Shekhtel and others. As a token of gratitude, for example, busts of architects were installed in front of Moscow railway stations. I. K. Roerich, E. E. Lanseray, B. M. Kustodiev and other famous artists participated in design of facades and internal halls.

The construction of railway stations is a kind of page in the history of architecture. Initially, the architecture of railway stations had been influenced by traditional public buildings while since the end of 19th century it was associated with the search for functionally grounded types of railway station buildings both in Russia and abroad. This can be illustrated by the examples of the buildings of railway stations built according to the project of K. A. Ton in Moscow and St. Petersburg, the end points of Petersburg–Moscow railway, as well as of Rizhsky railway station in Moscow. In the 1860s and later, railway station buildings at small stations were often built of wood. The abundance of carved details made them very elegant. Such buildings adorned the railway between St. Petersburg and Moscow. The design of the main station building in the city of Ivanovo-Voznesensk was of considerable artistic and architectural value and was used with minor changes in several cities of this region. In large cities, red-brick station buildings were built. For example, in Moscow, Smolensky (Belorussky) railway station, was erected using this design in 1870. At the end of the 19th and the beginning of 20th century, railway station buildings built in the Art Nouveau style became important elements of urban architecture, often forming the appearance of squares. Striking examples of such structures are the buildings of Small Moscow ring railroad, where 15 railway stations were built in 1903–1908.

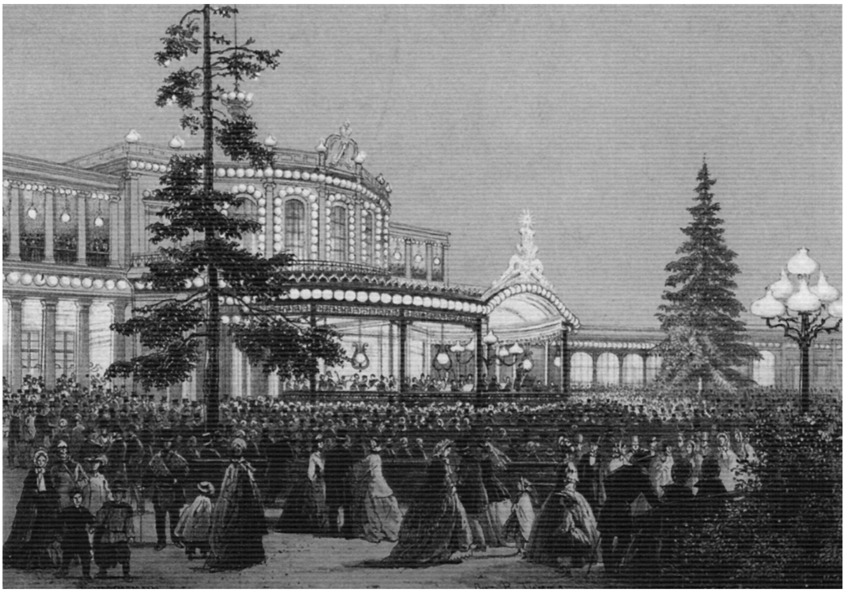
A unique architectural ensemble in Moscow is the so-called square of three railway stations. In 1987–1990 railway stations were reconstructed to renew their appearance, expand the premises for passengers, improve service offered to them, and equip stations with modern equipment.

Many architecturally remarkable railway stations were destroyed during the war years and

[1] [The Russian word «vokzal» meaning railway station] originated from the English word *Vauxhall,* the name of a park with a concert hall for an entertainment variety program [Vauxhall gardens], located in 17th century in the suburbs of London; in Russian, this word was first associated with the station building in Pavlovsk. – *Author's note for Russian readers edited by the translator.*



Pic. 1. Railway station in Pavlovsk.



Pic. 2. Ball at Pavlovsky railway station.

then rebuilt following their initial design or created as new buildings. Hence, the interest to the initial appearance of many significant railway stations.

FIRST RAILWAY STATION IN RUSSIA[2]

First Railway Station

The railway station in the city of Pavlovsk (Pic. 1) was built at the terminal station of the first railway in the Russian Empire which was Tsarskoye Selo railway. On May 23, 1838, a concert building with a restaurant, designed by the architect A. I. Shtakenshneider, was opened to the public in Pavlovsky Park. Pavlovsky Park belonged to the Grand Duke Mikhail Pavlovich, who, at the request of his brother, Emperor Nickolay I, allowed a railway to be built through the park. Pavlovsky railway station became the first permanent concert hall in Russia where symphony orchestras performed. It was there that outstanding musicians Johann Strauss (son), A. K. Glazunov, R. M. Glier, A. K. Lyadov, N. A. Malko, V. I. Suk, V. V. Andreev, S. S. Prokofiev, L. V. Sobinov, N. N. and M. I. Figner, I. V. Ershov, A. D. Vyaltseva, F. I. Shalyapin performed.

After the fire in 1844, the railway station was restored and re-opened. In 1860, 1871, 1884 the railway station was again rebuilt and enlarged. In 1875, according to the project of the great N. L. Benois, Pavlovsky theatre was built nearby. After 1918, the music station and the theatre formed a single complex. During the Great Patriotic War, the railway station building was destroyed.

Imperial Railway Station in Tsarskoe Selo

At the end of 19th century, the Alexander Palace became the permanent residence of Emperor Nickolay II. Immediately there emerged a state need to provide transport links between St. Petersburg and Tsarskoye Selo for the Tsar and the royal family. The existing Tsarskoye Selo branch of the railway was overloaded and could not provide necessary safety and comfort to high society people. Therefore, in 1899, it was decided to build its own imperial route from Vitebsky railway station to the Alexander Palace. The allocated 4 million rubles sounded astronomical amount at that time.

In 1902 the «imperial track» was put into operation, but the Imperial railway station (Pic. 3) was built only in 1912, on the site of the burnt down wooden imperial pavilion. A two-hundred-meter-long passenger platform adjoined the railway station. It was used by members of the imperial family, foreign guests and high-ranking officials arriving in Tsarskoe Selo.

[2] The journal has published many papers dedicated to the architecture and history of railway stations. As it is impossible to quote all the publications, here are just few examples: Vladimirov, Yu. V. «To fly from the station to the masquerade…». World of Transport and Transportation, 2015, Vol. 13, Iss. 6, pp. 272–279; Ovchinnikova, E. A. The CV of the Railway Station. World of Transport and Transportation, 2012, Vol. 10, Iss. 2, pp. 204–210. – *Ed. note.*

Pic. 3. Imperial railway station in Tsarskoe Selo.

Railway Stations of the First Railway Main Line in Russia

At the beginning of 1842, Nickolay I ordered the construction of a railway between St. Petersburg and Moscow to begin. Construction of the railway started in the summer of 1843 following the project of P. P. Melnikov, N. O. Kraft and A. D. Gotman. And already on May 5 (17)[3], 1847 at 10:00 the first passenger train set off to the village of Kolpino from the place near which Nikolaevsky railway station was subsequently built (it was called Nikolaevsky railway station until 1924, then until 1930 it was named Oktyabrsky railway station, then up to the present time it has been called Moskovsky).

Nikolaevsky railway station (Pic. 4) was designed by the architect K. A. Ton, with participation of R. A. Zhelyazevich and built in 1844–1851. The building combines the forms of the Italian Renaissance and Old Russian motives. A novelty at the time was a solution to cover the end sections of railway tracks and adjacent passenger platforms with metal roofing. If the passenger station building itself was designed by the architect Ton in traditional forms and with conventional structures, then the train shed had no past architectural analogues. The triangular trusses of the platform roof created a completely new image of the interior of a transport facility.

[3] Here and further two dates mean respectively dates according to old and modern style calendar used in Russia. – *Translator's note*.

The railway station building is round in plan and is located lengthwise along the entire Znamenskaya Square (currently it is Vosstaniya square). Konstantin Ton used the motives of the town halls of Western European cities, the clock tower indicates the direction of the main entrance. The Emperor personally took an active part in the design of the new square near the station.

N. I. Miklukha (father of the future ethnographer N. N. Miklukho-Maclay) was appointed the first head of the passenger and railway station of Petersburg-Moscow railway. His apartment was located in the station building, Besides, the offices of employees, the railway administration, and the imperial premises were located there as well.

In 1868, significantly increased passenger traffic resulted in the need to start the reconstruction of Nikolaevsky railway station. A two-storey wing was added for receiving luggage, the right wing of the building was connected to the royal chambers. In 1898, from the side of Ligovsky Avenue, a red brick building of Nikolayevskaya railway office was added.

In the late 1950s, based on the project of the architect V. I. Kuznetsov, the building of Moskovsky railway station was reconstructed and expanded, and a new outbuilding was added to the right wing. In 1967, a new «Light Hall» was opened (also designed by V. I. Kuznetsov), which increased the area of the railway station by 2700 square meters. A monument to Lenin

Pic. 4. Nikolaevsky railway station in St. Petersburg.

by the sculptor L. A. Messa was erected inside the hall. In 1976, the area between platforms and the light hall was covered with an aluminium shed. In 1993 the bust of Lenin in the arrival hall was replaced by the bust of Peter I by A. S. Charkin and V. V. Olenev. In the early 2000s the railway station was renovated.

Leningradsky railway station (it was called Peterburgsky railway station until 1855, Nikolaevsky railway station in 1855–1923, Oktyabrsky railway station in 1923–1937 (Pic. 5) is the oldest of nine railway stations of Moscow. The station building was built in 1844–1851 by the architect R. A. Zhelyazevich based on the project designed by K. A. Ton. For the future site of railway station, the construction commission chose Kalanchevsky wasteland on the north-eastern outskirts of Moscow.

The construction of Peterburgsky railway station in Moscow began in 1844 under the direction of P. A. Kleinmichel, the administrator (the Minister) of transportation, who had disagreements with Konstantin Ton. So, Kleinmichel demanded the use of brickwork with thin seams, which seemed to him the most aesthetic. The architect refused to comply with this instruction, fearing decrease in wall strength and the cracks. As a result of conflicts in 1847, the work was entrusted to R. A. Zhelyazevich, which was distinguished by greater compliance with administrative instructions.

The construction was completed in 1851. The building was a stylistic pair of the station in St. Petersburg, but it was smaller. The central part of the building was occupied by a spacious two-storey lobby. The station premises were decorated with oak parquet and Swedish marble stoves. The imperial halls had massive oak doors and mirrored wardrobes. The second floor of the main building of the station was allocated for apartments of employees.

On the side of the rear façade, two platforms extended from the building. A building with waiting rooms and station services was located along the right platform. For different strata of the population, separate premises were provided, but they all were the same in their purpose. The left platform was separated from the outer space by glass arches. Two additional pavilions adjoined it. One was intended to serve the royal family; the other was used for distribution and dispatch of luggage. Both platforms were connected by the cross platform and the lobby. The railway tracks were connected by turntables to rearrange the locomotives. The cable-stayed train shed was covered with a shed metal ceiling, and this was an innovation of that time.

The reconstruction of Leningradsky railway station took place in 1934. The cashier area was expanded, and the former imperial halls were rearranged to become a mother-and-child room. In 1949, the station premises were restored. In the mid-1970s, next reconstruction and redevelopment of the station took place (Pic. 6). New station tracks were laid, the building was expanded, and the third floor was added. In 1989–1993 during restoration, platforms were lengthened, roofs were erected over the platforms, and lighting was improved. In 2008–2013 during reconstruction, the area of the station was

Pic. 5. Nikolaevsky railway station in Moscow.

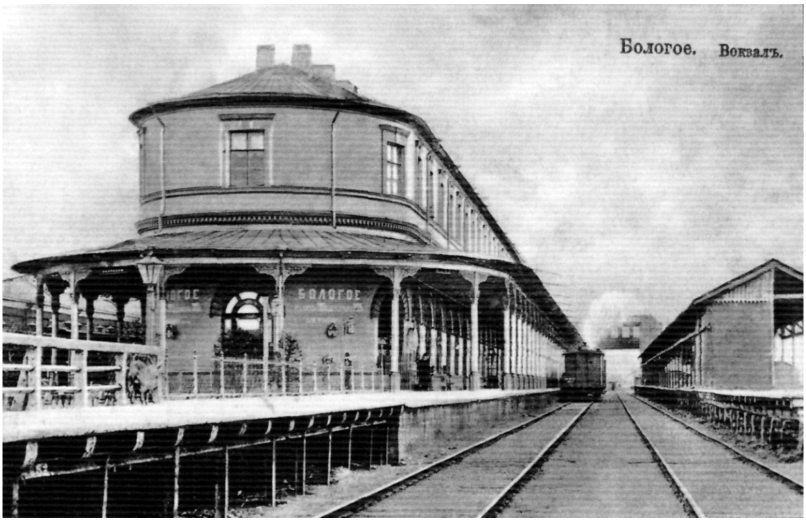
increased by 8000 m^2, of which 3000 are intended for commercial use, the layout of the station was changed, the main facade of the building was repaired, and the bust of Lenin was dismantled.

The railway station at Bologoye (Pic. 7), opened in 1851, was built based on the standard design by the architect R. A. Zhelyazevich, assistant to K. A. Ton. The same station buildings were erected in Malaya Vishera and Tver (Pic. 8), and some very slightly different station buildings were built in Lyuban, Okulovka, Spirov and Klin.

The one-storey brick building of the railway station, 115 m long, with platforms on both sides, is located between railway tracks. In 1877, the second floor was added to the station building. During the Great Patriotic War, Bologoye station was subjected to brutal bombing. In May 1985, Bologoye station was awarded the Order of the Patriotic War of I degree for logistics services provided to the Soviet Army and the Navy during the Great Patriotic War.

The railway station at Tver (Pic. 8) was built in 1845–1848 based on the standard design of the first-class station by architect R. A. Zhelyazevich. The building is of island type, located between two main routes, and built in the Russian-Byzantine style with elements of Florentine architecture (Bramante's windows). The building

Pic. 6. Leningradsky railway station.

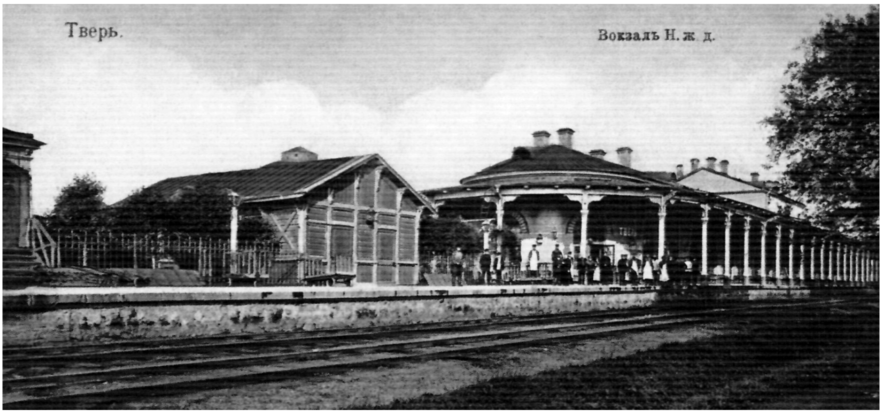


Pic. 7. Railway station of Bologoye.

is brick plastered, two-storey, 115 m long with rounded end facades, surrounded by a gallery on cast-iron columns allowing passengers to exit to the platform. It consisted of halls of respectively first, second, third classes, cash, luggage and telegraph offices, buffet, kitchen. In Moscow wing of the railway station there was a department for cashier receipts and luggage, in St. Petersburg wing there was an imperial compartment (five rooms), which played the role of representative offices, in which solemn ceremonies were held on occasion of arrival of His Imperial Majesty. A garden was laid out in front of the imperial compartment. The interior used drapery, coloured, and mirrored glass, oak parquet for the floor, marble fireplaces made by the Italian master P. Katozzi. The walls were covered with paper floral wallpaper with gilded baguettes. The doors were made to order by the carpenter's master Hasse in St. Petersburg. The most august persons have repeatedly visited the station, they were Nickolay I, Alexander III, Nickolay II.

In 1984–1990 the railway station complex was expanded, a new station building (coastal part) with a capacity of 2000 people was built. In the waiting room, a greenhouse was set up comprising more than 200 species and varieties of various plants collected.

By the beginning of 2000s a significant part of the historical architectural appearance of the railway station had been lost. In particular, the interiors of the station (including the imperial room), the canopy and columns of the front facades of the building were lost, the original appearance of the windows was changed. During the reconstruction of 2012–2015 the historical appearance of facades and the interior of the station, including the imperial room, halls of the second and third classes, were restored. The original Mettlach tiles, lost by beginning of the reconstruction, were replaced with



Pic. 8. Railway station of Tver.

Pic. 9. Nizhegorodsky railway station (now Kursky railway station).

similar ones manufactured in Great Britain; the crystal chandeliers in halls that did not survive were made at Tver Glass Factory.

Moscow Railway Stations

The history of ***Kursky railway station*** began with construction of Nizhny Novgorod railway and construction of Nizhegorodsky railway station in 1861. The railway station was built outside the city limits behind Kamer-Kollezhsky Val. The site was personally chosen by P. P. Melnikov, then the Minister of Railways. Land plots on the territory of Moscow district [outside city territory] was cheaper, and taxes and labour organisation requirements were noticeably softer than within Moscow.

The founder of the railway station, the Main Society of Russian Railways, intended to further obtain land closer to the city centre, therefore, documented the station as temporary one, reluctantly allocated funds for construction and limited itself to a one-storey wooden building designed by the architect Maximilian Arnold.

In November 1866, the railway was extended to Serpukhov, and then to Tula, Oryol, and Kursk. With the increase in the number of passengers, two annexes were adjoined to Nizhegorodsky railway station (Pic. 9), but this was still not enough: a new railway station was required. The discussion on its construction dragged on for 30 years. Many different options were proposed, but the Main Directorate of Russian Railways could not finance them.

The situation was resolved after Nizhny Novgorod railway was sold to state treasury in 1884 and Moscow–Kursk, Nizhny Novgorod and Murom railways were incorporate. Nizhegorodsky railway station was merged with the new station laid on the Garden Ring by the architect N. I. Orlov.

After the opening of Kursky railway station in 1886, Nizhegorodsky railway station was closed. In the 1930s, reconstruction of Kursky railway station was conceived, but it was finally limited to reshaping the existing building into the classical style. In 1968–1972 after all, a radical reconstruction was carried out. The new building received a two-hundred-meter-high glazed facade, lined with a grid of aluminium sashes, and an original folded roof with a nine-meter peak. The old building was included in the new one, retaining the architectural decor in its central part, decoration in one of waiting rooms and the facade facing railway tracks. The building was faced with marble. The final design did not include glazed strips between roof spans, which would have allowed penetration of sunlight, and the 30-storey hotel complex on the south side of the station square. However, the new station became the largest in the country. More than 6,5 million passengers are served there every month.

Belorussky railway station (in 1870–1871 it was called Smolensky railway station, in 1871–1912 and then again in 1917–1922 it was named Brestsky railway station, in 1912–1917 it got the name of Aleksandrovsky railway station, in 1922–1936 it was known as Belorussko-Baltiiskiy railway station) (Pic. 10) was opened on September 19, 1870, together with Moscow-

Pic. 10. Brestsky (now Belorussky) railway station at the beginning of 20th century.

Smolensk railway. In November 1871 the railway was extended to Brest and the railway station became known as Brestsky station.

In the early 1890s, the railway became double-tracked, while there was only one departure platform. The reconstruction of the railway station, which could no longer accommodate all passengers, began only in 1907. On May 15, 1910, the right wing of the new station was opened, and on February 26, 1912, the left wing (Pic. 11) followed. The project was authored by the architect Ivan Strukov. On May 4, 1912, the railway was renamed to Aleksandrovskaya, and the railway station was renamed Aleksandrovsky in honour of Emperor Alexander Pavlovich.

In August 1922, Aleksandrovskaya and Moscow-Baltic railways were merged into Moscow-Belarusian-Baltic railway, so the railway station was renamed to Moscow-Baltic railway station. In May 1936, after another reorganisation of railways, the railway station received its current name of Belorussky railway station.

In September 2007, Aeroexpress company began reconstruction to organise a railway connection to Sheremetyevo airport. The new air terminal, with an area of 600 m^2, is located in the fourth hall of Belorussky railway station. The terminal was opened on August 27, 2009. Railway express trains began to deliver passengers to Sheremetyevo Airport station.

The sights of Belorussky railway station comprise a mosaic panel on the theme of the Great October Socialist Revolution; portraits of the Soldier-Liberator, Alexander Nevsky and Georgy Zhukov; a memorial plaque dedicated to the first performance of the song «Sacred War» on June 26, 1941; the monument «Farewell of Slavianka», opened on May 8, 2014 on the platform.

Yaroslavsky railway station (from 1862 to 1870 it was called Troitsky [Trinity] railway station, from 1922 to 1955 it was named Northern railway station) was opened and consecrated by Metropolitan Filaret on August 18, 1862 (Pic. 12) A small two-storey U-shaped building with strict architectural forms leading to the platforms. The roof of the railway station was decorated with a flagpole with the banner of the Ministry of Railways. The left building was occupied by the Railway Board, the waiting room, and the luggage compartment, the right one was occupied by halls for different classes of passengers.

By 1870, construction of a railway line to Yaroslavl had been completed, passenger traffic increased, and the station was renamed to Yaroslavsky. In August 1897, the train arriving on the platform accelerated too quickly. The wall of the building of the Railway Board was destroyed. Fortunately, no one was there at the time.

With the increase in passenger traffic, it was decided to reconstruct the railway station. In 1895–1897 the east wing of the railway station was rebuilt, and construction of a water tower began. At this time, the head of Moscow-Yaroslavl Railway Society, Savva Mamontov, was accused of embezzling funds, and the new management preferred to choose a more

Pic. 11. Brestsky railway station (now Belorussky railway station).

economical project. In 1900, the railway station building was expanded with two wings, but this did not solve the problem. Fyodor Schechtel became the author of the new architectural concept. The architect's idea to implement the «North Russian style with some monastic tinge» was unanimously approved by the customers and was also liked by Nickolay II. Schechtel retained part of the former building, expanding only the passenger area using two side buildings on the side of Kalanchevskaya Square and one at the rear facade. He used materials that were new for that time: reinforced concrete and metal structures, which significantly reduced the cost and facilitated construction. Work began in the spring of 1902 and was completed two years later.

The new building (Pic. 13) was more than three times larger than the old one. The right side of the building was occupied by service and ceremonial rooms, the left hosted the waiting rooms. The second floor was allocated for offices of Railway Board members and for a conference room. The architect managed to skilfully use the space to place a large lobby with cash desks, spacious lounges for passengers, and to equip convenient exits to platforms.

In 1922 the railway station was renamed to Northern railway station to remove the reminder of Yaroslavl mutiny. On June 20, 1929, the first electric train departed from Northern railway station. During this period, the building could not cope with the increased passenger traffic and two years later it was reconstructed again. The railway tracks were moved away, increasing the inner part of the building. Because of this, the columns previously built above the north-eastern platform were then located in the centre of the waiting room. The lamps created according to Schechtel's sketches were removed, the wooden wall cladding, benches and food stalls were dismantled.

In the post-war years, Schechtel's interiors were rebuilt. The upper part of the walls between the semi-columns of the vestibule was decorated with reliefs depicting fishing and hunting, and the previous paintings by Konstantin Korovin were transferred to the storerooms of Tretyakov Gallery. The name of Yaroslavsky railway station returned only in 1955.

During the reconstruction of 1965–1966 railway tracks were pushed even further and between the wings of the old building a two-storey annex with a glass wall and reinforced concrete vaults was erected supposing that it responded to the «spirit of the time».

In the autumn of 1961, the management of Yaroslavsky railway station was the first in the city to take a decision to charge a fee for passage of persons accompanying the passengers to the carriages to reduce crowding at the platforms. In the future, the rule was repeatedly cancelled and renewed. In 1995, the layout of the station was greatly changed, which made it possible to double the capacity of the facility. In addition, the columned and heraldic halls were restored.

The building of Yaroslavsky railway station is considered one of the outstanding creations of F. Schechtel. He managed to combine elements of Old Russian architecture with Art Nouveau decor. The structure acquires a special similarity

Pic. 12. The first building of Yaroslavsky railway station.

Pic. 13. Yaroslavsky railway station at the beginning of 20th century.

with the «terem»[4] due to the combination of different architectural volumes. Thanks to this technique, unique images of the structure are formed from different points of view, the left tower being a single component for all of them. According to the architect's idea, it and the lobby became the main vertical axes of Yaroslavsky railway station. Their importance is emphasised by the shape of the roofs: a ridge-shaped roof rises above the vestibule, and a high tent crowns the tower.

The massive volume of the lobby is highlighted by a projection (*risalit, avant-corps*), which is intended to personify the «city gates» leading to a spacious arched waiting room. Above the entrance, the architect placed the coats of arms of the main cities of Yaroslavl railway: Moscow, Arkhangelsk, and Yaroslavl.

Savyolovsky railway station (before 1912 it was called Butyrsky railway station) (Pic. 14) was opened on March 10 (23), 1902. The construction of Savyolovskaya line to the village of Savyolovo with further plans to continue it to Kalyazin, Uglich and Rybinsk was initiated by Savva Mamontov, chairman of the Board of Moscow–Yaroslavl railway. The

[4] Separate living quarters occupied by women belonging to families of illustrious noblemen in ancient Muscovite Russia, the upper storey of a home or wooden castle. – *Translator's note*.

Pic. 14. One-storey building of Savyolovsky railway station.

building was mainly one-storey (it had two storeys only in the central part, where the service apartments were located). In the distance, there was a 30-meter water tower, necessary for steam locomotive traction. This tower, that has the same age as the railway station, is its only historical building that has survived intact to this day.

The railway station, which had not been reconstructed since its foundation, became dilapidated and could no longer cope with the increased passenger traffic. In 1987, work on its expansion began. The reconstruction was completed on September 1, 1992. As a result, the railway station building became two-storey, the internal area increased by 2,5 times, the style features were preserved.

In December 2012, the next modernisation of the railway station building was completed. A new waiting room, a ticket desks hall, a restaurant, and a medical centre were opened. The area of the railway station is 6 000 m^2.

Since 1999, it has been the only railway station in the city serving only suburban electric trains. Almost 100 electric trains depart daily from the station on Savyolovsky route and 28–33 electric trains on Belarusian route. In 2020, Moscow Central Diameters project was implemented, which provides for a through high-speed route Lobnya–Odintsovo through Savyolovsky railway station.

Kievsky railway station (until 1934 it was called Bryansky railway station) was built in 1914–1918 to replace old building (Pic. 15). Architectural project was developed by I. I. Rerberg with the participation of V. K. Oltarzhevsky, the project of the train shed and of hall roofs was designed by V. G. Shukhov, sculptures were created by S. Alyoshin, painting of halls was created by artists F. I. Rerberg and I. I. Nivinsky.

The architectural concept of the station, the murals of the halls and sculptures refer to the Patriotic War of 1812. The station was built in the style of neoclassicism with elements of the Empire style. The total area of Kievsky railway station is over 36 thousand m^2, the passenger traffic is over 400 people/hour (Pic. 16).

A train shed adjoins the station building: the space above the platforms is covered by a huge single-vaulted glazed arched roof (length 321 m, span width – 47,9 m, height – 28 m, weight of the structure – more than 1250 tons), shaped like a parabola. High steel three-articulated arched trusses demonstrate the grace of a stately structure.

The first train from the unique platform of Kievsky railway station departed on February 18, 1918.

The general plan for reconstruction of Moscow of 1935, to emphasise the grandeur of Kievsky railway station building, provided for expansion of the area of Kievsky railway station to Dorogomilovskaya street and for architectural design that would have highlighted the ensemble with the Moscow River and the Borodinsky bridge.

In 1940–1945 on the north side of the station, a building with a suburban ticket office and Kievskaya metro station was additionally built.

Pic. 15. Old building of Bryansky railway station.

Pic. 16. Bryansky (now Kievsky) railway station in 1920s.

The design of the suburban pavilion maintained the general style of the station building, while using the features of Venetian palazzo.

In 2003–2004 the train shed of Kievsky railway station was rebuilt according to a simplified project: 27 original riveted steel arches of the ceilings were replaced by welded ones, only four riveted Shukhov arches were left at the end of the roof, adjacent to the station building; transparent polycarbonate is used instead of glass. A mechanical clock is installed on the tower of Kievsky railway station.

After the reconstruction of 2012–2013, a new turnstile hall for suburban trains was opened at the station.

The first building of ***Kazansky railway station*** (until 1894 it was called Ryazansky railway station) (Pic. 17) was wooden and opened in 1862 to serve Ryazan railway, and since 1894 to also serve Kazan railway. In 1864, a stone railway station building was built (architected by M. Yu. Levestam). It was a small building with a common roof with a train shed over tracks and platforms. A clock tower was placed over the entrance. The station was cramped and inconvenient, and its architecture was rather modest. The building was rebuilt many times, and when Moscow–Kazan railway opened in 1893, and the passenger flow increased greatly, construction of a new station building was highly required. However, it was only in 1910 that the board of the joint-stock company of Moscow–Kazan railway decided to build a new building. The architect Shchusev proposed a project in the national-romantic style with elements of the neo-Russian style and art of the East.

Construction began in 1913 and overshadowed all other construction projects regarding Moscow stations. N. K. Roerich, A. N. Benois, B. M. Kustodiev, E. E. Lanseray, Z. E. Serebryakova

Pic. 17. Old building of Kazansky railway station.

took part in creation of the interiors of Kazansky railway station. In 1914–1915 the foundations were laid, a boiler room, a luggage compartment, a main entrance with a tower were under construction. However, during the World War I, construction was repeatedly stopped, and only by the winter of 1916–1917 builders had managed to build a roof. In 1919 the building was commissioned in a simplified form. In 1926, the first stage of construction and decoration was completed. In 1940, the last stage of construction was completed, but many of Shchusev's plans remained unfulfilled.

In 1935, an exit from Komsomolskaya metro station was built into the former luggage compartment. In the 1950s a commuter hall was completed, which was connected to the lobby of the metro station. In the 1970s, the railway station was reconstructed, and its transit capacity was increased.

In 1987–1997 the building was extensively reconstructed. The appearance was renewed, the internal premises were expanded and re-planned, roofs were erected over the platforms, the building was equipped with modern technology. In 2012, a two-storey ground building for suburban traffic was erected on the platforms.

Kazansky railway station (Pic. 18) is a complex composition in which symmetry is deliberately broken and in which different-sized masses of architectural volumes are connected to each other. The architect, wishing to «coordinate» the building with two already existing ones [now Leningradsky and Yaroslavsky railway stations] and at the same time to give it individuality, presented buildings elongated in a line with rooms of various functions in the form of volumes of different height, width and rhythm with peaked roofs, a small clock tower, and a high corner tiered tower above the base in the form of an arched passage. As a result, the station seems to be a complex historically formed for many years, and not implemented by a single architect according to a single project.

Paveletsky railway station (Pic. 19) was designed by architects N. A. Kvashnin and Yu. F. Diderikhs and opened on September 1, 1900, to serve Ryazan–Ural railway. Initially it was called Saratovsky railway station due to the fact that management of Ryazan–Ural railway had headquarters in Saratov, only after the Great Patriotic War the railway station received its present name after the village of Pavelets of Ryazan region.

The railway station was built according to the construction canons of that time: the building is symmetrical with an elevated centre, has high windows, a wide and convenient entrance. On the main facade from the side of the square, there were entrances, a lobby, a luggage compartment,

Pic. 18. Kazansky railway station.

Pic.19. Paveletsky railway station.

Pic. 20. Vindavsky (now Rizhsky) railway station.

halls for the public, ticket offices, a telegraph office, a pharmacy, and a buffet that all needed to be situated closer to the public halls. In the centre there is a high, extensive operating room that separated the first- and second-class rooms from the third-class room.

A brick building was built on a rubble foundation with two main storeys and with a third storey situated above the domed part of the building and with attics above the side protruding parts. The length of the station building was 83,7 m. The outer walls were 2,5 bricks thick: a fair margin of safety for a low building. The outer surface of walls was faced with special bricks, the plinth was faced with cut stone, the vestibule and cornices in the halls had stucco decorations. There was solidity in everything.

Office premises, a place for gendarmes, ceremonial royal rooms and exits to platforms were concentrated along the facade of the station from the side of railway tracks.

A funeral train with the body of V. I. Lenin arrived at the station on January 23, 1924. In 1979–1980 to the left of the railway station the pavilion-museum «Funeral train of V. I. Lenin» was built. From 1941 to 1992, the square in front of the station was called Leninskaya in memory of this event. In the mid-1920s, the station itself was called Leninsky.

In the 1980s a general reconstruction was carried out. The thoroughly renovated Paveletsky railway station was opened on November 3, 1987. The style of the previous building was preserved. The new railway station exceeded the old one by six times in volume and by four times in terms of capacity and has become much more convenient. Now it can receive, serve and accommodate in its halls about 10 thousand people per hour, this is the level of a very large transport interchange hub.

Rizhsky railway station (before 1930 it had been called Vindavsky railway station, until the mid-1930s its name was Baltiisky railway station, until 1946 it was called Rzhevsky railway station) (Pic. 20) was built in 1897–1901 during construction of Moscow–Vindavo–Rybinsk railway. The project was authored by St. Petersburg architect S. A. Brzhozovsky, the author of Vitebsky railway station in St. Petersburg.

Due to the low load of Rizhsky railway station, in the early 2000s, it was proposed to close it, transfer suburban trains to other stations and eliminate the tracks. The plan has never been implemented.

On July 31, 2004, an exposition site of the Museum of the history of development of rolling stock of Moscow Railway was opened near the Rizhsky railway station. The site features locomotives and wagons.

Railway stations are large public buildings that are important for the city and the country. Often, it is from them that visitors get their first impression of the city, and sometimes of the whole country. Therefore, such structures must meet the high requirements of the architectural composition. Old Russian train stations not only meet these requirements. They can be confidently called architectural masterpieces.

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World of Transport and Transportation,
2021, Vol. 19, Iss.4 (95), pp. 304–306

Report of O. A. Struve, Candidate for the Chairmanship of VIII Department. Part 1

News from the archives
An article in Rail Business [Zheleznodorozhnoe Delo] introduced 110 years ago to the readers the report of O. A. Struve, presented at the Solemn General Meeting of the members of the Imperial Russian Technical Society on April 15, 1911 on the occasion of the seventy-fifth anniversary of the beginning of railways in Russia, chaired by the Honorary Chairman of the Society His Imperial Highness Grand Prince Alexander Mikhailovich.
The publication of the report will be continued in the next issue.

Keywords: railway, history, railway availability, railway density, connectivity.

Your Imperial Highness, gracious ladies and gentlemen!

«We are suffering from an excess of distance». This was the reading of the significant words spoken by the Emperor Nicholas the First to Melnikov, when Melnikov, as one of the builders of the railway, intended to connect two capitals of the Empire, introduced himself to the Emperor.

At that time, there was only one railway in Russia, from St. Petersburg to Pavlovsk, 25 miles long, but since then the conditions have changed – and, despite the widespread rail network and thousands miles of lines that penetrate the territory of Russia in all directions and connect its borders from the Baltic coast to the Pacific Ocean, from the Black to the White Seas, these words have nevertheless retained their meaning to this day, have not lost their deep meaning to this day.

The development of our railway network after the first slow beginnings, accompanied, as everywhere else, by mistrust, proceeded at an accelerated pace, but internal productive forces of Russia and its needs developed at an even faster pace, the need for cheap, as for the cost of transportation, and reliable in terms of continuity of its activities, transportation routes was growing, and those transportation routes were associated with a new powerful tool – the railway.

Let me give you a few brief figures describing the progress in the coverage of Russia with railways over the past 75 years.

In the period up to 1850 inclusive, 468 versts were opened for public use within European Russia. 1019 versts were opened during the decade 1850–1860, 8734 versts in 1861–1870, and 10900 versts in 1871–1880.

Starting from a decade after, railway construction spread to Asian Russia. So, in the period 1881–1890 the network of European Russia increased by 5932 versts, while 1290 versts were built in Central Asia.

During the decade 1891–1900, 16 764 versts were opened for movement in European Russia,

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Acknowledgments. The editorial board expresses their gratitude to the staff of the library of Russian University of Transport for their assistance in preparing the publication.

The text of the article originally written in Russian is published in the first part of the issue.
Текст статьи на русском языке публикуется в первой части данного выпуска.

4633 versts in Asian Russia, in 1901–1910, respectively, 8233 versts and 3742 versts.

Currently, construction is underway, and the construction of 6287 versts will be started.

Thus, by the beginning of the current jubilee year, the operating railway network of Russia represents an impressive length of 61 715 versts, including 52 050 versts within European Russia, excluding Finland, and 9665 versts in Siberia and Central Asia.

Simultaneously and in parallel with development of the railway network the volumes of transportation also have increased. The measure of the transportation activity of the railway is considered to be the number of cargoes that travelled, on average, along each verst of the road, in other words, the amount of pood-versts per verst of the road.

In this regard, a significant fact can be noted, which is illustrated by the following data, namely: in 1884, with the operational length of the railways of European Russia of 22 500 versts, cargo turnover was expressed in 25,5 million pood-versts per verst, not counting economic transportation. As the network grew, the cargo turnover developed, and in 1907, with a total length of the network of 49 180 versts, 49,2 million pood-versts can be accounted per verst; in other words, and rounding up, per a verst of the network doubled in length, there was a doubled number of pood-versts, or summing up: the length of the network doubled, while the total cargo turnover quadrupled.

Isn't this eloquent fact, consistently observed over the past decades, the best proof that coverage of Russia with railways is still far from being exhausted? It is an indicator of responsiveness with which the country's productive forces meet the developing railway network, of the need, the need that is felt by the industrial and commercial life of the country in the ways of communication, providing cheap and uninterrupted transportation of mass products of the vast state throughout the year.

It is safe to say that further development of the network, in any case, for a sufficiently long time should be accompanied by approximately the same increase in the average cargo turnover per verst of the network, indicating the country's far from exhausted demand for railways.

A very clear indicator of how much Russia is not yet sufficiently served by railways can be compared to other countries in this area. Limiting ourselves only to the borders of European Russia and comparing its network with the railway network of other states, we have the following data on the length of railways in different states per hundred square kilometres and per 10 000 inhabitants (Table 1).

We see that Russia, with current development of its railway network, takes the last place in relation to the density of the network both in terms of space and population, and this position will not change significantly, even if we introduce an allowance in the sense of not accounting a vast northern region, sparsely populated and poorly served by railways.

However, the above characteristics of railway coverage in different countries and in Russia in relation to space and population, i.e., to two elements that are not directly related to each other, do not represent such an indicator that would simultaneously consider both main factors, on the totality of which the right of a given country to a certain development of railways in it could be justified.

Meanwhile, an assessment of the comparative coverage of different countries or individual regions and regions of a given country by railways is undoubtedly of significant importance when judging about the greater or lesser need for development of the railway network in a certain area.

If we proceed from the basic principle that the state as a whole is obliged to strive to endow with railways in an equally fair measure all the constituent parts of the common state territory, then, of course, it is desirable to indicate a meter that could serve to assess the right of a certain region to this or another development of railways within it.

It is clear that this meter would have to embrace a whole range of economic conditions and take into account various elements, such as population and productive forces of the area, considering at the same time the topographic and hydrographic features of the region in order to obtain the value of the meter applicable for assessment, but it is just as clear that it is precisely this indicated dependence of it on the most varied conditions that would give it such a complex appearance that the selection of such a meter would seem, if not impossible, then at least extremely difficult.

Therefore, it seemed to us quite appropriate, when trying to establish such a meter, to proceed from the most basic elements influencing it, by no means denying that in each particular case, for its correct assessment, a number of other circumstances will have to be taken into account.

The need of a given country or region for railways, undoubtedly, under the same conditions, depends on two factors: on the size of the serviced area and on the density of the population within this area.

Obviously, this area is the more served by railways, the greater their length per unit of surface is, i.e., the greater is the density of the network.

Table 1

Name of the state	Kilometres of railways accounted	
	per 100 sq. km	per 10 000 inhabitants
France	8,9	12,2
Germany	10,7	9,4
Great Britain	11,8	8,4
Austria-Hungary	6,7	9,2
United States of North America	3,8	43,1
European Russia	1,2	4,4

The area is considered richer endowed with railways, the greater is the length of those per unit of population, for example, ten thousand inhabitants, or, conversely, the smaller is the number of inhabitants per unit of length of railways.

Combining these two conditions and giving to their totality the value of a conventional indicator or coefficient of coverage of a given country with railways, we come to the conclusion after appropriate calculations that: the coefficient of railway coverage of a given country is proportional, other things being equal, to the square of the density of the network and is inversely proportional to the density of the population.

It seemed interesting to check the plausibility of this meter and to trace the values in which the coverage ratio determined by such a technique will be expressed for different countries; and consequently the following figures were obtained:

For France	103
For England	98
For Germany	100
For Austria-Hungary	61
For Belgium	100
For Switzerland	154
For United States of North America	149
For European Russia	4,3

The above conclusions indicate the same coverage in France, England, Germany, Belgium, for which the coefficient turned out to be about one hundred. In these countries, as is known, further railway construction is already manifested to a limited extent, as if indicating that they are satisfactorily served by railways.

Higher rates were revealed for Switzerland and America. Switzerland, as you know, is located at the junction of an integral series of transit routes and is a favourite of tourists and travellers; it is distinguished by the density of the network, almost equal to the density of the network of England, moreover, with a population density of only 80 people per sq. km. In England, per sq. km there are 140 inhabitants.

As for United States of North America, the widespread development of the network is for them a well-known distinguishing feature among cultural countries and an indicator of powerful industry and trade. Suffice it to recall that there are over 40 km of railways per 10 000 inhabitants, that is, approximately four times more than in Germany and France, moreover, with a relatively weak population density of 9 inhabitants per sq. km.

For European Russia, the coverage factor will be 4,3, with a network density of 1,1 versts per 100 sq. versts and an average population density of 27,9 inhabitants per sq. verst.

At the same time, however, the vast areas of Arkhangelsk, Vologda and Olonets provinces, with an area of 1 213 000 square versts, are taken into account, with a population of 2 387 000 inhabitants. Excluding this region and the railways located within its borders, with a length of 1 063 versts, the coverage ratio will slightly increase and turn out to be 5,6, still significantly inferior to the coverage indicators of other countries we have mentioned.

Moreover, 1,44 versts of railways and a population of 36,8 inhabitants per sq. verst relate to 100 sq. versts.

In order to be equal per degree of coverage to that of England, France or Germany, which all have almost the same degree of coverage, the network of European Russia should increase to approximately 190 000 versts, that is, in addition to the 55 570 versts currently under construction, about 135 000 versts must be built.

For comparison with Austria-Hungary in terms of coverage, our European network should expand to 150 000 versts, i.e., increase by about 95 000 versts.

At first glance, these figures may seem excessive, exaggerated, but let me shed light on this issue from another angle.

To be continued.

O. A. Struve
(Zheleznodorozhnoe delo
[Railway Business],
1911, No. 17–19, pp. 124−128) ●

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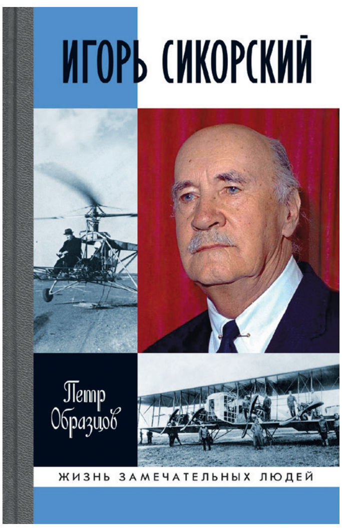

ORIGINAL ARTICLE | REVIEW
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The Book about Igor Sikorky

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Obraztsov, P. A. Igor Sikorsky: four wars and two homelands of the famous aircraft designer. Moscow, Molodaya gvardiya publishing house, 2021, 239 [1] p.: ill. (Series of biographies: The life of remarkable people; issue 1875). ISBN 978-5-235-04435-7.

Igor Sikorsky created a family of the world's best helicopters, which transported marines and doctors during almost all wars of the 20th and 21st centuries, mail and fire extinguishing equipment, oversized cargo, ordinary passengers and even US presidents. In Russia, this Russian-American genius created the world's first huge multi-engine aircrafts Russky Vityaz [Russian Knight] and Ilya Muromets, and in America, where he was respectfully called Mister Helicopter, extraordinary seaplanes that crossed the Atlantic and Pacific Oceans even before World War II.

Keywords: *aviation, Sikorsky, helicopter, history of transport.*

Throughout the 20th century aviation significantly changed the face of our civilisation, opening unprecedented opportunities for people. In this regard, the study of various aspects of development of domestic and world aviation is an important area of modern historical science. The desire of researchers to analyse and comprehend the most significant events in this area can be of great benefit, identifying the most successful social practices in this area. Modern aircraft designers and managers tackling the problems of air traffic control can gain food for thought from such research. In this regard, the appearance in the series «The life of remarkable people» of the biography of the outstanding Russian and American aircraft designer Igor Ivanovich Sikorsky (1889–1972) should be considered very timely.

The author of the book, Petr A. Obraztsov, turned to a topical and interesting issue. For a long time in our country, the life and work of the hero of the above-mentioned book has hardly been studied. This was due to the monarchical views of Igor Ivanovich Sikorsky, who emigrated from Soviet Russia to the West in the spring of 1918. After 1991, following changes in ideological orientations in our society, interested Russian readers had the opportunity to discover many outstanding figures of the Russian Diaspora, to become familiar with their rich heritage. Igor I. Sikorsky is part of this constellation. The book of the writer, translator, journalist, Ph.D. (Chemistry) Petr A. Obraztsov is an important milestone in the study of the activities of this outstanding personality.

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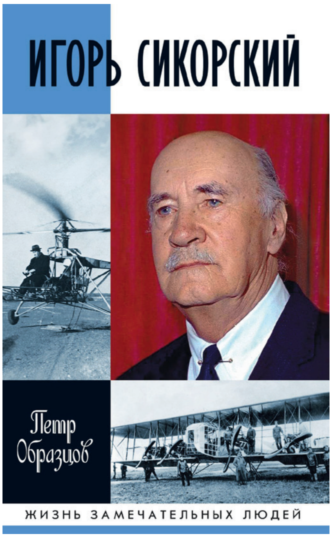
The text of the review article originally written in Russian is published in the first part of the issue.
Текст статьи-рецензии на русском языке публикуется в первой части данного выпуска.

The biography of Igor I. Sikorsky is distinguished by a well-thought-out structure. The first seven chapters are devoted to the life of an aircraft designer in Russia (he had lived in our country for 29 years). Chapters 8–14 talk about the stay of the hero of the book abroad. This period of his life turned out to be longer than the first and lasted 54 years. In the remaining seven chapters, the author focuses on various aspects of Igor Sikorsky's biography, associated with both the Russian and American periods of his life. These chapters allow the reader to appreciate the versatility of the hero of the book and expand the understanding of his family, friends, and colleagues. The text of the book is also supplied with appendices (the first of them contains an overview of the world helicopter market compiled by V. Shoshin, and the second contains a list of works by Igor I. Sikorsky). In accordance with the traditions of the biographical series, the main milestones in the life and work of the hero of the book and a list of publications dedicated to him are offered as well.

Analysing the life of Igor I. Sikorsky, the author identifies the factors that influenced formation of his interest in science and technology. The beneficial effect of the intellectual environment in which the future aircraft designer developed is noted: he studied at the famous First Kiev classical gymnasium (within the walls of which, for example, M. A. Bulgakov and K. G. Paustovsky were educated), the Naval Cadet Corps in the capital of the Russian Empire, Technical School in Paris, as well as at Kiev Polytechnic Institute. The family also had a noticeable influence on formation of Igor I. Sikorsky's vision and opinions (for example, the father of the main character of the book, Ivan Alekseevich Sikorsky, was a well-known psychiatrist and a well-educated person).

Describing the achievements of Igor I. Sikorsky during the first, Russian, period of his life, Petr A. Obraztsov draws attention to the emergence of his hero's interest in creation of helicopters at the dawn of his professional career. The author quite reasonably explains Sikorsky's transition to creation of aircraft, which happened soon after, with relative failures in the field of helicopter design. The main achievements of Igor I. Sikorsky before emigration were, as the author rightly notes, creation at the Russian-Baltic Carriage Works (RBCW) of heavy multi-engine planes called Russian Knight and Ilya Muromets. These aircraft turned out to be unique even at the world level. The first of them was made in a single copy and was distinguished by a high level of



comfort, unusual for that time. It set a record for flight duration. Emperor Nicholas II, who paid tribute to this aircraft, awarded Sikorsky with a gold watch. Ilya Muromets biplane, designed in 1913 based on Russian Knight, became the world's first passenger aircraft, and was produced in series. During the World War I, it was re-profiled and used as a combat aircraft. At the end of 1914, a whole squadron of Muromets bombers was created.

The author of the book highlighted the foreign period of Igor I. Sikorsky's life in no less detail. Political views forced the aircraft designer to emigrate soon after the Bolsheviks came to power, and his whole further life passed outside Russia (first in France, and then – for more than 50 years – in the USA). Petr A. Obraztsov succeeded in describing in detail the greatest achievements of his hero during the American period of his life. Relying on the support of other Russian emigrants, Igor I. Sikorsky founded the Sikorsky Aero Engineering Corporation. The author showed that during the 1920s and 1930s Igor I. Sikorsky created seaplanes, outstanding in flight and technical feature, but nevertheless stopped the development of such aircraft.

Petr A. Obraztsov explained Igor I. Sikorsky's transition to helicopters in the late 1930s both by the appearance on the market of powerful competitors who created more efficient aircraft (first in Holland and Germany, and then in the USA), and by the sagacity of Igor I. Sikorsky. The latter, soberly assessing the international situation of that time, could not help but understand how high the chances of the USA entering a major war were. The use of helicopters at the front would be quite promising since these aircraft were to become an important means of rescuing the wounded from the battlefield. The arguments given by Igor I. Sikorsky convinced the management of the «parent» company, and Igor I. Sikorsky set foot on the path already partly familiar to him from the pre-revolutionary period. He was engaged in creation of helicopters for a long 30 years, starting with the VS-300 and ending with the S-67 Blackhawk.

Analysing various types of helicopters of Igor I. Sikorsky, the author of the book skilfully shows their specifics, points to their widespread use not only at the battlefield (and they were used with great success in World War II, the Korean and Vietnam wars), but also in civilian life.

The author rightly calls the latter's tendency to create single-rotor helicopters as a feature of the creative style of Sikorsky the designer. He retained his adherence to it over the course of thirty long years in the New World (although in his youth he paid tribute to coaxial helicopters).

Depicting the ups and downs of Igor I. Sikorsky, Petr A. Obraztsov creates a relief image of his main character, reveals important features of his personality, which largely ensured the outstanding professional success of the designer. The author convincingly shows that Sikorsky was inherent in the ability not to give up in case of temporary failures, a tendency to take risks and a striving for self-improvement that runs like a keynote throughout his long life.

The strong point of the book, of course, is the author's serious attitude to the conceptual apparatus. Because the books of «The life of remarkable people» series are addressed to a wide range of readers, Petr A. Obraztsov clearly explains the meaning of those aviation terms that are used in the book (swashplate, gyroplane, rotorcraft, tiltrotor, etc.).

Separately, I would like to note the polemical fervour characteristic of Petr A. Obraztsov, which enlivens the text of the book. On the pages of the biography of Igor I. Sikorsky, we find the author's desire to debunk various myths associated with the name of his hero. For example, he quite reasonably claims that, despite his many merits, Igor I. Sikorsky was still not the creator of the helicopter as a type of aircraft. He also points out the fallacy of the widespread point of view, according to which helicopters of the Sikorsky company were shown in the F. F. Coppola's «Apocalypse Now» film.

Noteworthy is such a feature of the author's style as the tendency to deviate from the main theme of a particular chapter. At the same time, the digressions are quite justified and contribute to deepening of the readers' understanding of the problems under consideration.

The author could not ignore another important aspect of the creative activity of the indefatigable Igor I. Sikorsky: his works on philosophy and theology. But we must admit that in this case the author's tone changes: Petr A. Obraztsov speaks out about the designer's books written on «humanitarian» topics, quite sceptically. Thus, the analysis of the prayer «Our Father» conducted by Sikorsky is subjected to criticism (it was made by Igor I. Sikorsky, as the author notes, not based on the original text).

Some (albeit minor) shortcomings of the book should also be noted. Sometimes Petr A. Obraztsov allows himself to cite not completely verified information. For example, talking about the history of creation of aircraft heavier than air, the author calls the Russian designer of 20th century A. F. Mozhaisky Major General (while he was Rear Admiral). The reader can also come across a contradictory description of the Russian Knight aircraft (on p. 91 it was called a passenger aircraft, and earlier – an aircraft intended for long-range strategic reconnaissance). But these shortcomings do not detract from the author's contribution to the study of the life and work of Igor I. Sikorsky.

It must be admitted that an interesting, vivid biography of Igor I. Sikorsky appeared thanks to the pen of Petr A. Obrztsov, allowing readers to trace his entire path, filled to the last days with inspired creative work and an unquenchable interest in various problems of technology and philosophy issues.

The book can be useful to scientists and professors who teach courses on the history of transport, to students of secondary profiled and higher educational institutions, as well as to all readers who are interested in the history of science and technology. ●

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ABSTRACTS OF D.SC. AND PH.D. THESES SUBMITTED AT RUSSIAN TRANSPORT UNIVERSITIES

The texts of the abstracts originally written in Russian are published in the first part of the issue.
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Nguyen Xuan Hien. Methodology for developing location requirements for image and video registration complexes under the conditions of the Socialist Republic of Vietnam. Abstract of Ph.D. (Eng) thesis [*Metodika opredeleniya trebovanii k mestam razmeshcheniya kompleksov foto-videofiksatsii dlya uslovii sotsialisticheskoi respubliki Vietnam. Avtoref. dis... kand. tekh. nauk*]. Moscow, MADI publ., 2021, 23 p.

The objective of the thesis is to improve road safety in the city of Hanoi (Vietnam) by developing a methodology for determining the requirements for location of photo and video registration complexes under the given financing conditions.

Were developed:

• A mathematical model of functioning of the photo-video recording system, which makes it possible to assess the degree of its influence on the characteristics of the transport flow and accident rates.

• A software for choosing the structure and justifying the parameters of the system of photo-video recording of traffic violations.

• A methodology for determining the requirements for location of photo and video registration complexes to increase the efficiency of the photo and video registration system.

The analysis of road accident rates in the world and in Vietnam was carried out that showed that road traffic accidents are currently a social problem that is faced all over the world. The role of intelligent transport systems in improving safety and organization of road traffic has been determined.

To improve road safety and quality of traffic, the world experience is considered, which shows that some countries, such as Sweden, Japan, Singapore, etc., have received good results from implementation of state programs to improve efficiency and safety of the road transport system.

The analysis of the state of application of intelligent transport systems and the system of photo and video recording in Vietnam shows that the practices of implementing ITS in Vietnam meet a number of significant shortcomings and problems, such as lack of standards for installation and use of photo and video recording complexes; lack of principles of synchronisation of photo and video recording within the system; limited functionality of photo and video registration complexes, mainly for traffic monitoring.

The main elements of the target function are substantiated to optimise the parameters of the given type of a photo and video recording complex, based on the following aspects: increasing road safety (by reducing the focus points of accidents); improving the efficiency of traffic management (by increasing traffic capacity); introduction of control in areas of systemic violations of traffic rules (violation of the speed limit, road marking requirements, dangerous and aggressive driving).

Two variants of the objective function have been synthesised:

• Maximum efficiency of installation of the photo and video registration system was determined when funding is limited.

• Maximum relative efficiency of implementation of the photo and video recording system with the maximum profitability has been determined.

A mathematical model of influence of functioning of the photo and video recording system on safety and on organisation of road traffic has been developed. Such a model can identify additional baseline data using expert estimates and a hierarchy analysis method based on the official incomplete data on road accidents in Vietnam.

The analysis of problem points within the road network of the city of Hanoi was carried out. 10 points with existing cameras of photo and video recording and 10 points without cameras were identified. Based on identification of the total weighted value of effectiveness of the installation of the means of photo and video recording, the points were determined where new types of photo and video cameras should be installed.

Software has been developed to assess the efficiency of the photo and video recording system. The program evaluates the efficiency of the photo and video recording system based on the established criterion. With the help of the developed software, it is possible to select the best version of the photo and video recording system that will better implement its goals and objectives.

A method for choosing an effective solution while creating a photo and video recording system has been developed, considering the established criterion for choosing its rational option. The method makes it possible to calculate feasibility of using various technical means of photo and video recording system at the points under consideration.

A method has been developed for determining the requirements for location of the photo and video registration complexes in Vietnam under the specified financing conditions.

It is advisable to further develop and improve the studied approach towards:

• Development of a system of national standards for ITS and for the system of photo and video recording, regarding also implementation of scientifically grounded methods for setting state priorities for implementation of a system of photo and video recording.

• Development of principles for coordinating the actions of ministries and other executive authorities to complete the system for collecting and storing data on road safety, to increase the accuracy of analysis and research in this subject area and the use of reliable methods of calculation and analysis.

• Development of software based on modern programming languages, for example, C++, Python, SQL, which is easy to update and to use to provide calculation results for users, including investors.

05.22.10 – Operation of road transport.

The work was performed and defended at the Moscow Automobile and Road Construction State Technical University (MADI).

Russkikh, S. V. Nonlinear mechanics of elastic transformable and controlled space systems. Abstract of D.Sc. (Physics and Mathematics) thesis [*Nelineinaya mekhanika uprugikh transformiruemykh i upravlyaemykh kosmicheskikh sistem. Avtoref. dis... doc. fiz.-mat. nauk*]. Moscow, MAI publ., 2021, 40 p.

The work is a contribution to the solution of an urgent and important problem which is the creation of reliable mathematical models that allow solving a wide class of problems of nonlinear mechanics of elastic transformable and controlled space systems and structures containing rod and tether elements:

New equations for the dynamics of spatial and plane motion of a spacecraft with a tether in the central gravitational field of the Earth have been obtained, which can be used for numerical simulation of motion of spacecraft with tether elements, in particular, a spacecraft with a tether ejected from it as a space tug for those satellites that have exhausted their resource, capture of large objects of space debris, etc.

For the first time, nonlinear equations with analytical expressions of all coefficients for plane motion in a moving coordinate system of a spacecraft with an attached system of rods interconnected by elastic-viscous hinges, allowing large angles of rotation, are obtained. These equations make it possible to solve a new class of problems of deploying a system of rods from a transport position folded into a package to an operating position in various ways, including due to inertial forces of rotation and movement of the spacecraft.

New equations of unsteady rotation and nonlinear oscillations in the roll plane of a spacecraft with two elastic multi-section solar panels are obtained. Based on these equations, it is possible to carry out numerical ground testing of deployment of panels under the action of pre-stressed springs at the nodes connecting the sections.

A functional diagram has been proposed and a mathematical model has been developed for a cyclically symmetric umbrella-type antenna consisting of flexible radial multi-link rods interconnected in nodes along parallels by tensile cables. A new method has been developed for solving the inverse nonlinear problem of quasi-static antenna shaping after deployment of radial rods due to their bending under the action of the force created by a damping hydraulic cylinder, considering the reactions of tensile cables. This will contribute to creation of large-size antennas deployable in space.

For the first time, refined equations of thermoelastic bending vibrations of a thin-walled extension rod with a circular cross-section, connected to a mobile spacecraft, and subjected to solar heating, are obtained considering changes in the angles of incidence of solar rays due to rotations of surface elements of an elastic rod and taking into account external and internal heat radiation. The equations are used to calculate non-stationary thermoelastic vibrations of a rod with a spacecraft when it leaves the shadow.

An approach is presented to obtain equations of motion for elastic composite nonlinear systems with geometric constraints based on the principle of possible displacements by using equations in coupled moving coordinates and in generalised coordinates for individual free subsystems, considering unknown interaction reactions and attaching the conditions of connection to these equations. The solution of these differential-algebraic nonlinear equations can be obtained using the well-known standard integration algorithms for «rigid» systems.

A new approach to solving terminal problems of passive force and kinematic control of elastic, in the general case, non-stationary and nonlinear systems has been developed using Bubnov–Galerkin method in the time domain with their finite movements for a certain time from one state (rest or motion) to another state with elimination of fluctuations at the end of the operation. Problems for linear systems with constant parameters are solved by expansion in terms of natural vibration modes using exact solutions of equations in normal coordinates for several lower modes to be eliminated. In this case, the control action is sought in the form of a finite series of simple finite functions with unknown coefficients, which are determined from the initial and final conditions.

A new method is proposed for «tuning» several lower natural frequencies of oscillations of linear systems with constant parameters, which repeatedly perform the same type of operations, like high-speed manipulators, to eliminate oscillations at the end of each operation using a simple control function with one unknown factor.

01.02.04 – Mechanics of a deformable solid.
The work was performed at the Institute of Applied Mechanics of the Russian Academy of Sciences (IPRIM RAS) and defended at Moscow Aviation Institute (National Research University).

Sakharov, R. A. Technical diagnostics of the profile of the rolling surface of railway wheels during operation. Abstract of Ph.D. (Eng) thesis [*Tekhnicheskoe diagnostirovanie profilya poverkhnosti kataniya zheleznodorozhnykh koles v protsesse ekspluatatsii. Avtoref. dis... kand. tekh. nauk*]. St. Petersburg, PSTU publ., 2020, 18 p.

The objective of the study is to improve safety of train traffic by technical diagnostics of critical states of structural heterogeneity of the metal of the rolling surface profile and adjacent layers of solid-rolled wheels of freight cars (SRWFC) directly during operation (when the train is moving).

As a result of the thesis, it was determined that the existing systems for technical diagnostics of SRWFC on the railway network, due to the specifics of their operation, cannot provide an assessment of structural heterogeneity of the metal of RSP and the adjacent layers of SRWFC during operation, and, consequently, an adequate assessment of the residual technical resource.

A list of requirements for on-board equipment has been formed, with the help of which technical diagnostics of RSP is carried out during operation of the latter;

Methods have been developed for assessing structural heterogeneity of the metal of the rolling surface profile and adjacent layers of SRWFC with the possibility of determining their pre-defect state and predicting the residual technical resource based on:

• An improved magneto-variational control method as applied to the problems of technical diagnostics of anisotropic objects, for example, railway wheels.

• The results of experimental studies to assess the structural heterogeneity of RSP in the conditions of the car repair depot, laboratories of PSTU and DTSNTI, confirming the possibility of a qualitative and quantitative assessment of the structural state of the metal of RSP and adjacent layers.

• The data obtained on the induction of the self-magnetic field of RSP and adjacent layers of wheels, which can be considered criteria and parameters of the main defects related to both the sudden and gradual mechanism of their formation and which have the greatest impact on the technical state of RSP and adjacent layers of SRWFC.

A device has been developed for the technical diagnostics of RSP and adjacent layers of SRWFC, which makes it possible to increase the accuracy of registration of defects, which is associated with the revealed relationship between the magnetic and structural state of the metal, due to which the application of physical criteria was justified to assess the configuration of the magnetic field near possible stress concentration zones of RSP and adjacent layers of SRWFC.

Scientific and technical proposals and recommendations for application of the developed device and methods for assessing the structural heterogeneity of the metal of RSP and adjacent layers of SRWFC are proposed and substantiated.

The experimentally confirmed dependence between the values of the hardness of RSP and the adjacent layers of SRWFC and the values of the magnetic field B above RSP of the wheel shows that the stresses in the near-surface layers of the wheel rim and the response surface of the magnetic field signal B correlate in the planes corresponding to the slip planes of the crystal lattice of the metal structure.

The main economic effect is the effect of automating the process of technical diagnostics in real time. It is shown that the technical maintenance and repair of RSP based on the actual state in comparison with the traditional method can significantly reduce operating costs.

05.22.07 − Railway rolling stock, train traction and electrification.

The work was performed and defended at Emperor Alexander I St. Petersburg State Transport University.

Stepanova, K. K. Improvement of electrical devices for railway power supply with high voltage direct current systems. Abstract of Ph.D. (Eng) thesis [*Sovershenstvovanie elektrotekhnicheskikh ustroistv zheleznodorozhnogo elektrosnabzheniya sistemy postoyannogo toka vysokogo napryazheniya. Avtoref. dis... kand. tekh. nauk*]. St. Petersburg, PSTU publ., 2021, 24 p.

The objective of the study is to improve performance and energy efficiency of direct current electric traction based on increasing the voltage level, applying achievements of power electronics and digital technologies.

The thesis contains a solution to a scientific and technical problem that is important for improving electrical devices for railway power supply based on a high voltage direct current system. Scientifically grounded solutions are presented that allow increasing the technical and energy efficiency of the electric traction system, including subsystems of the traction electric drive, electric rolling stock and the subsystem of direct current traction power supply.

A high-voltage direct current electric traction system is proposed, which makes it possible to implement energy-efficient and safe power supply of high-performance train traffic systems. It has been established that the efficiency of using high voltage direct current in comparison with an alternating current system of 25 kV (2 x 25 kV, 50 Hz) is achieved by increasing the efficiency of the contact network by about 6–8 %, reducing the consumption of copper for construction of the contact network by about 20 %, simplification of the contact network due to the absence of neutral inserts; increasing the distance between traction substations and reducing their number on the electrified railway line; reducing the negative impact on the external power supply system; and by eliminating the need to install reactive power compensating devices.

The rate of high voltage in the direct current catenary is established, at which the direct current system in terms of energy efficiency approaches the indicators of a single-phase alternating current system. The minimum value of this level is 18 kV. To improve efficiency, a DC system of 24 kV and higher up to 35 kV is recommended, depending on the application conditions of the system.

The structure of the high-voltage electrical complex of traction power supply and high-voltage direct current electric rolling stock is substantiated, including a rectifier unit with a voltage of 24...35 kV, an electric traction network of 24...35 kV direct current and an input converter of a 24–35 kV for electric rolling stock. The structure of a converter complex based on high voltage direct current electric rolling stock on a reversible converter AIN PWM is proposed. Based on this structure of electricity conversion for electric rolling stock, it is proposed to develop multi-system electric rolling stock (24–35 kV DC/25 kV 50 Hz/3 kV DC).

A method has been developed for determining the parameters of the devices of the electric power complex of the high voltage direct current electric traction system at the stage of designing the life cycle of the electric traction system.

A simulation model of a direct current system with a high-voltage electric power complex has been built and its performance has been confirmed by conducting experiments using the model. A proposal was formulated for reconstruction of passenger-intensive lines with the transfer of 3 kV system to a centralised system of traction power supply with high voltage direct current 24 kV with a universal electric rolling stock.

05.09.03 – Electrical engineering complexes and systems.

The work was performed and defended at Emperor Alexander I St. Petersburg State Transport University.

Zhaisan, Isa. Ensuring traffic safety for freight wagons manufactured in the PRC on the railways of Central Asia. Abstract of Ph.D. (Eng) thesis [*Obespechenie bezopasnosti dvizheniya gruzovykh vagonov postroiki KNR po zheleznym dorogam stran tsentralnoi Azii. Avtoref. dis... kand. tekh. nauk*]. Moscow, RUT publ., 2021, 24 p.

The objective of this thesis work is to study the indicators of dynamics, traffic safety and wear of the wheel and rails in the presence of elastic side bearings of constant contact and diagonal rods on silent blocks, as well as to determine the range of rational values of parameters of elastic side bearings and silent blocks.

The scientific novelty of the work lies in development of a refined, parametrised mathematical model of movement of a freight bogie equipped with elastic side frames of constant contact and diagonal rods of side frames along straight and curved track sections. The developed model makes it possible:

• To carry out a wide range of studies of dynamic characteristics of freight wagons of the main types, equipped with elastic side beams of constant contact and diagonal rods of side frames when moving along sections of the railway track with an arbitrary shape, considering the effect of irregularities in the rail lines.

• To evaluate the influence of deviations in the dimensions of wagon parts and wear of individual elements of the running gear on dynamic performance and safety of freight wagons.

• To evaluate the influence of deviations in the technical condition of the rail track in straight and curved track sections on the dynamic performance of a freight wagon.

• To carry out the selection of rational parameters of geometric, inertial, stiffness and damping characteristics of the elements of the freight wagon and bogie.

As a result of the research carried out, an assessment was made of the influence of side bearings of constant contact and diagonal rods of the 18-9996 bogie on driving performance of freight wagons, traffic safety, wear in the wheel-rail system, and the choice of rational values of parameters of side bearings and silent blocks of this type.

A mathematical model has been developed describing the movement of a freight bogie 18-9996, equipped with side supports of constant contact and diagonal rods, along straight and curved track sections. The graphic 3D model was developed in the 3D modelling software «KOMPAS3D» environment. The model was imported into the «Universal Mechanism» software package and there it was implemented as a system of rigid bodies connected by means of hinges and load-bearing elements.

A fully parametrised, generalised design scheme and a mathematical model of the lateral sidewall of constant contact, diagonal rods, adapter gaskets, adapted to changing parameters and allowing to simulate various versions of the design and technical condition of supports and silent blocks of this type, have been developed.

The developed mathematical model of wagon movement has a high degree of detail and considers the real geometry of bodies, which makes it possible to use it to study the influence of parameters of side supports of the body of continuous contact and diagonal rods on the dynamics and safety of movement of rolling stock, considering the wear and tear arising in operation.

To determine angular stiffness, theoretical and experimental studies have been carried out. Calculations have been carried out to identify the parameters of the calculation model of bogies' diagonal ties. The results obtained were close to the experimental data, which shows the adequacy of the selected parameters.

Identification of the work of the side body supports and diagonal rods showed good convergence of the results obtained with the results of previous studies.

Comparison of the results of computer modelling and experimental data on the indicators of dynamics and traffic safety showed their satisfactory agreement. At the same time, the discrepancies do not exceed 15–17 %. This indicates reliability of the results obtained.

Based on the results of a numerical experiment and the subsequent analysis of all assessed indicators, rational values of the adapter gasket were determined, which are within the following limits: vertical stiffness – 17–20•103 kN/m, longitudinal stiffness 3,5–5•103 kN/m, transverse stiffness – 2•103 kN/m.

An assessment of the influence of elastic-dissipative characteristics of the silent block of diagonal rods on the indicators of dynamics and traffic safety has been made. Based on the results of computer modelling, it is recommended to take values in the range from 5•103 N/m to 7•103 N/m as rational values of stiffness of silent blocks.

The results of calculations performed for bogies equipped with sideways of constant contact with rollers and diagonal rods, with selected rational parameters, show an improvement in the main estimated indicators when moving along straight and curved track sections.

The reduction in wear in the contact area between the wheel and the rail in the presence of an elastic side bearing with a roller and diagonal rods of side frames is 82 % for a straight line in an unladen mode, 36 % – for a straight line in a loaded mode, 25 % – for a curve R = 650 m in an unladen mode, 30 % – for a curve R = 650m in loaded mode, 20 % – for a curve R = 350 m in unladen mode and 36 % – for a curve R = 350 m in loaded mode.

Calculations to assess the impact of the roller mechanism on estimated indicators showed that the presence of a roller helps to reduce the moments of friction forces between the body and the bolster when driving along the curve R = 350 m by an average of 22 %, and the decrease in the main indicators is 3–11 %.

05.22.07 – Railway rolling stock, train traction and electrification.

The work was performed and defended at Russian University of Transport. ●

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Abrosimov, N. V., Akimov, V. A., Alyoshin, A. V. [*et al*]. Security of Russia: legal, socio-economic, scientific and technical aspects. Thematic block «Safety of railway transport». Section 2. Technogenic safety of railway rolling stock: Collective monograph [*Bezopasnost' Rossii: pravovyye, sotsial'no-ekonomicheskiye i nauchno-tekhnicheskiye aspekty. Tematicheskiy blok «Bezopasnost' zheleznodorozhnogo transporta». Razdel II. Tekhnogennaya bezopasnost' podvizhnogo sostava zheleznodorozhnogo transporta: Kollektivnaya monografiya*]. Moscow, MGOF «Znanie», 2021, 484 p. ISBN 978-5-87633-193-9.

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