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This issue of the World of Transport and Transportation Journal appears with the updated structure.

While continuing the open access publication of all the articles, texts and materials in bilingual fully identical Russian and English versions, the journal starting from this issue will be divided into two conditional parts for your comfort when reading paper copy or acquainting with its e-version indexed in digital databases. Rather than divide a single article into two consecutive parts respectively in Russian and English, the first part of the issue will contain articles in Russian, and the second part will include the same articles in English. The covers will continue to be bilingual, while the contents in two languages will be published at the pages 1–4 with different numbering of pages for Russian and English versions of the articles.

Besides, the slightly updated publications' design allows to change the form of presenting

the authors, and to include additional information on the type of the article and for its citation.

We dare hope that this updating intended for our readers and researchers will be useful and will allow more productive acquaintance with the journal.

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Besides submitting original articles, we welcome researchers, academic staff, students, and readers to submit materials on new books on transport and transportation, recent Ph.D. and D.Sc. theses resulted in attribution of scientific degrees, in view of possible publication of relevant information and materials in the journal.

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Application of Elastic Fastenings of Equipment to Increase Vibration Frequency of the Wagon Body



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ABSTRACT

Improving dynamic performance is a priority when designing new rolling stock. The frequency of natural bending vibrations of the body is one of the most important standardised indicators, a preliminary assessment of which allows obtaining optimal body designs.

The objective of the work is to assess the prospects for the use of elastic fastenings of equipment to increase the natural vibration frequency of wagon bodies of suburban electric trains. Calculations were based on the finite element method and block Lanczos method.

It is shown that it is advisable to use the rigid area tool and linearly elastic finite elements to calculate the frequencies in the simulation. The main ranges of fastening stiffness are highlighted,

where the effect of using elastic supports is different. It is proposed to determine the stiffness of fastenings according to a given vibration frequency of the equipment. When the equipment is rigidly attached, the relative mass of the equipment does not affect the body bending vibration frequency. With elastic fastening, a greater effect can be achieved with a larger relative weight of the equipment. The effect of using resilient mounts increases with heavier equipment located closer to the centre of the body. It is shown that the effect of shear admittance of fastenings on the body vibration frequency is within 1 % and may not be considered in the simulation. In the considered example of a wagon body of a suburban electric train, the use of elastic supports allows an increase in the frequency of oscillations of the body by 3–10 %.

Keywords: railway, body, electric train, fastening stiffness, finite element method, modal analysis, natural frequency, wagon dynamics.

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INTRODUCTION

The development of modern railway transport involves an increase in design speeds while ensuring traffic safety. An increase in speed of movement inevitably causes difficulties in ensuring the dynamic qualities of the running gear. One of the ways to solve this problem is to reduce the weight of wagons. Optimisation of the design of the running gear to reduce weight is relevant for any speed of movement, since it leads to a decrease in wear in the wheel-rail system, a reduction in energy consumption and an increase in passenger capacity [1].

One of the elements of the wagon with the highest specific weight is the body. However, reduction in the mass of the bodies leads to a decrease in overall rigidity that negatively affects frequency of natural vibrations, the level of vibration acceleration, and, accordingly, the indicators of smoothness. An increased level of dynamic loading of the body can lead to fatigue damage [2]. Therefore, development of various damping systems is relevant. For the entire vehicle, the correct choice of parameters of two stages of spring suspension is first of all important [3; 4]. Choosing the most efficient body design in terms of weight and rigidity is also important to ensure dynamic performance. One of the normalized parameters of dynamic properties is the first frequency of natural bending vibrations of the body (FNBV). According to Russian domestic regulatory documents, its value for a fully equipped car body of multiple unit rolling stock should not be less than 8 Hz¹. This parameter allows an express assessment of the dynamic qualities of the body without building a complete dynamic model. The higher is FNBV value, the lower the average levels of vertical acceleration will be and, other things being equal, the lower will be the smoothness of the ride. An increase in the value of the first FNBV can be achieved with the help of new structural materials, optimisation of the body structure and the location of the internal ribs of extruded panels, and variation in the location of window and door openings [5–8]. In case of using a rigid fastening of undercarriage equipment, an increase in the value of FNBV can be achieved with the help of a rational arrangement of boxes [9]. Meanwhile, the elastic attachments of equipment can also affect the dynamic qualities of the vehicle [10].

¹ GOST [Russian state standard] 33796-2016. Multiple unit rolling stock. Requirements for strength and dynamic properties, P. 3.

Studies of high-speed rolling stock show that the use of elastic supports, with the correct choice of rigid and damping properties, makes it possible to reduce the amplitudes of vibration accelerations in the vertical and transverse directions and improve the smoothness of the ride [11]. Suspension parameters must be carefully selected to avoid resonance during joint vibrations of equipment and body [12].

Vibration damping is possible due to the use of active and passive vibration dampers, vibration isolating supports. Due to the high cost of dampers, vibration isolating supports are most often used. However, in this case, it is not possible to achieve high values of the damping coefficient due to significant heating of the isolating material, which increases the likelihood of its aging and destruction [13].

Dynamic calculations can be performed analytically, using the differential equation of motion and a beam model of the body [14], or using three-dimensional finite element models [11]. The latter method is the most accurate, as it allows to adequately consider the actual rigidity of the body [15]. Until now, studies of influence of flexibility of equipment fastenings have been carried out for high-speed rolling stock without considering the influence of standing passengers [10; 12; thirteen].

The *objective* of this work is to assess the prospects of using flexible supports for fastening equipment of wagons of suburban electric trains marked by intense vibrations of the frame structure.

RESULTS

Body Design and Calculation Procedure

The body of a suburban train wagon taken as an example for further study (Pic. 1), made of structural steel, consists of a frame, side and end walls and a roof. For the body material, Young's modulus is set to $2,1 \cdot 10^5$ MPa and Poisson's ratio is 0,3. A structure with two planes of symmetry is considered, which, under symmetric vertical loading, allows using a quarter of the body in calculations. The body frame has a classic design, consisting of a closed profile body frame, cross bearers, span bolsters and reduced centre sills. The span bolsters are connected to the body frame with side frame diagonals. The vestibules are located in the end parts of the body, there are exits to the lower platforms. In the undercarriage space there are four equipment boxes of the same weight. The





Pic. 1. Structural diagram of an electric train wagon body (the author's diagram).

structure is loaded with its own gross weight, including the weight of passengers sitting and standing on the free floor area at the rate of 7 persons/m². The location of all internal elements of the wagon is considered on the basis of the design documentation. Loads are applied by varying the density of the respective body parts.

The body is located on elastic supports with a vertical stiffness of 0,66 MN/m, which corresponds to the total stiffness of two suspension stages for a gross weight of 55000 kg of a wagon body. Since only vertical vibrations are considered, stiffness of supports in other directions is not taken into account in all cases, with the exception for a separate assessment of their impact on FNBV. For four boxes of undercarriage equipment, an assessment was made of the influence of rigidity of equipment fastenings on FNBV. Each box weighs from 275 to 1100 kg. The rigidity of the box was modelled in two ways: using the full frame model of the box and using the rigid area. The rigid area assumes the mutual limitation of translational degrees of freedom for the main node corresponding to the centre of mass of the box, and the secondary nodes, which are located at eight points of the box attachment – the lower nodes of elastic elements that simulate flexible attachments. The upper nodes of these elastic elements are located on the brackets and bearers of the body at the attachment points of the equipment.

Frequencies of natural vibrations are determined using ANSYS software package by the finite element method using the block Lanczos method. To simulate the body and equipment, four-node thin shell elements, one-node mass elements, and two-node linear elastic elements are used. The average shell finite element size in the model is 50 mm.

Analysis of Simulation Results

The results of calculating FNBV with

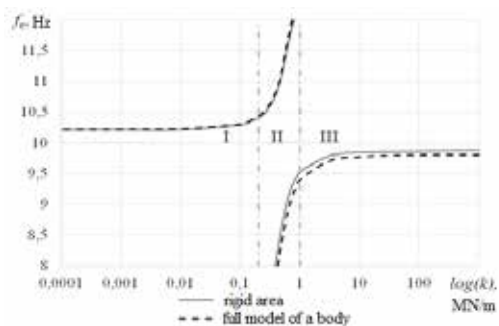
stiffness of fastenings from 0 to 1000 MN/m are shown in Pic. 2. Simulation of equipment boxes with a rigid area leads to an error in determining the upper FNBV up to 1 % (left curve) and the lower FNBV up to 3,5 % (right curve) for a given body design. In further calculations, the rigidity of the equipment is modelled using a rigid area.

Natural vibration frequencies of equipment boxes as a rigid whole body with low rigidity of fastenings do not cause bending vibrations of the body. Their oscillations occur at frequencies of 3–6 Hz, which exceed the frequency of body bouncing oscillations, but do not exceed FNBV. With an increase in rigidity of fastenings, the natural vibrations of the boxes begin to cause bending vibrations of the body, the amplitudes of which increase. At a certain stiffness value of fastenings, the amplitude of body oscillations on the lower FNBV (at which the boxes and the body experience in-phase oscillations) become comparable to the amplitudes on the upper FNBV (oscillations of the boxes and the body in antiphase). With a further increase in rigidity of fastenings, bending vibrations of the body are determined by the lower FNBV (Pic. 2). In the limiting state, when the rigidity of fastenings is high (the absence of elastic fastenings), the masses of the body and equipment also vibrate in one and the same direction.

Thus, it is possible to distinguish three conditional ranges of rigidity of equipment fastenings, which affect the dynamic qualities of the body. The first range of low stiffness (Pic. 2) is characterized by low vibration frequencies of the equipment and does not meet safety requirements of railway transport due to possible resonance with vibrations of the body on spring suspension. The second range of medium stiffness is transitional and its left part contains mostly the values of the fastening stiffness that are the most optimal from the point of view of improving the dynamic qualities of the body. However, when the stiffness values correspond to its right side, it is possible that low FNBV appear, which devalues the use of elastic fastenings. Finally, in the third range of high stiffness, the body experiences in-phase vibrations with the equipment boxes at frequencies lower than the frequency when the equipment is rigidly attached.

Also, FNBV values were obtained for various weight fractions of equipment. The values of stiffness of elastic fastenings were taken at a given natural vibration frequency of the equipment as of a body with one degree of freedom:

² GOST 33796-2016. Multiple unit rolling stock. Requirements for strength and dynamic properties, P. 3.



Pic. 2. FNBV with different rigidity of fastening of undercarriage equipment with a total weight of 4400 kg (developed by the author).

$$k = \frac{4\pi^2 f^2 m_{eq}}{n}, \quad (1)$$

where f is frequency of natural vibrations of the equipment;

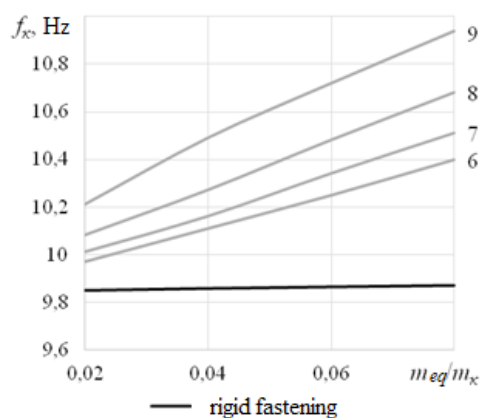
m_{eq} – mass of the equipment;
 n – number of box fasteners.

The range of equipment vibration frequencies 6–9 Hz is considered. For all considered fastening stiffnesses, the upper FNBV is proportional to the value of the specific weight of the equipment (Pic. 3). Consequently, the greater is the weight of the equipment located on the body, the greater increase in the upper FNBV can be achieved.

When setting a certain frequency of the box for selection of the stiffness of fastenings, it should be borne in mind that the actual natural frequencies of the boxes can be, as the calculation shows, 2–5 % less than the indicated frequency. This is due to the additional flexibility of the fastening areas in the body bearers.

To effectively reduce body vibrations with a relative weight of the equipment of 0,02–0,08, the frequency of the equipment should be approximately 12–42 % lower than FNBV on spring suspension, taking into account the flexibility of the equipment fastenings.

With a given mass of equipment, the greatest influence of the equipment on FNBV can be achieved by increasing the rigidity of its fastenings. However, the stiffness values in this case must belong to the left side of the transition range in order to avoid the appearance of resonant oscillations at the lower FNBV. For example, Pic. 4 shows the forms of bending vibrations of the body for a specific gravity of the equipment of 0,08 and vibration frequencies of the equipment of 6 and 9 Hz. If at a frequency of 6 Hz the amplitudes of body oscillations at the lower frequency are an order of magnitude less than the amplitudes at the



Pic. 3. Dependence of FNBV on specific weight of the equipment (on the right – values of f , Hz) (developed by the author).

upper one (Pic. 4a), then at a frequency of 9 Hz the amplitudes of the oscillations differ by a factor of two (Pic. 4b). Thus, the use of the equipment fastening rigidity higher than 0,44 MN/m (which corresponds to the equipment vibration frequency of 9 Hz) in this case can lead to the undesirable appearance of resonant oscillations at the lower FNBV of 8,38 Hz (Pic. 4b). In fact, this will mean a negative effect of the use of flexible fastenings, since FNBV with a rigid fastening of equipment in this case is 9,85 Hz.

When the equipment is rigidly attached, FNBV on flexible supports does not depend on the specific weight of the equipment. At the same time, it is known that there is a proportional increase in FNBV on rigid supports with an increase in the specific weight of rigidly fixed equipment [9].

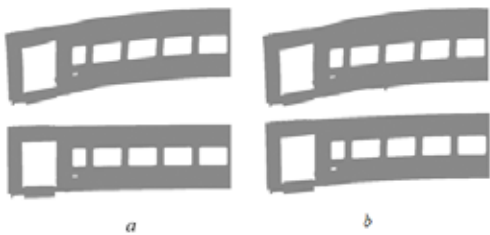
The influence of arrangement of boxes of undercarriage equipment was estimated by calculations for models with four, two and one boxes of the same total mass of 4,4 tons. Each box had eight fastenings (Pic. 5).

When the equipment is located in four boxes, the upper FNBV turns out to be the smallest. When the equipment is located on the sides of the wagon in two boxes or in the centre of the body in a single box, FNBV increases by about 2–3 % (Table 1). The instability of frequency values in case of one or two boxes is explained by the different flexibility of the fastening bearers. A more distant location of the equipment from the centre of the body leads to less compensation for body oscillations in antiphase with the equipment and, accordingly, to a lower value of FNBV. Thus, it is most efficient to locate heavy equipment on elastic supports in places

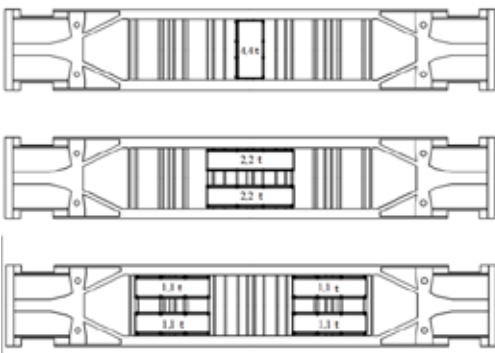


Influence of equipment location on FNBV

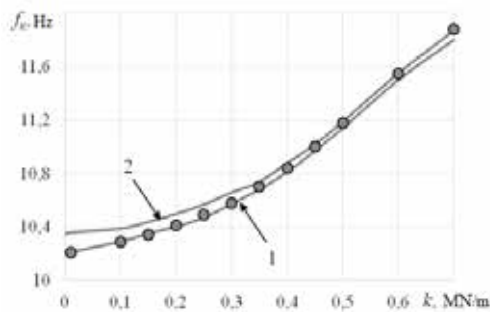
Equipment vibration frequency, Hz	FNBV with the indicated number of boxes, Hz		
	1	2	4
6	10,61	10,62	10,4
7	10,77	10,8	10,51
8	10,94	11,02	10,68
9	11,13	11,28	10,94



Pic. 4. Forms of body vibrations on the upper (top) and lower (bottom) FNBV at the equipment frequency of 6 (a) and 9 (b) Hz (author's scheme).



Pic. 5. Variants of location of the undercarriage equipment (the author's schematic diagram).



Pic. 6. Dependence of FNBV on vertical stiffness of the equipment fastenings with absolute flexibility (1), absolute rigidity (2) of fastenings in two perpendicular directions. Markers show the same rigidity of fastenings in three directions (developed by the author).

with the highest vibration amplitudes of the body, that is, near its central section. Nevertheless, it is more important to choose the optimal value of rigidity of the equipment fastenings, which allows increasing FNBV in the example under consideration by 3–10 %.

Anti-vibration mountings usually exhibit flexibility not only in the vertical, but also in the longitudinal and transverse directions [13]. To assess the effect of the shear stiffness of supports in the other two directions on FNBV, the body model was supplemented with elastic elements in the attachment areas, which ensure that the stiffness of the supports in the longitudinal and transverse directions is taken into account. Thus, each support for fixing the equipment box was modelled by three independent elastic elements.

The calculation results are shown in Pic. 6. FNBV values corresponding to curve 1 were obtained without considering shear stiffness of fastenings, to curve 2 – considering the absolute shear stiffness. The results obtained at any actual values of shear stiffness are located between these curves. For example, in the case of equal rigidity of fastenings in three directions (markers in Pic. 6). For the values of the vertical stiffness that can be used to increase FNBV (0,1–0,7 MN/m), the differences in FNBV values at various shear stiffnesses do not exceed 1 %. Therefore, when choosing rigidity of equipment fastenings, the shear rigidity of fastenings can be neglected. This simplification is permissible in the case of a bending body shape characterised by intense vertical vibrations. However, in case of considering other modes of vibration (for example, asymmetric diamond-shaped one [16]), shear stiffnesses can have a more significant effect on frequency of natural vibrations.

CONCLUSION

The installation of equipment on flexible fastenings with the optimal selection of their

rigidity leads to an increase in FNBV of a suburban electric train wagon. The preliminary selection of rigidity of fastenings can be carried out according to the values of the natural vibration frequency of the equipment.

Simulation of equipment installed on flexible supports is most efficiently performed using linear elastic elements and a rigid area tool, which allows estimating FNBV with an error of no more than 1 % compared to the method of full modelling of the equipment frame. In this case, the influence of the shear stiffness of the supports on FNBV is less than 1 % and may not be taken into account.

The heaviest equipment, when installed on flexible fastenings, is advisable to be located closer to the centre of the body for more effective compensation of bending vibrations of the body.

With a constant gross mass of the body, an increase in the relative mass of the equipment installed on flexible mountings from 0,02 to 0,08 leads to an increase in FNBV on elastic supports, and practically does not cause changes in FNBV in case of a rigid attachment of the equipment.

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Goals and Risks of Activity as Factors of Regulation in Social Systems in Transport Sector



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ABSTRACT

Significant changes that are currently taking place in the external environment are objective prerequisites for emergence of new management methods that predetermine the practical period of transition of enterprises from strategic planning to strategic management (transfer of thinking based on the future to the thinking based on the present following the principle «here and now»).

So, for example, large production structures focus on stability, therefore they react slowly to changes in the external environment, take little risks, and tend to traditional solutions. Modifying options developed at large enterprises are developing what is, as well as complementing and differentiating the existing situation, where the limited possibilities of any kind of evolution of any system can exist solely within its limits.

Efficiency reflects the results of development, but is not identical with the results, because no saving of some factors of

production can be achieved without additional costs of others. The strategy turns here into real one only if it based on the concept of developing new specific products or processes subject to the following indicator of progress: the maximum earned with the minimum of expenditures.

The objective of the study is to identify modern regulatory factors in social systems in transport sector concealed in the goals and risks of such activities, while the main object of study is road transportation. The article uses methods of theoretical and empirical research in relation to goals and risks that can be determined and observed in the activities of transport socio-technical systems.

Goals and risks are defined as factors that allow regulating key performance indicators of socio-technical systems that affect their effectiveness.

Keywords: transport, risks, risk reduction, risk management, risk regulation, transport risks, risk identification, efficiency.

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

INTRODUCTION

The transport industry is among the sectors more vulnerable to risks, which requires transport companies to use effective enterprise risk management strategies. By using right methods and tools, these companies can reduce a significant portion of their risks and better respond to the situations when they arise [1].

Modern regulatory factors in social systems in transport sector lie in the actual goals of transportation activities, including work in the interests of customers, conscientious fulfilment of obligations undertaken, support and development of mutually beneficial, long-term relationships with partners. Besides, modern regulatory factors in social systems in transport sector are closely related to risks as integral components of transport activities. By managing risks, it is possible to effectively influence both the social and technical components of transport systems.

Risk management is a process of analytical and managerial activity aimed at identifying and responding to emerging uncertainty inherent in managing a complex system and its assets.

The risks that transport companies face vary but can include integrity and safety of the vehicle fleet, safety and retention of drivers, and compliance issues. Some of these risks are directly influenced by external factors such as weather, traffic, and road conditions. Carriers also bear many other risks. They are responsible for delivering the shipments that support the business of their shipper clients. Any disruption, including accidents, loss of cargo or financial problems, can cause a disruption in the supply chain, which damages reputation and lowers profits [2].

Some of the «modern» risks that the transport industry face are related to technological advances, cyber vulnerabilities and market fluctuations caused by international trade disputes. In addition, the deepening shortage of qualified drivers, regulatory compliance and the poor state of road infrastructure are also ongoing challenges. Although many of these risks are beyond the control of transport companies, there are actions they can undertake to reduce their risks and be able to respond to them appropriately [3].

The *objective* of the study is to determine modern factors regulating social systems in transport sector concealed in goals and risks of transportation activity. The study uses the *methods* of theoretical research, based on the study of the degree of elaboration of similar issues by other researchers, of their relevance, on their critical

assessment. Besides theoretical methods, the article uses methods of empirical research in relation to goals and risks, expressed in the presentation of information obtained empirically.

RESULTS

Goals and Risks in Transport Sector

Implementing transport risk management is a way of assessing specific risks and developing a strategy to meet those risks.

With so much at stake regarding the impact of transport risks on commercial activity, each transport company must develop a transport risk management solution that will guide their policies and operations. The solution not only reduces risk but can also serve as a powerful sales tool that will attract shippers who want to be sure their goods are in good hands.

When a transport company is unable to implement an effective transport risk management solution, its management advises their employees and customers that risk management is not a top priority. This can be detrimental to morale, to attracting knowledgeable, skilled drivers and winning business. Many shippers are now asking their carriers what rules are in place to mitigate the risks that could affect their shipping. Without a concrete and clear risk management solution that they can easily show customers and determine the level of risks involved, shippers are more likely to go to another carrier. There is too much at stake to take risks.

The main concern of a modern carrier is to ensure smooth operation of the supply chain. As part of their transport risk management efforts, carriers should consider insurance coverage and its terms, responsibility at each stage of the supply chain, business continuity plans, the value of their cargo, as well as ensure loss prevention [4].

Transport risk management may not be the same for any company. However, there are fundamental elements that each transport company should implement in their practices. There are some useful recommendations to be made for transport companies looking to mitigate the risks inherent in their industry:

- Development of executive support for risk management.
- Defining the principles of risk management and responsibility of the organisation.
- Formalisation of approaches to risk management, using a holistic approach to support decision-making and improve successful achievement of strategic goals and objectives.
- Using risk management to revise existing policies, processes, and standards.



- Incorporating risk management into existing business processes so that decisions are made successfully when assets, productivity and risk management are pooled.

- Identification of risk owners and risk management at the appropriate level.

- Use of the risk management process to support distribution of risks in decision-making, development of programs and projects.

- Using risk management to obtain a business case for transportation and gain trust of stakeholders.

- Use of sophisticated risk analysis tools followed by communication of the results to stakeholders.

Modern solutions allow carriers to identify risks, analyse their severity and automate the task of finding alternatives with less risk. Revealing risks involves identifying the shipment and the variables that could affect its delivery. Unfavourable weather conditions, extreme temperatures, social hazards, natural disasters and outages (failures) of infrastructure are among the most common risks [4].

The decision can then accept these identified risks and assess their likelihood at any stage of the delivery route. This is an important factor to consider because when looking only at pick-up and drop-off locations, intermediate points are ignored, while the biggest disruptions can occur right there. Most carriers lack the manpower, technology, or time to gather this amount of information, especially when multiple shipments move to different locations across the country. Technology has dramatically improved accuracy, scale, and speed of revealing this data, and it has improved dramatically over the past decade.

Besides identifying potential risks, they must be analysed to find out their likelihood, severity, geography, and timing. For example, forecasted freezing rain may have a 70 percent chance of falling in one of the northern regions of a country on a Monday route, but if vehicles are expected to leave that region on Sunday, shipment can be made as scheduled. Alternatively, if vehicles are not expected to leave until Tuesday, there is a 50 percent chance that the shipment will be delayed due to road icing.

This is where the next stage of a risk management process can be effective which is decision making. With the information obtained, the carrier can decide when the shipment should begin. If you move the pickup date to an earlier week or postpone it until the temperature rises above freezing, freezing rain may not affect the shipment. Yes, the shipment can be early or late, depending on this decision, but cargo will be safe and will not be affected by low temperatures or slippery roads that can damage cargo and/or vehicles [5].

The carrier can better plan a pickup date, determine which risk the company is willing to take with each shipment, decide what equipment might be needed to protect cargo, determine which mode of transport is the best one. This decision-making phase should include accurate real-time data and predictive data presented in a clear manner.

Flexible planning means transport risk management and it is critical to stay competitive, profitable, and delivering value to the customers.

The key to finding a solution to transport risk management is understanding transparency associated with risks. Both shippers and carriers need to receive real-time information about shipments: what each vehicle carries, how a specific cargo should be transported, delivery routes, expected and actual times of receipt and delivery, as well as all the variables that may affect these various elements [6].

There are many variables, and some of them are unpredictable. Weather, natural disasters, crime, protests or riots, infrastructure problems, drivers' health and safety, and other issues can directly or indirectly affect delivery reliability. By predicting these variables in advance, carriers can better set expectations, lower costs, and ensure that goods are properly cared for and delivered as expected.

This type of detailed visibility, of course, requires appropriate technology, but basic or outdated technology does not meet the needs. Today, more and more companies are relying on artificial intelligence, cognitive technology, and machine learning to collect data that is distributed across multiple systems. The opportunities are numerous, and now the transportation industry must use them to manage their solutions.

When looking for a solution for managing transport risks, it is imperative to find the one that eliminates all risk threats to the company, and provides useful data that will be used for decision making. This means that the company must be aware of its risks, regularly conducting a thorough assessment of them. Transport companies should ask themselves: «What risks can affect the strategic goals and objectives of the company? How should we prioritise our investments? What is the likelihood of delivery on time and on budget» [7]?

Once these factors are understood, a risk management solution can be developed.

In addition to weather and other variables that can affect a carrier's performance, there are always safety concerns. If, for example, the driver does not adhere to the rules of safe driving, not only the cargo is at risk, but also the company, which can be liable for accidents, injury and even death. They are

responsible for each vehicle leaving the warehouse/ storage/dock. The responsibility for compliance by drivers with safety regulations and serviceability of rolling stock lies with the carrier. These considerations are critical to mitigate risks.

Compliance, safety, accountability are pillars of risk prevention, making carriers and their drivers responsible for complying with rules that directly affect safety [8].

Factors of Risk Management in Social Systems in Transport Sector

Below are the risk management factors in social systems in transport sectors.

1. *Unsafe driving* – unsafe driving of a commercial vehicle, for example, speeding, reckless driving, wrong lane changes, inattention, etc. [9].

2. *Failure to comply with working hours* – violation or non-observance of the rules of working hours or driving when tired.

3. *Fitness of a driver* – drivers must have adequate health, psychological and personal qualities, as well as appropriate training and experience to safely operate a vehicle.

4. *Prohibited substances / alcohol* – misuse of prescribed or over-the-counter drugs, or a change in the driver's condition for the worse due to prohibited substances.

5. *Vehicle maintenance* – non-observance of vehicle maintenance rules (headlights, brakes, necessary damage repair, timely maintenance).

6. *Failure to comply with the rules for transportation of dangerous goods* – prevention of leakage of containers and tanks with hazardous substances, incorrect labelling, improperly packed and loaded dangerous goods.

7. *Failure indicator* – frequency and severity of failures.

The goal of transport risk management is not to eliminate risks. Risks are inherent in every industry, and many of them are completely outside the control of any organisation. Instead, transport risk management serves as a system for predicting potential disruptions with a single goal: to help transport companies develop dynamic processes and systems that respond quickly, efficiently, and reliably to changing logistics and transportation challenges [10].

These predictions are just the beginning. They shed light on what can happen sometime and somewhere, but the main goal is to have the right mechanisms available to respond appropriately to these predictions before they negatively impact the business. To have a plan of action in all circumstances

(known, foreseeable or unknown), transport companies must constantly reassess their risks. These are also not one-time procedures. Risks «travel» with each vehicle across thousands of kilometres of roads and across borders. They fluctuate and can change every kilometre of the route [11].

Companies must have access to accurate, reliable, and comprehensive information that provides a clear understanding of vulnerabilities of the supply chain and transport networks. By anticipating outages, companies can proactively minimise their impact. They can create backup plans or reverse plans to reduce the impact. In fact, they can be more resilient to change and threats [12].

An important aspect is the development of relevant skills of management to cope with risks management and to create motivation systems diversified by criteria and rewards [13] comprising development and implementation of corporate risk management systems as evaluated and rewarded indicator. The risk management should be included into corporate training, strategies and concepts of efficiency improvement, leadership development at the corporate headquarters', divisional and front-line units. Many works are dedicated to the development of those systems, particularly regarding risk management (e.g., [14–16]) but each transport company should thoroughly adapt its own system of indicators to existing risks and to remedial actions within its managerial system. It should be explained by the fact that transport companies (in contrast to e.g., banking) have widely different activity features predetermined by body of factors comprising features of rolling stock, transported goods, customers (big shippers, general cargo, etc.), logistics facilities, geography of activity, other factors.

CONCLUSION

So, risk is the effect of uncertainty on goals. In the broadest sense, risk is everything that can become an obstacle to achieving goals and objectives. Risk management is a process of analytical and managerial activity aimed at identifying and responding to uncertainties inherent in managing a complex organisation and its assets.

The practices of risk management in biggest companies show the following:

- Risk management supports strategic organisational alignment.
- Mature organisations have a clear structure for risk management.
- Successful organisations have a culture of risk management.





- A wide range of risk management tools are used.
- Risk management tools are key for making program investment decisions.
- Various methods of risk management are available.
- Active risk communication strategies improve decision making.
- Risk management improves knowledge management and personnel development.

The conclusions drawn are general ones and make a basis for development of risk management systems in particular transport companies.

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Heavy Train Starting Model



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ABSTRACT

The starting mode for a ground vehicle is the most difficult since the static friction force is much greater than the dynamic friction force. For trains, this mode is such a serious problem that sometimes it is necessary to take special measures, such as the use of sand in the contact area of the wheel tire with the rail or an auxiliary locomotive. An effective way of starting a train is to select coupling clearances. In this case, cars are set in motion sequentially and the inert mass, as well as the static friction force at the immediate moment of starting are minimal.

This method, however, has two significant drawbacks: a small set value of clearances in couplings, which limits the effectiveness of the method, and the shock nature of the impulse transmission negatively affecting the state of train structural elements. These disadvantages can be avoided by using elastically deformable couplings.

The objective of the work is to show the advantage of starting a train with elastic couplings in comparison with the

traditional mode using its mathematical description and analysis. Starting a train with elastic couplings is much easier than that of a non-deformable one. Moreover, the greater is the number of wagons, the greater is the advantage of the former over the latter. The softening of the mode of starting the train from rest is essentially due to replacement of the simultaneous start-off of the sections by alternate. This process is relevant for inertial forces. Regarding the static friction force, the mechanism will be similar, i.e., not all the static friction force is overcome at the same time, but its small parts are overcome one by one. To exclude longitudinal vibrations of the train, after reaching the maximum tension of the coupling, it is necessary to mechanically block the possibility of its harmonic compression with subsequent sampling of elastic deformation, for example, using damping devices.

The elimination of the transmission of shock loads to the locomotive engines can be considered as an additional positive effect from the use of elastic couplings.

Keywords: transport, railway, train, starting, couplings, friction, movement, speed.

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INTRODUCTION

The static friction force significantly exceeds the motion friction force. This leads to the fact that the starting mode for a ground vehicle is the most difficult [1–4]. For trains, this mode is such a serious problem that sometimes it is necessary to take special measures, such as the use of sand in the contact zone of the wheel tire with the rail or an auxiliary locomotive [5–7]. This problem is exacerbated by the steady trend of increasing train mass and length.

An effective way of starting a train is to select coupling clearances. In this case, wagons are set in motion alternately and the inert mass, as well as the static friction force immediately at the moment of starting, are minimal [8; 9].

This method, however, has two significant drawbacks: a small fixed value of clearances in couplings, which limits the effectiveness of the method and the shock nature of the impulse transmission negatively affecting the state of train structural elements.

These disadvantages can be avoided by using elastically deformable couplings [10].

The literature presents the results of theoretical studies of structural elements using flexible and elastic components [11–13].

In this regard, the dynamics of the entire train in the starting mode is of interest.

The *objective* of the work is a *mathematical description* of the «easy» starting of a train with elastic couplings.

RESULTS

Calculation of the mechanical system containing massive locomotives, wagons and elastic couplings is rather cumbersome [14; 15]. To minimise it, the following assumptions are made: the force F developed by the locomotive is a constant value; masses of the locomotive and wagons are equal to each other and are m .

Locomotive and a Single Wagon

The equation of the forces applied to the locomotive has the form:

$$F = m \frac{d^2 x_1}{dt^2} + k(x_1 - x_2), \quad (1)$$

where x_1, x_2 are movements of, respectively, the locomotive and the wagon;

k is elasticity coefficient of the coupling [16].

The forces applied to the wagon satisfy the equation:

$$0 = m \frac{d^2 x_2}{dt^2} - k(x_1 - x_2).$$

From the latter equation it follows that:

$$x_1 = \frac{m}{k} \frac{d^2 x_2}{dt^2} + x_2. \quad (2)$$

Substitution of this equation in (1) gives:

$$\begin{aligned} F &= \frac{m^2}{k} \frac{d^4 x_2}{dt^4} + m \frac{d^2 x_2}{dt^2} + m \frac{d^2 x_2}{dt^2} + kx_2 - kx_2 = \\ &= \frac{m^2}{k} \frac{d^4 x_2}{dt^4} + 2m \frac{d^2 x_2}{dt^2}. \end{aligned} \quad (3)$$

Then let:

$$\frac{d^2 x_2}{dt^2} = z. \quad (4)$$

And then (3) is written as:

$$z'' + 2 \frac{k}{m} z = \frac{kF}{m^2}. \quad (5)$$

Characteristic equation is:

$$r^2 + 2 \frac{k}{m} = 0.$$

Its roots are equal to:

$$r_{1,2} = \pm i \sqrt{2 \frac{k}{m}}.$$

General solution of the corresponding homogeneous equation is:

$$z_1 = C_1 \cos \sqrt{2 \frac{k}{m}} t + C_2 \sin \sqrt{2 \frac{k}{m}} t.$$

Particular solution in accordance with (5) has the form:

$$z_2 = A.$$

Its substitution in (5) gives:

$$2 \frac{k}{m} A = \frac{kF}{m^2}, \quad A = \frac{F}{2m}.$$

General solution of the equation (5) is found as:

$$z = z_1 + z_2 = C_1 \cos \sqrt{2 \frac{k}{m}} t + C_2 \sin \sqrt{2 \frac{k}{m}} t + \frac{F}{2m}.$$

At the moment of time $t = 0$ the coupling is not deformed, therefore, the force does not act on the wagon and the value (4) is equal to zero. Therefore, for $t = 0$, the latter expression will take the form:

$$z(0) = 0 = C_1 \cos \sqrt{2 \frac{k}{m}} 0 + C_2 \sin \sqrt{2 \frac{k}{m}} 0 + \frac{F}{2m}, \quad C_1 = -\frac{F}{2m}.$$

Taking this into account:

$$z = -\frac{F}{2m} \cos \sqrt{2 \frac{k}{m}} t + C_2 \sin \sqrt{2 \frac{k}{m}} t + \frac{F}{2m}. \quad (6)$$

In accordance with (4):

$$\begin{aligned} v_2 &= \int z dt = -\frac{F}{2m} \frac{1}{\sqrt{2 \frac{k}{m}}} \sin \sqrt{2 \frac{k}{m}} t - \\ &- C_2 \frac{1}{\sqrt{2 \frac{k}{m}}} \cos \sqrt{2 \frac{k}{m}} t + \frac{F}{2m} t + C_3; \\ x_2 &= \int v_2 dt = \frac{F}{4k} \cos \sqrt{2 \frac{k}{m}} t - \\ &- C_2 \frac{m}{2k} \sin \sqrt{2 \frac{k}{m}} t + \frac{F}{4m} t^2 + C_3 t + C_4. \end{aligned} \quad (7)$$

Taking into account (2), (4), (6) and (7):

$$\begin{aligned}
 x_1 &= -\frac{F}{2k} \cos \sqrt{\frac{2k}{m}} t + C_2 \frac{m}{k} \sin \sqrt{\frac{2k}{m}} t + \\
 &+ \frac{F}{2k} + \frac{F}{4k} \cos \sqrt{\frac{2k}{m}} t - \\
 &- C_2 \frac{m}{2k} \sin \sqrt{\frac{2k}{m}} t + \frac{F}{4m} t^2 + C_3 t + C_4; \\
 v_1 &= \frac{dx_1}{dt} = \frac{F}{2k} \sqrt{\frac{2k}{m}} \sin \sqrt{\frac{2k}{m}} t + C_2 \sqrt{\frac{2k}{m}} \frac{m}{k} \cos \sqrt{\frac{2k}{m}} t - \\
 &- \frac{F}{4k} \sqrt{\frac{2k}{m}} \sin \sqrt{\frac{2k}{m}} t - C_2 \sqrt{\frac{2k}{m}} \frac{m}{2k} \cos \sqrt{\frac{2k}{m}} t + \frac{F}{2m} t + C_3; \\
 a_1 &= \frac{dv_1}{dt} = \frac{F}{2k} \sqrt{\frac{2k}{m}} \cos \sqrt{\frac{2k}{m}} t - \\
 &- C_2 \sqrt{\frac{2k}{m}} \frac{m}{k} \sin \sqrt{\frac{2k}{m}} t - \frac{F}{4k} \sqrt{\frac{2k}{m}} \cos \sqrt{\frac{2k}{m}} t + \\
 &+ C_2 \sqrt{\frac{2k}{m}} \frac{m}{2k} \sin \sqrt{\frac{2k}{m}} t + \frac{F}{2m}; \\
 x_2(0) &= 0 = \frac{F}{4k} \cos \sqrt{\frac{2k}{m}} 0 - C_2 \frac{m}{2k} \sin \sqrt{\frac{2k}{m}} 0 + \\
 &+ \frac{F}{4m} 0^2 + C_3 0 + C_4; \\
 \frac{F}{4k} + C_4 &= 0; \quad C_4 = -\frac{F}{4k}; \\
 v_2(0) &= 0 = -C_2 \sqrt{\frac{2k}{m}} + C_3; \\
 v_1(0) &= 0 = C_2 \sqrt{\frac{2k}{m}} \frac{m}{k} - C_2 \sqrt{\frac{2k}{m}} \frac{m}{2k} + C_3 = \\
 &= C_2 \sqrt{\frac{2k}{m}} \frac{m}{2k} + C_3; \\
 \begin{cases} -C_2 \sqrt{\frac{2k}{m}} + C_3 = 0 \\ C_2 \sqrt{\frac{2k}{m}} \frac{m}{2k} + C_3 = 0 \end{cases} &; \quad C_2 = 0, \quad C_3 = 0.
 \end{aligned}$$

The final solution is:

$$\begin{aligned}
 x_1 &= -\frac{F}{4k} \cos \sqrt{\frac{2k}{m}} t + \frac{F}{4m} t^2 + \frac{F}{4k}; \\
 x_2 &= \frac{F}{4k} \cos \sqrt{\frac{2k}{m}} t + \frac{F}{4m} t^2 - \frac{F}{4k}; \\
 v_1 &= \frac{F}{2\sqrt{2km}} \sin \sqrt{\frac{2k}{m}} t + \frac{F}{2m} t; \\
 v_2 &= -\frac{F}{2\sqrt{2km}} \sin \sqrt{\frac{2k}{m}} t + \frac{F}{2m} t; \\
 a_1 &= \frac{F}{2m} \cos \sqrt{\frac{2k}{m}} t + \frac{F}{2m}; \\
 a_2 &= -\frac{F}{2m} \cos \sqrt{\frac{2k}{m}} t + \frac{F}{2m}.
 \end{aligned}$$

The characteristic time interval τ_2 (the index «2» means the number of components of the train) for the case under consideration is determined from the condition of maximum stretching of the elastic coupling. Where in:

$$a_1(\tau_2) - \frac{F}{2m} = 0 \quad \text{or} \quad \frac{F}{2m} \cos \sqrt{\frac{2k}{m}} \tau_2 = 0;$$

$$\sqrt{\frac{2k}{m}} \tau_2 = \frac{\pi}{2}; \quad \tau_2 = \frac{\pi}{2} \sqrt{\frac{m}{2k}}.$$

For time τ_2 the locomotive will cover the distance:

$$\begin{aligned}
 x_1(\tau_2) &= -\frac{F}{4k} \cos \sqrt{\frac{2k}{m}} \frac{\pi}{2} \sqrt{\frac{m}{2k}} + \\
 &+ \frac{F}{4m} \frac{\pi^2}{4} \frac{m}{2k} + \frac{F}{4k} = \frac{F\pi^2}{32k} + \frac{F}{4k}
 \end{aligned}$$

and will develop the speed:

$$\begin{aligned}
 v_1(\tau_2) &= \frac{F}{2\sqrt{2km}} \sin \sqrt{\frac{2k}{m}} \frac{\pi}{2} \sqrt{\frac{m}{2k}} + \\
 &+ \frac{F}{2m} \frac{\pi}{2} \sqrt{\frac{m}{2k}} = \frac{F}{2\sqrt{2km}} + \frac{F\pi}{4\sqrt{2km}}.
 \end{aligned}$$

It is appropriate to compare these indicators with the corresponding values for a non-deformable train:

$$a = \frac{F}{2m}; \quad v = \frac{F}{2m} t; \quad x = \frac{F}{4m} t^2;$$

$$x(\tau_2) = \frac{F}{4m} \frac{\pi^2}{4} \frac{m}{2k} = \frac{F\pi^2}{32k};$$

$$v(\tau_2) = \frac{F}{2m} \frac{\pi}{2} \sqrt{\frac{m}{2k}} = \frac{F\pi}{4\sqrt{2km}};$$

$$\frac{x_1(\tau_2)}{x(\tau_2)} = \frac{F\pi^2/(32k) + F/(4k)}{F\pi^2/(32k)} = 1 + \frac{32}{4\pi^2} \approx 1,81;$$

$$\frac{v_1(\tau_2)}{v(\tau_2)} = \frac{F/(2\sqrt{2km}) + F\pi/(4\sqrt{2km})}{F\pi/(4\sqrt{2km})} = 1 + \frac{2}{\pi} \approx 1,64.$$

The ratio of kinetic energies of the locomotive [17] is:

$$\frac{E_1(\tau_2)}{E(\tau_2)} = 2,69.$$

The obtained ratios clearly demonstrate that the starting-off of a train with elastic couplings is much easier than that of a non-deformable one.

Locomotive and Two Wagons

The equations of forces applied, respectively, to the locomotive and the cars are:

$$F = m \frac{d^2 x_1}{dt^2} + k(x_1 - x_2); \quad (8)$$

$$k(x_1 - x_2) = m \frac{d^2 x_2}{dt^2} + k(x_2 - x_3); \quad (9)$$

$$k(x_2 - x_3) = m \frac{d^2 x_3}{dt^2}.$$

From the latter equation it follows that:

$$x_2 = \frac{m}{k} \frac{d^2 x_3}{dt^2} + x_3. \quad (10)$$

The derivative of this expression is:

$$\frac{d^2 x_2}{dt^2} = \frac{m}{k} \frac{d^4 x_3}{dt^4} + \frac{d^2 x_3}{dt^2}.$$

Substitution of two latter expressions in (9) gives:



$$x_1 = \frac{m}{k} \frac{d^2 x_2}{dt^2} + 2x_2 - x_3 =$$

$$\frac{m^2}{k^2} \frac{d^4 x_3}{dt^4} + \frac{m}{k} \frac{d^2 x_3}{dt^2} + 2 \frac{m}{k} \frac{d^2 x_3}{dt^2} + 2x_3 - x_3 =$$

$$= \frac{m^2}{k^2} \frac{d^4 x_3}{dt^4} + 3 \frac{m}{k} \frac{d^2 x_3}{dt^2} + x_3. \quad (11)$$

The derivative of this expression is equal to:

$$\frac{d^2 x_1}{dt^2} = \frac{m^2}{k^2} \frac{d^6 x_3}{dt^6} + 3 \frac{m}{k} \frac{d^4 x_3}{dt^4} + \frac{d^2 x_3}{dt^2}.$$

Substitution of the obtained expressions in (8) gives:

$$\frac{F}{k} = \frac{m^3}{k^3} \frac{d^6 x_3}{dt^6} + 3 \frac{m^2}{k^2} \frac{d^4 x_3}{dt^4} + \frac{m}{k} \frac{d^2 x_3}{dt^2} +$$

$$+ \frac{m^2}{k^2} \frac{d^4 x_3}{dt^4} + 3 \frac{m}{k} \frac{d^2 x_3}{dt^2} + x_3 - \frac{m}{k} \frac{d^2 x_3}{dt^2} - x_3 =$$

$$= \frac{m^3}{k^3} \frac{d^6 x_3}{dt^6} + 4 \frac{m^2}{k^2} \frac{d^4 x_3}{dt^4} + 3 \frac{m}{k} \frac{d^2 x_3}{dt^2},$$

$$\frac{d^6 x_3}{dt^6} + 4 \frac{k}{m} \frac{d^4 x_3}{dt^4} + 3 \frac{k^2}{m^2} \frac{d^2 x_3}{dt^2} = \frac{k^2 F}{m^3}. \quad (12)$$

Let:

$$\frac{d^2 x_3}{dt^2} = z. \quad (13)$$

Then (12) is written as:

$$z''' + 4 \frac{k}{m} z'' + 3 \frac{k^2}{m^2} z = \frac{k^2 F}{m^3}. \quad (14)$$

Characteristic equation:

$$r^4 + 4 \frac{k}{m} r^2 + 3 \frac{k^2}{m^2} = 0;$$

$$r_{1,2}^2 = -2 \frac{k}{m} \pm \frac{k}{m}; \quad r_1^2 = -3 \frac{k}{m};$$

$$r_2^2 = -\frac{k}{m}; \quad r_{1,2} = \pm i \sqrt{3 \frac{k}{m}}; \quad r_{3,4} = \pm i \sqrt{\frac{k}{m}}.$$

General solution of the corresponding homogeneous equation is:

$$z_1 = C_1 \cos \sqrt{3 \frac{k}{m}} t + C_2 \sin \sqrt{3 \frac{k}{m}} t +$$

$$+ C_3 \cos \sqrt{\frac{k}{m}} t + C_4 \sin \sqrt{\frac{k}{m}} t.$$

Particular solution has the form:

$$z_2 = A.$$

Its substitution in (14) gives:

$$3 \frac{k^2}{m^2} A = \frac{k^2 F}{m^3}; \quad A = \frac{F}{3m}.$$

General solution is found as:

$$z = z_1 + z_2 = C_1 \cos \sqrt{3 \frac{k}{m}} t + C_2 \sin \sqrt{3 \frac{k}{m}} t +$$

$$+ C_3 \cos \sqrt{\frac{k}{m}} t + C_4 \sin \sqrt{\frac{k}{m}} t + \frac{F}{3m}. \quad (15)$$

In accordance with (13):

$$v_3 = \int z dt = C_1 \sqrt{\frac{m}{3k}} \sin \sqrt{3 \frac{k}{m}} t - C_2 \sqrt{\frac{m}{3k}} \cos \sqrt{3 \frac{k}{m}} t +$$

$$+ C_3 \sqrt{\frac{m}{k}} \sin \sqrt{\frac{k}{m}} t - C_4 \sqrt{\frac{m}{k}} \cos \sqrt{\frac{k}{m}} t + \frac{F}{3m} t + C_5; \quad (16)$$

$$x_3 = \int v_3 dt = -C_1 \frac{m}{3k} \cos \sqrt{3 \frac{k}{m}} t - C_2 \frac{m}{3k} \sin \sqrt{3 \frac{k}{m}} t -$$

$$- C_3 \frac{m}{k} \cos \sqrt{\frac{k}{m}} t - C_4 \frac{m}{k} \sin \sqrt{\frac{k}{m}} t + \frac{F}{6m} t^2 + C_5 t + C_6. \quad (17)$$

Taking into account (10), (13), (15) and (17):

$$x_2 = \frac{m}{k} C_1 \cos \sqrt{3 \frac{k}{m}} t + \frac{m}{k} C_2 \sin \sqrt{3 \frac{k}{m}} t +$$

$$+ \frac{m}{k} C_3 \cos \sqrt{\frac{k}{m}} t + \frac{m}{k} C_4 \sin \sqrt{\frac{k}{m}} t + \frac{m}{k} \frac{F}{3m} -$$

$$- C_1 \frac{m}{3k} \cos \sqrt{3 \frac{k}{m}} t - C_2 \frac{m}{3k} \sin \sqrt{3 \frac{k}{m}} t - C_3 \frac{m}{k} \cos \sqrt{\frac{k}{m}} t -$$

$$- C_4 \frac{m}{k} \sin \sqrt{\frac{k}{m}} t + \frac{F}{6m} t^2 + C_5 t + C_6 =$$

$$= \frac{2m}{3k} C_1 \cos \sqrt{3 \frac{k}{m}} t + \frac{2m}{3k} C_2 \sin \sqrt{3 \frac{k}{m}} t +$$

$$+ \frac{F}{3k} + \frac{F}{6m} t^2 + C_5 t + C_6; \quad (18)$$

$$v_2 = \frac{dx_2}{dt} = -\frac{2m}{3k} \sqrt{\frac{3k}{m}} C_1 \sin \sqrt{3 \frac{k}{m}} t +$$

$$+ \frac{2m}{3k} \sqrt{\frac{3k}{m}} C_2 \cos \sqrt{3 \frac{k}{m}} t + \frac{F}{3m} t + C_5 =$$

$$= -\frac{2}{3} \sqrt{\frac{3m}{k}} C_1 \sin \sqrt{3 \frac{k}{m}} t +$$

$$+ \frac{2}{3} \sqrt{\frac{3m}{k}} C_2 \cos \sqrt{3 \frac{k}{m}} t + \frac{F}{3m} t + C_5; \quad (19)$$

$$a_2 = \frac{dv_2}{dt} = -2C_1 \cos \sqrt{3 \frac{k}{m}} t - 2C_2 \sin \sqrt{3 \frac{k}{m}} t + \frac{F}{3m}. \quad (20)$$

Taking into account (11), (17), (18) and (20):

$$x_1 = -2C_1 \frac{m}{k} \cos \sqrt{3 \frac{k}{m}} t - 2C_2 \frac{m}{k} \sin \sqrt{3 \frac{k}{m}} t + \frac{F}{3m} \frac{m}{k} +$$

$$+ 2 \frac{2m}{3k} C_1 \cos \sqrt{3 \frac{k}{m}} t + 2 \frac{2m}{3k} C_2 \sin \sqrt{3 \frac{k}{m}} t +$$

$$+ \frac{2F}{3k} + \frac{2F}{6m} t^2 + 2C_5 t + 2C_6 +$$

$$+ C_1 \frac{m}{3k} \cos \sqrt{3 \frac{k}{m}} t + C_2 \frac{m}{3k} \sin \sqrt{3 \frac{k}{m}} t + C_3 \frac{m}{k} \cos \sqrt{\frac{k}{m}} t +$$

$$+ C_4 \frac{m}{k} \sin \sqrt{\frac{k}{m}} t - \frac{F}{6m} t^2 - C_5 t - C_6 =$$

$$= -C_1 \frac{m}{3k} \cos \sqrt{3 \frac{k}{m}} t - C_2 \frac{m}{3k} \sin \sqrt{3 \frac{k}{m}} t + C_3 \frac{m}{k} \cos \sqrt{\frac{k}{m}} t +$$

$$+ C_4 \frac{m}{k} \sin \sqrt{\frac{k}{m}} t + \frac{F}{k} + \frac{F}{6m} t^2 + C_5 t + C_6;$$

$$v_1 = \frac{dx_1}{dt} = C_1 \sqrt{\frac{m}{3k}} \sin \sqrt{3 \frac{k}{m}} t -$$

$$- C_2 \sqrt{\frac{m}{3k}} \cos \sqrt{3 \frac{k}{m}} t - C_3 \sqrt{\frac{m}{k}} \sin \sqrt{\frac{k}{m}} t +$$

$$+ C_4 \sqrt{\frac{m}{k}} \cos \sqrt{\frac{k}{m}} t + \frac{F}{3m} t + C_5; \quad (21)$$

$$a_1 = C_1 \cos \sqrt{3 \frac{k}{m}} t - C_3 \cos \sqrt{\frac{k}{m}} t + \frac{F}{3m}.$$

In accordance with (20):

$$a_2(0) = -2C_1 + \frac{F}{3m} = 0; \quad C_1 = \frac{F}{6m}.$$

Table 1

Number of train sections	$\frac{x_1(\tau)}{x(\tau)}$	$\frac{v_1(\tau)}{v(\tau)}$	$\frac{E_1(\tau)}{E(\tau)}$
2	1,81	1,64	2,69
3	2,6	2,22	4,93

In accordance with (15):

$$z(0) = 0 = \frac{F}{6m} + C_3 + \frac{F}{3m}; \quad C_3 = -\frac{F}{2m}.$$

In accordance with (18):

$$x_2(0) = \frac{2m}{3k} C_1 + \frac{F}{3k} + C_6 = 0;$$

$$\frac{F}{9k} + \frac{F}{3k} + C_6 = 0; \quad C_6 = -\frac{4F}{9k}.$$

In accordance with (16), (19) and (21):

$$v_1(0) = -C_2 \sqrt{\frac{m}{3k}} + C_4 \sqrt{\frac{m}{k}} + C_5 = 0;$$

$$v_3(0) = -C_2 \sqrt{\frac{m}{3k}} - C_4 \sqrt{\frac{m}{k}} + C_5 = 0, \quad C_4 = 0;$$

$$v_2(0) = \frac{2}{3} \sqrt{\frac{3m}{k}} C_2 + C_5 = 0; \quad C_2 = 0; \quad C_5 = 0.$$

Final solution is:

$$x_1 = -\frac{F}{18k} \cos \sqrt{\frac{3k}{m}} t - \frac{F}{2k} \cos \sqrt{\frac{k}{m}} t + \frac{F}{6m} t^2 + \frac{5F}{9k};$$

$$x_2 = \frac{F}{9k} \cos \sqrt{\frac{3k}{m}} t + \frac{F}{6m} t^2 - \frac{F}{9k};$$

$$x_3 = -\frac{F}{18k} \cos \sqrt{\frac{3k}{m}} t + \frac{F}{2k} \cos \sqrt{\frac{k}{m}} t + \frac{F}{6m} t^2 - \frac{4F}{9k};$$

$$v_1 = \frac{F}{6\sqrt{3km}} \sin \sqrt{\frac{3k}{m}} t + \frac{F}{2\sqrt{km}} \sin \sqrt{\frac{k}{m}} t + \frac{F}{3m} t;$$

$$v_2 = -\frac{F}{3\sqrt{3km}} \sin \sqrt{\frac{3k}{m}} t + \frac{F}{3m} t;$$

$$v_3 = \frac{F}{6\sqrt{3km}} \sin \sqrt{\frac{3k}{m}} t - \frac{F}{2\sqrt{km}} \sin \sqrt{\frac{k}{m}} t + \frac{F}{3m} t;$$

$$a_1 = \frac{F}{6m} \cos \sqrt{\frac{3k}{m}} t + \frac{F}{2m} \cos \sqrt{\frac{k}{m}} t + \frac{F}{3m};$$

$$a_2 = -\frac{F}{3m} \cos \sqrt{\frac{3k}{m}} t + \frac{F}{3m};$$

$$a_3 = \frac{F}{6m} \cos \sqrt{\frac{3k}{m}} t - \frac{F}{2m} \cos \sqrt{\frac{k}{m}} t + \frac{F}{3m}.$$

The characteristic time interval τ_3 for the case under consideration is determined from the condition of maximum tension of the elastic coupling.

Thus:

$$a_1(\tau_3) - \frac{F}{3m} = 0 \quad \text{or} \quad \frac{F}{6m} \cos \sqrt{\frac{3k}{m}} \tau_3 + \frac{F}{2m} \cos \sqrt{\frac{k}{m}} \tau_3 = 0;$$

$$\frac{1}{3} \cos \sqrt{3} \sqrt{\frac{k}{m}} \tau_3 + \cos \sqrt{\frac{k}{m}} \tau_3 = 0.$$

Solution of the latter equation has the form:

$$\sqrt{\frac{k}{m}} \tau_3 = 0,427\pi; \quad \tau_3 = 0,427\pi \sqrt{\frac{m}{k}}.$$

For time τ_3 the locomotive will cover the

distance:

$$x_1(\tau_3) = -\frac{F}{18k} \cos \sqrt{\frac{3k}{m}} \cdot 0,427\pi \sqrt{\frac{m}{k}} -$$

$$-\frac{F}{2k} \cos \sqrt{\frac{k}{m}} \cdot 0,427\pi \sqrt{\frac{m}{k}} +$$

$$+\frac{F}{6m} \left(0,427\pi \sqrt{\frac{m}{k}} \right)^2 + \frac{5F}{9k} =$$

$$= \frac{F}{k} \left[-\frac{1}{18} \cos \sqrt{3} \cdot 0,427\pi - \right. \\ \left. -\frac{1}{2} \cos 0,427\pi + \frac{1}{6} (0,427\pi)^2 + \frac{5}{9} \right] =$$

$$= \frac{F}{k} \left[-\frac{1}{18} \cos \sqrt{3} \cdot 0,427\pi - \right. \\ \left. -\frac{1}{2} \cos 0,427\pi + \frac{1}{6} (0,427\pi)^2 + \frac{5}{9} \right] = 0,78 \frac{F}{k}$$

and will develop speed:

$$v_1(\tau_3) = \frac{F}{6\sqrt{3km}} \sin \sqrt{\frac{3k}{m}} \cdot 0,427\pi \sqrt{\frac{m}{k}} +$$

$$+\frac{F}{2\sqrt{km}} \sin \sqrt{\frac{k}{m}} \cdot 0,427\pi \sqrt{\frac{m}{k}} + \frac{F}{3m} \cdot 0,427\pi \sqrt{\frac{m}{k}} =$$

$$= \frac{F}{\sqrt{km}} \left(\frac{1}{6\sqrt{3}} \sin \sqrt{3} \cdot 0,427\pi + \right. \\ \left. + \frac{1}{2} \sin 0,427\pi + \frac{1}{3} 0,427\pi \right) = \frac{F}{\sqrt{km}}.$$

It is appropriate to compare these indicators with the corresponding values for a non-deformable train:

$$a = \frac{F}{3m}; \quad v = \frac{F}{3m} t; \quad x = \frac{F}{6m} t^2;$$

$$x(\tau_3) = \frac{F}{6m} \left(0,427\pi \sqrt{\frac{m}{k}} \right)^2 = 0,3 \frac{F}{k};$$

$$v(\tau_3) = \frac{F}{3m} \cdot 0,427\pi \sqrt{\frac{m}{k}} = 0,45 \frac{F}{\sqrt{mk}};$$

$$\frac{x_1(\tau_3)}{x(\tau_3)} = 2,6;$$

$$\frac{v_1(\tau_3)}{v(\tau_3)} = 2,22.$$

The ratio of kinetic energies for the locomotive is:

$$\frac{E_1(\tau_3)}{E(\tau_3)} = 4,93.$$

CONCLUSIONS

The use of elastically deformable couplings solves the problem of starting a heavy train.

Table 1 summarises displacements, speeds and kinetic energies of the locomotive for the moments of maximum tension of the elastic coupling, referred to corresponding parameters of the non-deformable train.



The obtained ratios clearly demonstrate that the starting-off of a train with elastic couplings is much easier than that of a non-deformable one. Moreover, the greater is the number of wagons, the greater is the advantage of the former over the latter.

The softening of the train start-off mode is essentially due to replacement of simultaneous start-off of sections by alternate start-off. This process is described above for inertial forces. Regarding the static friction force, the mechanism will be similar, i.e., not all static friction force is overcome at the same time, but its small parts are overcome one by one.

The expressions obtained for displacements, speeds and accelerations of the locomotive and wagons have harmonic components. To exclude longitudinal vibrations of the train, after reaching the maximum tension of the coupling, it is necessary to mechanically block the possibility of its harmonic compression with subsequent sampling of elastic deformation, for example, using damping devices.

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Mathematical Modelling of Tank Wagon Vibrations Considering Partially Filling of the Tank with Liquid Cargo



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ABSTRACT

Mathematical modelling of processes of motion makes it possible to assess the dynamic characteristics of a wagon at the stage of its design. However, it is necessary to consider the type of cargo transported, the movement of which affects the values of these features.

The paper considers a mathematical model of an eight-axle railway tank wagon developed using the Lagrange's equation of the second kind. The considered mathematical model suggests an approach based on the consideration of the influence of the energy of a liquid cargo in a steady state of motion. This influence was considered by evaluating the kinetic and potential energies of vibrations of the transported liquid cargo.

Differential equations of vibration compiled for the model under consideration represent the liquid cargo as a solid. The approach

for considering the effect of liquid cargo during vibrations of a tank wagon assumes that the total volume of the displaced liquid approximately corresponds to the volume of the layer of the fluid determined by displacement of bouncing, or in the case of galloping, with an angular displacement of one end section of the tank wagon, the second section rises by the same value, in other words, we observe the system of communicating vessels. Based on these assumptions, energy additions are obtained that consider movement of a liquid cargo under steady-state modes of motion.

According to the proposed approach, preliminary calculations were performed, and the results obtained were assessed. The results obtained showed satisfactory convergence with the calculations carried out using other approaches to modelling of the processes of movement of railway tank wagons.

Keywords: transport, tank wagon, dynamic properties, liquid cargo vibrations, eight-axle tank wagon, loading, barrel.

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INTRODUCTION

While modelling the processes of rolling stock movement along a railway track, researchers are interested in indicators of dynamic properties (dynamic coefficients, dynamic forces of various directions, acceleration, movement of structural elements) [1; 2], the values of which are ultimately determined by the values of kinetic and potential energies and by their ratios during operation of the system.

Given this circumstance, we can say that if studying the processes of movement of a wagon with a liquid cargo with a mathematical model, it becomes possible to reflect with relative success the energy indicators of moving masses of liquid, then as a result, it will be possible to create an optimised simplified model reflecting the effect of a liquid cargo on the indicators of smoothness at steady state of motion [3]. The solution to this problem would allow to obtain assessment of the ride performance and loading of the cargo tank for any transport units associated with transportation of liquid cargo. The *objective* of the work is to solve this problem by creating an optimised simplified model reflecting the effect of a liquid cargo on the indicators of smoothness at steady state of motion regarding railway tank wagons.

MATERIALS AND METHODS

It should be noted that, as a rule, when developing mathematical models of oscillations of tank wagons, the transported cargo is considered as a solid body [4; 5]. However, as noted above, the transported cargo affects the indicators of the dynamic properties of the considered models of tank wagons. Thus, it is necessary to use computational approaches that

consider the energy contribution of the liquid cargo to the overall system.

The works [6–9] estimate the influence of a liquid cargo during transient modes of operation, where the description of flow of fluid is carried out by equations of continuum mechanics. Consideration of the influence of liquid cargo in modern software systems is carried out by solving the problems of hydrodynamics [10; 11] or using pendulum analogy [12–14].

In the proposed work, the technique is based on the assumptions that the tank shell is absolutely rigid, and the structure is symmetrical with respect to the longitudinal and transverse planes. The tank has a circular cylindrical shape. The origin of coordinates coincides with the centre of the middle cross section. The longitudinal X axis is directed along the cylinder axis, the Y transverse axis coincides with the horizontal diameter of the middle cross section, and the vertical Z is directed along the vertical diameter of the middle cross section.

The generated models are fundamentally based on the law of conservation of energy, i.e., transformation of kinetic energy, associated with the speed of the wave, into potential energy, specified by the height of the wave.

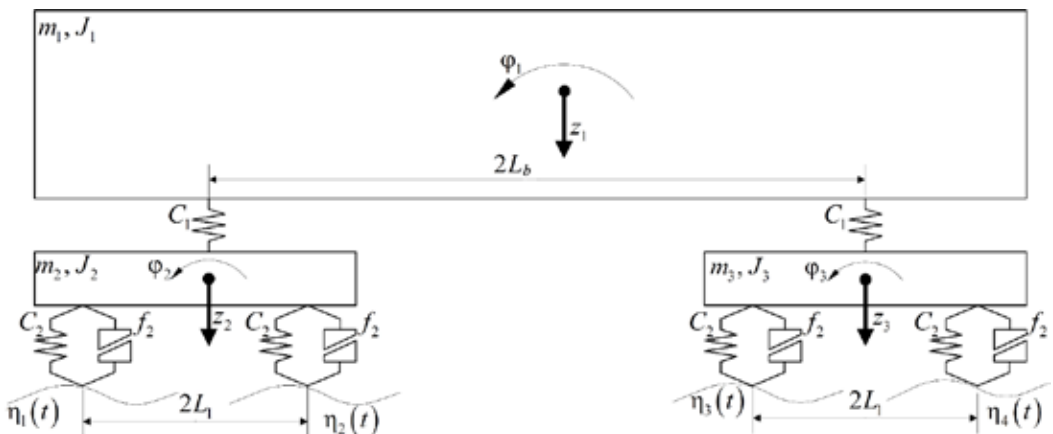
The development of mathematical models is carried out using the Lagrange's equation of the second kind [15], which for the problem under consideration will get the form:

$$\frac{d}{dt} \frac{\partial T_{\Sigma}}{\partial \dot{q}_i} + \frac{\partial P_{\Sigma}}{\partial q_i} = 0, \quad (1)$$

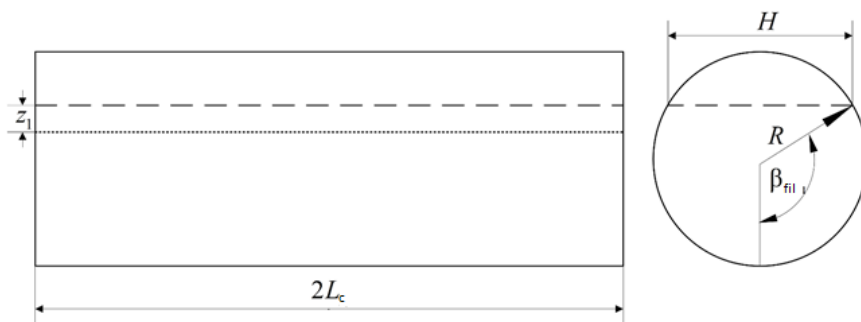
where q_i is generalised coordinate,

T_{Σ} – kinetic energy of the system,

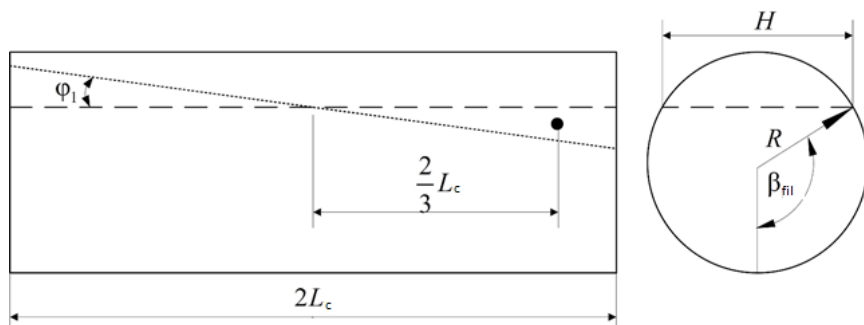
P_{Σ} – potential energy of the system.



Pic. 1. Design scheme for determining oscillations of a tank wagon (developed by the authors).



Pic. 2. Design scheme for determining the energy additions due to vibrations of the liquid load during oscillation of bouncing (developed by the authors).



Pic. 3. Design scheme for determining the energy additions due to vibrations of the liquid cargo during galloping oscillations (developed by the authors).

RESULTS

System of Differential Equations

As a design model, we will consider a conditional model of an eight-axle railway tank wagon.

In this work, we use the following designations:

m_1 – gross mass of the tank;
 J_1 – moment of inertia of the tank;
 $m_{2,3}$ – mass of the connection beam;
 $J_{2,3}$ – moment of inertia of the connection beam;

C_1 – vertical stiffness of the connection beam;

C_2 – vertical stiffness of the spring suspension

set;

f_2 – coefficient of dry friction of the friction vibration damper;

$2L_b$ – tank base;

$2L_c$ – length of the cylindrical part of the tank;

$2L_l$ – bogie base;

$\eta_{1,2,3,4(t)}$ – function of unevenness of the track under the corresponding bogie;

z_1 – vertical displacement of the centre of mass of the tank;

ϕ_1 – angle of rotation of the tank relative to the transverse axis Y ;

$z_{2,3}$ – vertical displacement of the centre of mass of the connection beam;

ϕ_2 – angle of rotation of the connection beam relative to the transverse axis Y ;

ρ_l – density of the mass of the transported liquid cargo;

g – acceleration of gravity;

β_{fil} – angle of filling with the liquid cargo;

R – radius of the tank;

H – linear area of the free surface of the liquid in the transverse direction, defined as $H = 2\sin\beta_{fil}$.

For the scheme shown in Pic. 1, the system of differential equations will look like this:

$$\begin{cases} m_1 \ddot{z}_1 + C_1 (2z_1 - z_2 - z_3) = 0 \\ J_1 \ddot{\phi}_1 + C_1 L_b (2\phi_1 L_b - z_2 + z_3) = 0 \\ m_2 \ddot{z}_2 + C_1 (-z_1 - \phi_1 L_b + z_3) + \\ + C_2 (1 + f_{tr} \text{sign}(\Delta_3, \dot{\Delta}_3)) (2z_2 - \eta_1(t) - \eta_2(t)) = 0 \\ J_2 \ddot{\phi}_2 + C_2 (1 + f_{tr} \text{sign}(\Delta_4, \dot{\Delta}_4)) (2\phi_2 L_1 - \eta_1(t) - \eta_2(t)) = 0 \\ m_3 \ddot{z}_3 + C_1 (-z_1 + \phi_1 L_b + z_2) + \\ + C_2 (1 + f_{tr} \text{sign}(\Delta_5, \dot{\Delta}_5)) (2z_3 - \eta_3(t) - \eta_4(t)) = 0 \\ J_2 \ddot{\phi}_3 + C_2 (1 + f_{tr} \text{sign}(\Delta_6, \dot{\Delta}_6)) (2\phi_3 L_1 - \eta_3(t) - \eta_4(t)) = 0, \end{cases} \quad (2)$$



where $\Delta_{3,5} = 2z_{2,3} - \eta_{1,3}(t) - \eta_{2,3}(t)$,

$$\dot{\Delta}_{3,5} = 2\dot{z}_{2,3} - \dot{\eta}_{1,3}(t) - \dot{\eta}_{2,3}(t),$$

$$\Delta_{4,6} = 2\phi_{2,3}L_1 - \eta_{1,3}(t) - \eta_{2,4}(t),$$

$$\dot{\Delta}_{4,6} = 2\dot{\phi}_{2,3}L_1 - \dot{\eta}_{1,3}(t) - \dot{\eta}_{2,4}(t),$$

$$\text{sign}(x) = \begin{cases} 1 & \text{when } x \geq 0 \\ -1 & \text{when } x < 0 \end{cases} - \text{discontinuous function}$$

denoting sign change.

In the given system of differential equations (2), the transported liquid cargo is perceived as a solid. Naturally, the values of the kinetic and potential energies of the wave motion of the fluid surface depend on the height of the waves arising on the free surface of the liquid cargo. When simulating oscillations of the free surface of a liquid in problems, it is possible to introduce the assumption that the total volume of the moving liquid approximately corresponds to the volume of the layer of fluid determined by the bouncing displacement, i.e., by the value z_l (Pic. 2). This assumption can be substantiated by the fact that the volume of the wave lifted above the layer in state of rest is equal to the volume of the wave under this layer. Thus, the presented model additionally introduces the contributions of the kinetic T_l and potential P_l energies of the liquid cargo moving due to the vibrations of the tank.

Let's determine the volume and mass of the liquid cargo captured because of bouncing oscillations. We will assume that this level corresponds to the level of displacement of the tank z_l . Then the volume of this mass will be equal to:

$$V_l = 2R \sin \beta_{\text{in}} 2L_c z_l.$$

Then the kinetic T_{vert} and potential P_{vert} energies will be determined as:

$$T_{\text{vert}} = \frac{\rho_l 2R \sin \beta_{\text{in}} 2L_c z_l}{2} \dot{z}_l^2, \quad (3)$$

$$P_{\text{vert}} = \rho_l 2R \sin \beta_{\text{in}} 2L_c z_l g z_l.$$

Substituting expressions (3) into equation (1), we obtain expressions for substitution into the initial system of differential equations (2):

$$\frac{d}{dt} \frac{\partial^2 T_{\text{vert}}}{\partial \dot{z}_l^2} = 4\rho_l R \sin \beta_{\text{in}} L_c (\dot{z}_l^2 + z_l \ddot{z}_l); \quad (4)$$

$$\frac{\partial P_{\text{vert}}}{\partial z_l} = 8\rho_l R \sin \beta_{\text{in}} g L_c z_l.$$

Let's consider angular oscillations. With angular vibrations, we observe the model of communicating vessels, i.e., with an angular

displacement of one end section of the tank (for example, downward), the second section rises by the same value. And at the same time, there is obviously a displacement of the volume of the liquid. With angular vibrations, the volume of the liquid situated to the left of the middle section should be equal to the volume of the liquid situated to the right.

Let's find the volume of liquid V_{lang} and speed of movement of the centre of mass v_{ct} , changing due to angular oscillations of the tank

$$V_{\text{lang}} = L_c^2 R \sin \beta_{\text{in}} \phi_1; \quad v_{\text{ct}} = \frac{2}{3} L_c \dot{\phi}_1. \quad (5)$$

Taking this into account, the kinetic T_{lang} and potential P_{lang} energies of the flowing liquid will be determined as:

$$T_{\text{lang}} = \frac{4}{9} \rho_l L_c^4 R \sin \beta_{\text{in}} \dot{\phi}_1^2; \quad (6)$$

$$P_{\text{lang}} = \frac{4}{3} L_c^3 \rho_l R \sin \beta_{\text{in}} g \phi_1^2.$$

Substituting expressions (6) into equation (1), we obtain expressions for substitution into the initial system of differential equations (2):

$$\frac{d}{dt} \frac{\partial^2 T_l}{\partial \dot{\phi}_1^2} = \frac{8}{9} \rho_l L_c^4 R \sin \beta_{\text{in}} (\dot{\phi}_1^2 + \phi_1 \ddot{\phi}_1); \quad (7)$$

$$\frac{\partial P_l}{\partial \phi_1} = \frac{8}{3} L_c^3 \rho_l R \sin \beta_{\text{in}} g \phi_1.$$

Besides vertical displacement of the centre of mass of the flowing liquid, it is necessary to consider its horizontal displacement. Using the reasoning described above, we obtain the values of the kinetic T_{hor} and potential P_{hor} energies of the horizontal displacement of the centre of the mass of the flowing liquid cargo:

$$T_{\text{hor}} = 2 \frac{\rho_l L_c^2 R \sin \beta_{\text{in}} \phi_1}{2} \left(\frac{2}{3} R \cos \beta_{\text{in}} \dot{\phi}_1 \right)^2; \quad (8)$$

$$P_{\text{hor}} = 2\rho_l L_c^2 R \sin \beta_{\text{in}} \phi_1 g \frac{2}{3} R \cos \beta_{\text{in}} \phi_1.$$

Substituting expressions (8) into equation (1), we obtain expressions for inclusion in the initial system of differential equations (2):

$$\frac{d}{dt} \frac{\partial^2 T_l}{\partial \dot{\phi}_1^2} = \frac{8}{9} \rho_l L_c^2 R^3 \sin \beta_{\text{in}} \cos^2 \beta_{\text{in}} (\dot{\phi}_1^2 + \phi_1 \ddot{\phi}_1); \quad (9)$$

$$\frac{\partial P_l}{\partial \phi_1} = \frac{8}{3} L_c^2 \rho_l R^2 \sin \beta_{\text{in}} \cos \beta_{\text{in}} g \phi_1.$$

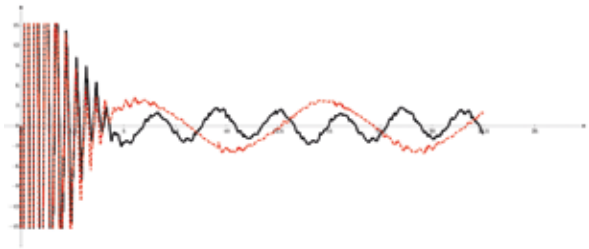
Thus, substituting expressions (4), (7) and (9) into the expression, we obtain a general system of differential equations for the oscillations of the shell of the tank considering the dynamics of the liquid cargo (10).

Table 1

Coefficients of vertical dynamics (authors' calculations)

Speed, km/h	Rate of loading of the tank with the liquid cargo							
	95 %		80 %		70 %		50 %	
	k_{d1}	k_{d2}	k_{d1}	k_{d2}	k_{d1}	k_{d2}	k_{d1}	k_{d2}
20	0,003	0,004	0,006	0,004	0,012	0,004	0,022	0,004
40	0,014	0,017	0,01	0,017	0,015	0,017	0,017	0,016
60	0,041	0,045	0,033	0,041	0,033	0,046	0,029	0,042
80	0,124	0,132	0,1	0,124	0,087	0,126	0,079	0,131
100	0,26	0,287	0,217	0,279	0,22	0,27	0,197	0,264

k_{d1} – coefficient of vertical dynamics considering oscillations of the liquid cargo.
 k_{d2} – coefficient of vertical dynamics without considering oscillations of the liquid cargo.



Pic. 4. An example of a graph of changes in the forces acting on the seats of the tank: black lines denote changes in forces without considering movement of the liquid cargo, red lines (italics) show changes in the forces on the seats of the tank considering movement of the liquid cargo (developed by the authors).

$$\begin{aligned}
 & m_1 \ddot{z}_1 + C_1 (2z_1 - z_2 - z_3) + 4\rho_1 R \sin \beta_{\text{in}} L_c (\dot{z}_1^2 + z_1 \ddot{z}_1) + \\
 & + 8\rho_1 R \sin \beta_{\text{in}} g L_c z_1 = 0 \\
 & J_1 \ddot{\phi}_1 + C_1 L_b (2\phi_1 L_b - z_2 + z_3) + \\
 & + \frac{8}{9} \rho_1 L_c^4 R \sin \beta_{\text{in}} (\dot{\phi}_1^2 + \phi_1 \ddot{\phi}_1) + \\
 & + \frac{8}{3} L_c^3 \rho_1 R \sin \beta_{\text{in}} g \phi_1^2 + \\
 & + \frac{8}{9} \rho_1 L_c^2 R^3 \sin \beta_{\text{in}} \cos^2 \beta_{\text{in}} (\dot{\phi}_1^2 + \phi_1 \ddot{\phi}_1) + \\
 & + \frac{8}{3} L_c^2 \rho_1 R^2 \sin \beta_{\text{in}} \cos \beta_{\text{in}} g \phi_1 = 0 \\
 & m_2 \ddot{z}_2 + C_1 (-z_1 - \phi_1 L_b + z_2) + \\
 & + C_2 (1 + f_{\text{tr}} \text{sign}(\Delta_3, \dot{\Delta}_3)) (2z_2 - \eta_1(t) - \eta_2(t)) = 0 \\
 & J_2 \ddot{\phi}_2 + C_2 (1 + f_{\text{tr}} \text{sign}(\Delta_4, \dot{\Delta}_4)) \cdot \\
 & \cdot (2\phi_2 L_1 - \eta_1(t) - \eta_2(t)) = 0 \\
 & m_3 \ddot{z}_3 + C_1 (-z_1 + \phi_1 L_b + z_3) + \\
 & + C_2 (1 + f_{\text{tr}} \text{sign}(\Delta_5, \dot{\Delta}_5)) (2z_3 - \eta_3(t) - \eta_4(t)) = 0 \\
 & J_3 \ddot{\phi}_3 + C_2 (1 + f_{\text{tr}} \text{sign}(\Delta_6, \dot{\Delta}_6)) \cdot \\
 & \cdot (2\phi_3 L_1 - \eta_3(t) - \eta_4(t)) = 0.
 \end{aligned}
 \tag{10}$$

SOLUTION

The system of differential equations (10) was solved by the numerical Runge–Kutta method in the MathCad software environment [16]. The roughness approximating function proposed in the literature [4] served to denote the track roughness:

$$\eta(t) = b_1 \sin\left(\frac{\pi v}{L_t} t\right) + b_2 \sin\left(\frac{3\pi v}{L_t} t\right).$$

Numerical integration of the system of differential equations allowed to obtain the values of the forces on the tank seats.

Pic. 4 shows an example of a graph constructed for the case of a car moving at a speed of 20 km/h with a tank filled at 80 % of its capacity. The graph shows that under steady-state modes of motion, the amplitude of forces, considering movement of the liquid cargo, has increased by about 60 %, and the period of oscillations has also increased threefold.

DISCUSSION

Some results of the numerical implementation of the proposed approach are shown in Pic. 4 and Table 1. The results obtained are in good agreement with the results obtained by the method of mathematical modelling using the Universal Mechanism software package [12; 13]. It should be noted that at low speeds of movement and, consequently, with low frequencies of disturbing influence, the impact of the liquid cargo is maximal. This is quite well traced from the results presented in Table 1. Particularly, at the speed of 20 km/h and with the tank filled at 50 % of its capacity, a significant impact of liquid cargo is noticeable.



Verification of the obtained solutions regarding various initial data showed satisfactory convergence of the results with the results obtained using other approaches.

CONCLUSIONS

The proposed approach has allowed to develop the system of differential equations. The system of equations is non-linear. Due to the complexity of obtaining an analytical solution of this system, a numerical method was applied to solve the Runge–Kutta differential equations of the 4th order.

This approach makes it possible to assess the impact of liquid cargo transported in railway tank wagons, e.g., to determine the effect of the level of tank loading with a liquid cargo on the dynamic properties for different parameters of the tank and the elastic elements of the entire wagon.

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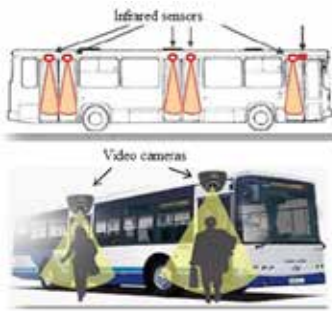
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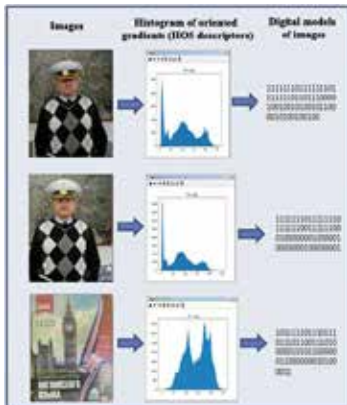
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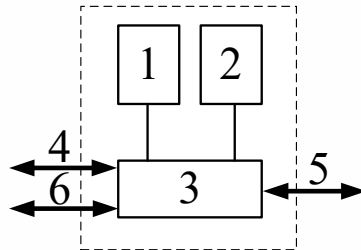
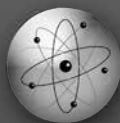


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Computer vision and neural networks serve to automate development of travel matrices.

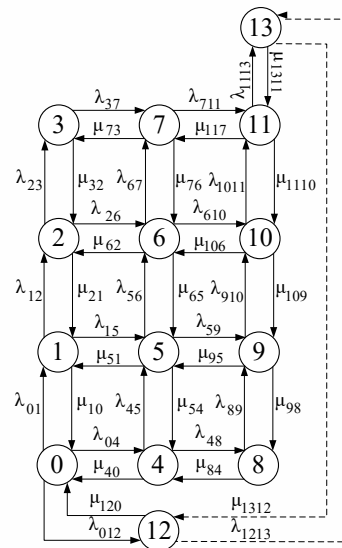


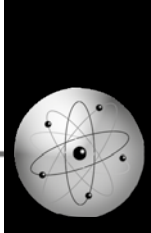
SCIENCE AND ENGINEERING



TRANSPORT RADIO COMMUNICATIONS 183

Calculation of performance and conditions of base stations in digital networks.





Automation of Collection of Primary Data for Development of a Passenger Origin-Destination Trip Correspondence Matrix Based on Computer Vision and Neural Network Technologies



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ABSTRACT

The origin-destination trip matrix is a fundamental characteristic of a transport network, and development of a reliable correspondence matrix is the most important task in organising passenger traffic. It is the basis on which the public transport route network of a city (region) is built and optimised.

Currently, collection of initial information for construction of a travel correspondence matrix is carried out through field surveys comprising questionnaire surveys of the population; accounting for movement of passengers according to the coupons issued to them; checkers, tellers manually counting passengers in vehicle compartments; simple surveys of passengers. Besides, mathematical modelling is used based on statistical data on the number of residents in various districts of the city, employees in enterprises and students in educational institutions, as well as on available data on the characteristics of passenger traffic along certain routes. All these surveys are very expensive and are carried out once over few years; they give a large error, which is why decisions made on the basis of these data are far from being optimal.

There are a lot of solutions in the software and hardware market that provide automated collection of data on passenger flows. They are based on the use of infrared sensors or of video recording. However, none of these systems provide information about the points of entry and exit of each passenger.

The objective of this study was to develop methods for automating the collection of reliable information about passenger trips, that will be the base for building up-to-date and reliable passenger trip correspondence matrices. This task can be solved by constant monitoring of passengers' trips with fixing places of entry and exit of each passenger.

The study describes the possibility of creating software based on computer vision and artificial intelligence which will provide automation of collection of primary information about travel of each passenger from the place of boarding into the vehicle to exit from it, that is, automation of data generation to build a passenger trip correspondence matrix.

Keywords: passenger transport, passenger flows, trip correspondence matrix, artificial intelligence, neural networks, machine learning, computer vision.

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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

Trip origin-destination correspondence matrix is a basic table describing how people travel around a city. It shows how many residents move from one district of the city to another and is the base for building the route network, identifying the required number of vehicles, developing the traffic timetable [1; 2].

In modern cities and megalopolises, a lot of residential and industrial infrastructure is being built, enterprises are being relocated, residential and employment locations are changing, resulting in a dynamic change in the volume and directions of trips. Under these conditions, the construction of true trip correspondence matrices requires absolutely reliable information about real passenger trips.

There are a lot of solutions in the software and hardware market that provide automated collection of passenger traffic data. In most cases, they are based on infrared sensors [3] and video recording by cameras located in the entry and exit door openings of vehicles [4]. However, none of the existing automation systems for collecting data on passenger traffic provides information about the points of entry and exit of each passenger, while these data are basic for developing passenger origin-destination trip correspondence matrices. Due to the lack of such data, the trip correspondence matrices are still developed based on sample surveys, population surveys, statistical data on the number of residents in certain districts of the city and the number of employees at enterprises. These data do not reflect the real picture of daily migration of the urban population. Accordingly, decisions made based on this information are far from being optimal. All existing methods of automating

the accounting of passenger flows do not allow obtaining data for constructing a trip origin-destination correspondence matrix.

Based on the foregoing, the *objective* of this study was to develop methods for automating data acquisition to develop a complete and reliable correspondence matrix of population trips with public land passenger transport.

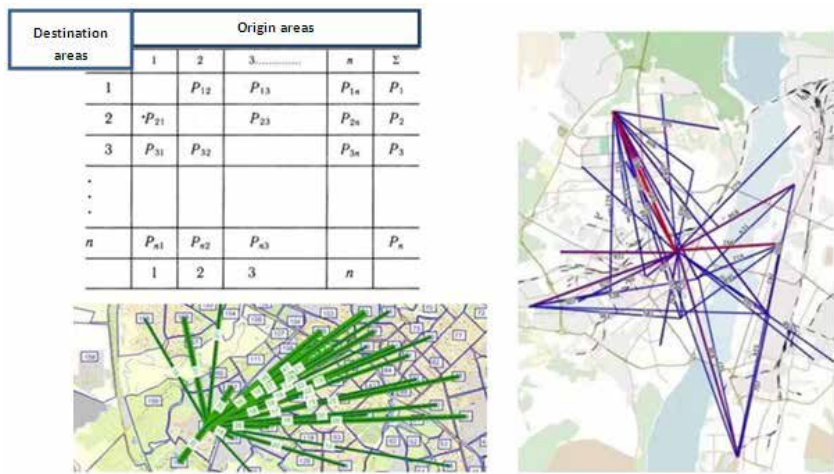
This task can be solved by constant monitoring of passengers' trips with fixing the place of entry and exit of each passenger. To fix the place of entry and exit of each passenger, it is proposed to use the *methods* of computer vision and artificial intelligence.

RESULTS

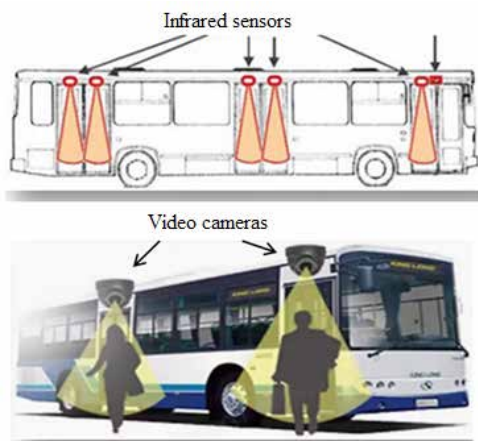
Shortages of Existing Technology to Solve Pertinent Problems

When solving the problem of optimising the route network of public transport, two concepts should be clearly distinguished: passenger traffic and the passenger trip correspondence matrix. Passenger flow largely characterises the general statistics of passenger movement (the number of passengers at different times of the day, days of the week, during different seasons, etc.) with reference to a stop, route, transport company, city, etc. The passenger trip origin-destination correspondence matrix (Pic. 1) is a quantitative characteristic that determines the volume of passenger flow between each pair of «points» [1; 2]. Here «points» refer either to specific stops of public transport, or conditional zones that were obtained by combining stopping points to some areas (for example, city districts).

The trip origin-destination correspondence matrix is a fundamental characteristic of the



Pic. 1. Trip origin-destination correspondence matrix [1; 2].



Pic. 2. Automated passenger traffic accounting systems [4].

transport network, and development of a true trip origin-destination correspondence matrix is the most important task in organising passenger transportation. The trip origin-destination correspondence matrix is the basis on which the public transport route network is built and optimised. In turn, a well-built route network allows you to determine the required number of vehicles on routes, optimise the timetable, reduce material costs for organising transportation, and, ultimately, meet the people's need for transport services with minimal costs.

Automation of passenger traffic accounting is currently quite deeply developed and implemented in the form of many different technical solutions: contact sensors on the steps of a vehicle, infrared sensors [3] or video cameras [4] in the area of the front door (Pic. 2).

However, statistical data on passenger traffic on routes does not make it possible to construct a passenger trip origin-destination correspondence matrix. These data provide just a summary of incoming and outgoing passengers.

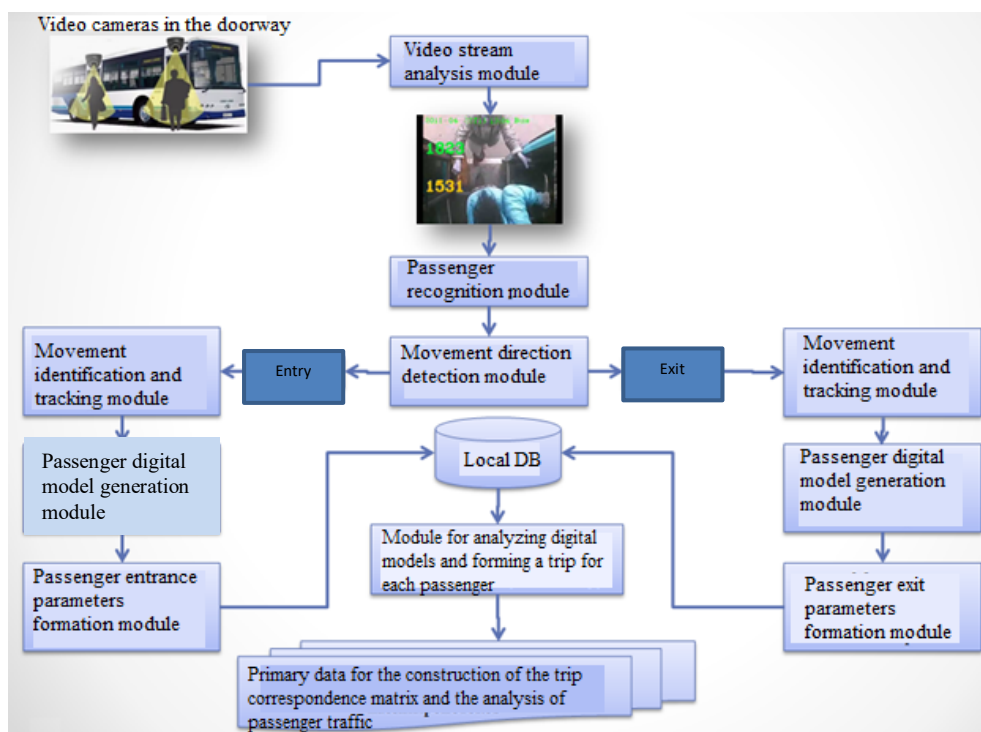
Currently, automation of data collection for development of a passenger trip origin-destination correspondence matrix has not actually been implemented. This problem is solved with a fairly large error and with great expense on the basis of specially organised field surveys. It should be noted that full-scale survey methods are often associated with significant organisational, financial, and legal problems, so their application sometimes becomes impossible, especially in large cities where passenger flows are large. For some modes of transport (rail, air, water), the problem of developing a trip correspondence

matrix can be solved based on the analysis of purchased tickets that indicate the points of departure and arrival.

The classical method of obtaining data for constructing a trip origin-destination correspondence matrix is associated with field surveys (special travel coupons, questionnaires of the population, polling of passengers by pollsters in vehicles, etc.), as well as with mathematical modelling methods [5]. The disadvantages of field surveys are explained through significant laboriousness of collecting and processing data, low reliability of data due to the human factor, high cost of the survey, lack of repeatability statistics (it is impossible to distinguish weather conditions, season, and other features of the current day). The high cost and labour intensity of the survey are the reasons why such surveys are carried out every 15–20 years only, which does not make it possible to promptly update and optimise management decisions.

There are approaches to automating development of an approximate trip origin-destination correspondence matrix in the metro using mobile phones of passengers [6]. Cellular operators can track the entries and exits of passengers from the metro, determining the moments when their mobile subscriber switches to a base station located in the metro (enters the metro) or to a base station in the city (exits the metro). Such anonymous data can serve as the basis for development of a trip correspondence matrix for each pair of metro stations. However, this approach is unacceptable for land passenger transport. Difficulties in solving this problem are also associated with the large dimension of primary information, and with the lack of a single methodology for obtaining a trip correspondence matrix for a given city, which should include not only job and education-related trips, but also travelling with cultural and household purposes, as well as travelling of retirees.

The city's working population and students travel daily by public transport to job and study locations. Such trips account for the largest share as they are regular. However, there are trips of unemployed retirees, as well as other travelling of residents which is of a cultural and household nature. These trips, one way or another, affect the congestion of city routes. The general trip origin-destination correspondence matrix, which includes labour, cultural and household trips, will fully describe the nature of all trips in the city.



Pic. 3. The basic structure of a system for automating the collection of primary data on passenger trips with public transport based on neural network technologies (compiled by the author).

Such detailing seems to be especially important for the purposes of optimising the route network.

Description of Suggested Technology

Is it possible to automate the process of recording trips with a clear fixation of the entry and exit point for each passenger? It is almost impossible to solve such a problem based on infrared sensors, since they do not allow identifying an object. But it is quite possible based on video recording. In recent years, with development of convolutional neural networks (CNN, R-CNN, Mask R-CNN), there has been an explosive development of neural network technologies and computer vision systems. Accordingly, it became possible to develop fundamentally new automated systems for accounting and analysis of passenger flows based on these technologies with the possibility of forming a reliable and complete passenger trip origin-destination correspondence matrix for urban land passenger transport. The development of such a system, which is absent in the software and hardware market, is the novelty of this work.

The basic structure of the system for automating the collection of primary data on passenger trips in public transport, which is based on neural

network technologies and developed within the framework of this study, is shown in Pic. 3.

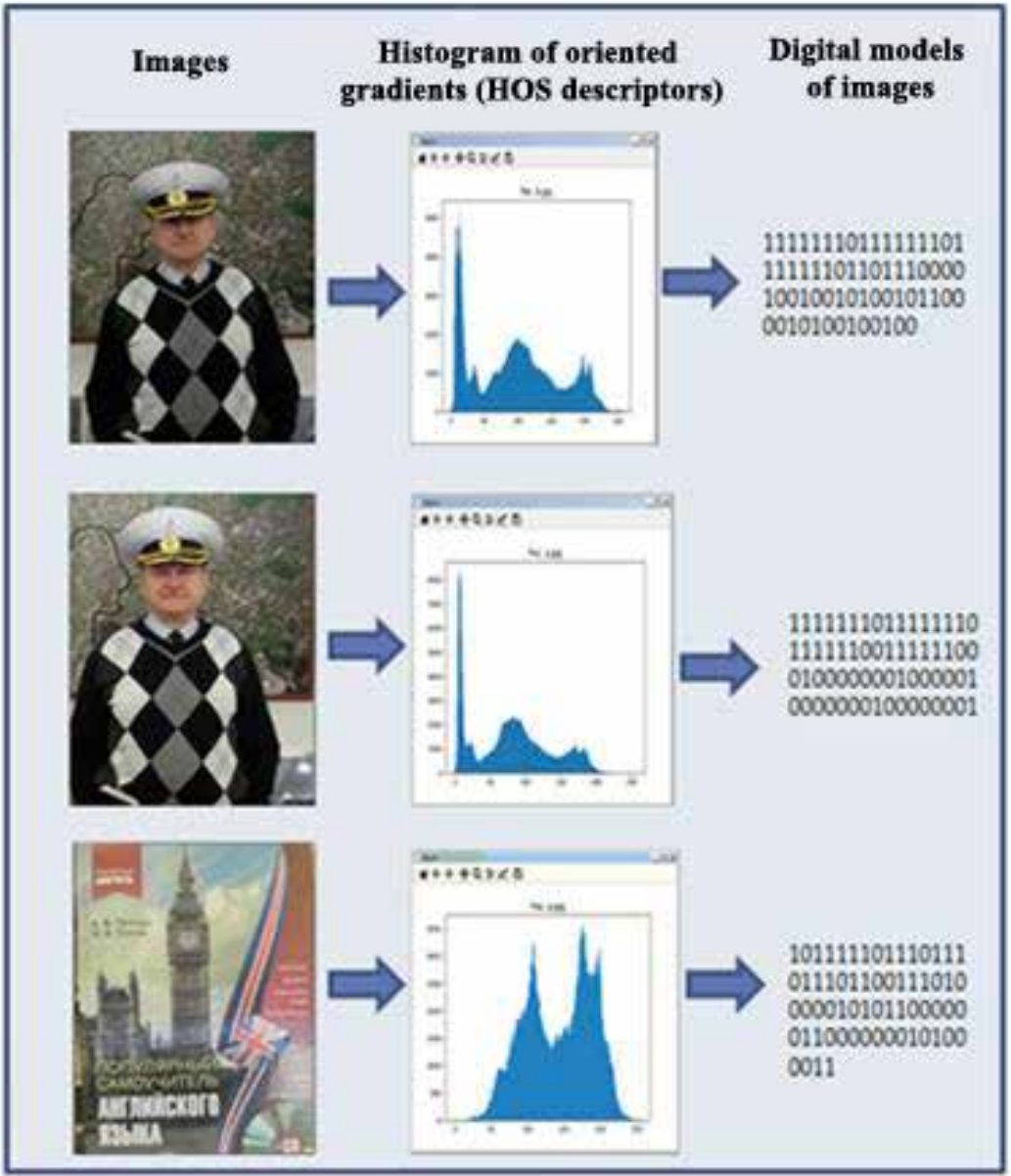
The software and hardware complex shown in Pic. 3, consists of the following elements:

- Video camera located in the upper part of the vehicle entrance door opening.
- Onboard minicomputer.

This complex works as follows. The video stream in real time comes from the video camera to the onboard computer and is processed by specialised software. This software solves the following tasks:

- Recognises passengers entering and exiting the vehicle (passenger detector – top view).
- Converts the image of each entering passenger into a unique digital model and saves it.
- Fixes the entry parameters of each passenger (date, time, entry stop).
- Converts the image of each exiting passenger into a unique digital model and saves it.
- Fixes the exit parameters of each passenger (date, time, exit stop).
- Compares the digital model of the image of exiting passengers with digital models of the passengers who have entered the vehicle and generates a unique pair of entry-exit values for each passenger.





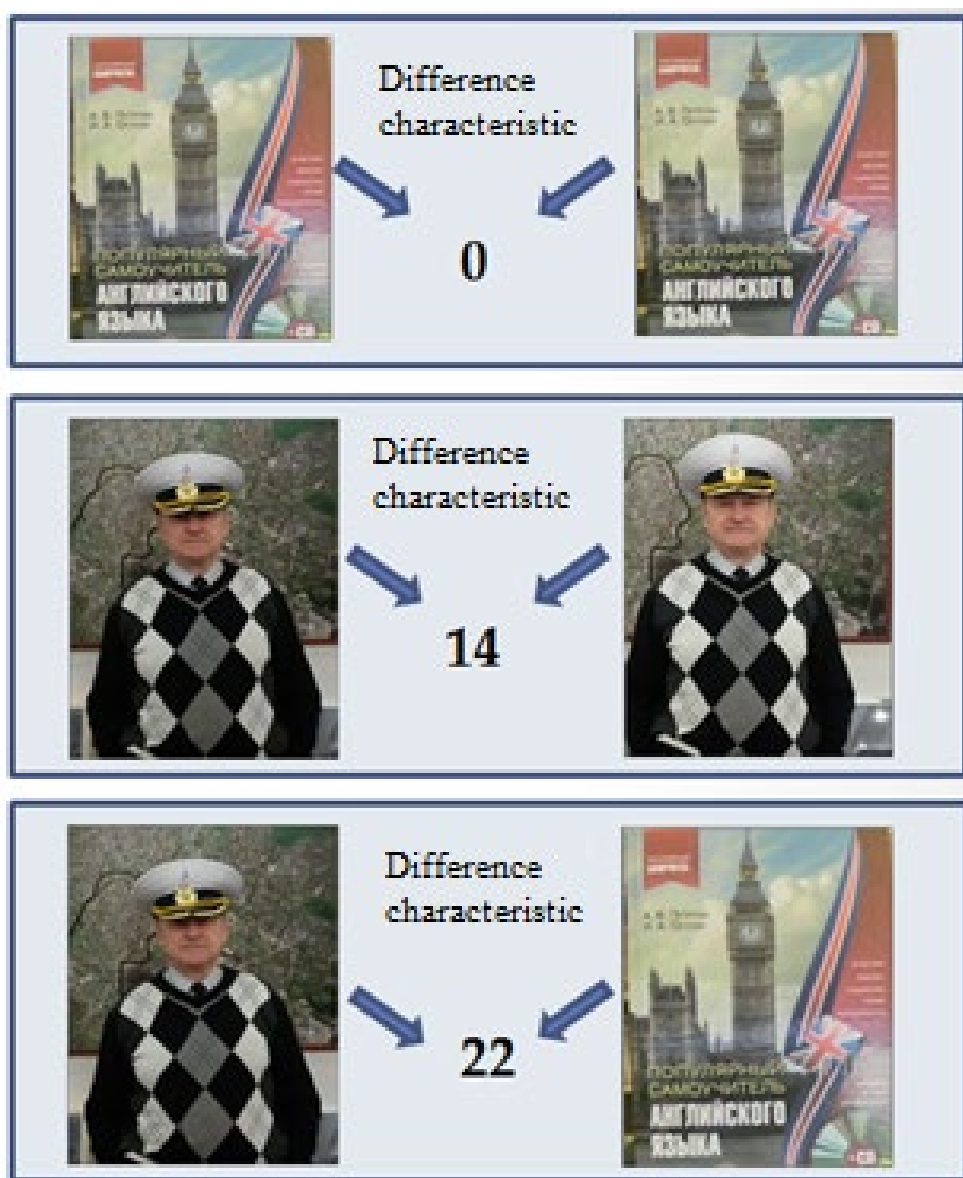
Pic. 4. Digital models of images based on the histogram of oriented gradients (developed by the author).

- Counts the number of passengers: who entered the cabin, exited the cabin, who are in the cabin of the vehicle at each stopping point.

The parameters of the trip of each passenger obtained in this way are transferred to the server platform upon completion of operation of the vehicle on the route, where, based on the server software, the passenger trip origin-destination correspondence matrix and statistics on passenger traffic will be formed.

At first glance, it is possible, without using digital models, to simply compare the snapshot of the passenger at the entrance with the snapshot of the passenger at the exit. However, for such a

comparison, it is imperative to perform the image normalisation procedure. But even after normalising the images, you may not get the desired result, since the passenger can enter directly and exit sideways, at some angle or even backward. Multiple cyclic image rotation and comparison will be required, which will require additional processing time and may not lead to the expected result. In addition, the complete image takes up a fairly large amount of RAM, which will also require large time resources for processing. It is more correct in this case to use a digital identification model of the image. Such models are based on selection of a set of key



Pic. 5. Examples of image comparison based on their digital models (developed by the author).

points on images. The Delaunay triangulation or Voronoi diagrams, which are used in face matching and morphing systems, can be used as a basis for such models. Histograms of oriented gradients (HOG singular point descriptors) can be used, which are applied in computer vision for object recognition [7].

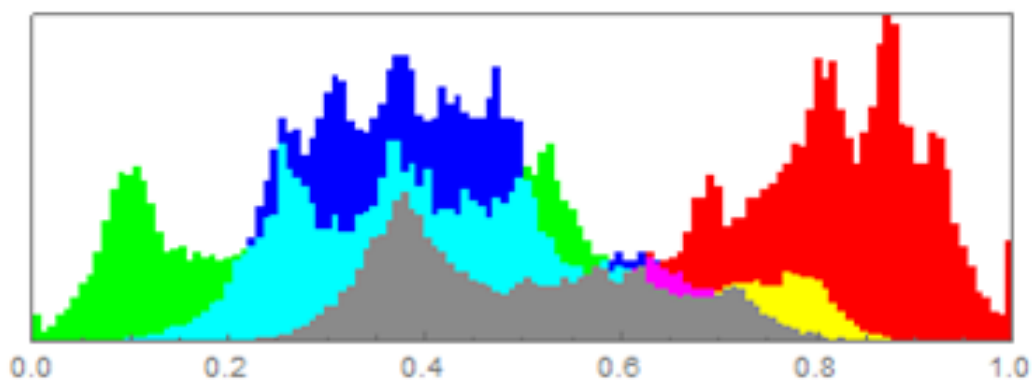
Currently, the implementation of technology and software modules to automate collection of data on passenger trips based on neural network technologies and computer vision with participation of the author has started. The Pic. 4 shows examples of generation of digital image models, which are built on the basis of a

histogram of oriented gradients. Here the images were reduced to one colour which is grayscale.

Naturally, the digital model takes up much less space in the computer's memory and, in addition, it makes it possible to compare images and evaluate their similarity. Pic. 5 shows examples of image comparison based on their digital models.

As can be seen from Pic. 5, for absolutely identical images, the difference coefficient calculated based on the digital model is zero. With the growth of the difference between the fragments of images, the characteristic of the



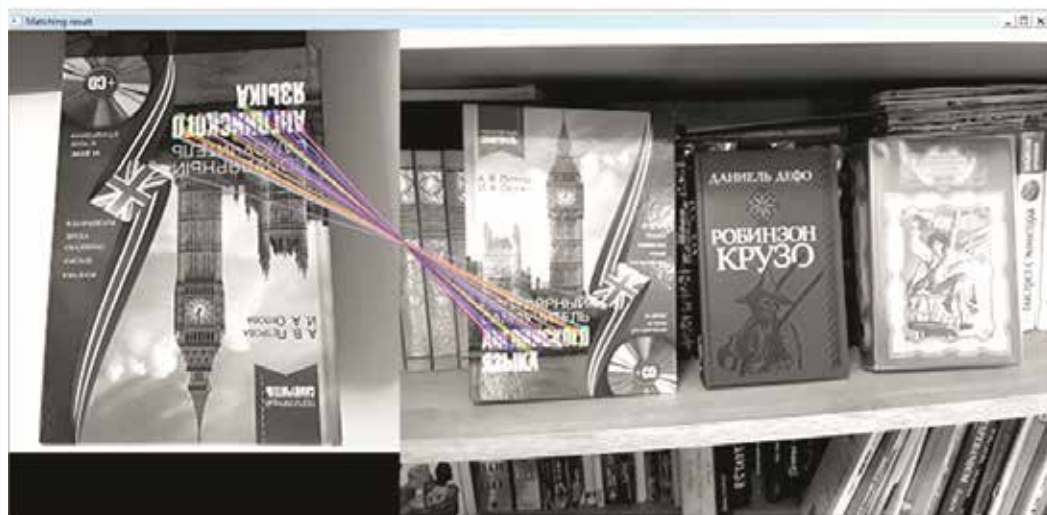


Pic. 6. An example of a histogram of image colours (developed by the author).

differences increases. So, in the second row the same person changed the position of the head, and this change was recorded in the histogram. However, the characteristic of difference (14) did not exceed the threshold value (19), and the objects depicted on them can be classified as identical. But in the third row, the characteristic of difference (22) exceeded the threshold value, which suggests that the images picture different objects (the threshold value is determined empirically). Using a digital model and a correctly selected threshold value, it is possible to assess similarity or differences of objects in the images, that is, for the problem under consideration, to find a correspondence between the passenger who entered and exited. With even greater accuracy, it is possible to

compare objects in images using a histogram of not a single colour, but a histogram of a group of colours (Pic. 6).

Homography methods are of particular interest for searching for similarity in images. When using them, the angles of rotation and tilt of compared images are not of fundamental importance [8]. This is especially important for solving the problem under consideration, since the position of the passenger moving in the area of the camera above the entrance door cannot be strictly fixed. Pic. 7 shows an example of visual comparison of images using the homography method. To ensure sufficient accuracy of passenger recognition at the entrance and exit, it will be necessary to use a combination of the above methods of forming and comparing digital models.



Pic. 7. Visual comparison of images by the method of homography (compiled by the author).

To fix the location of entry-exit of a passenger based on his image in the video stream, it is necessary to perform the following steps, particularly, to:

- Recognise the silhouette of a passenger when he enters the vehicle.
- Segment the silhouette, transform it into a digital model and fix the parameters of the entrance.
- Recognise the silhouette of a passenger when he exits the vehicle.
- Segment the silhouette, transform it into a digital model and fix the parameters of the entrance or exit.
- For the passenger who exited the vehicle, based on the comparison of digital models, find the parameters of the entrance, and form the trip (stop at the entrance – stop at the exit).

The location (stop) of the passenger's entrance and exit can be determined using the onboard satellite navigation system of the vehicle. Synchronisation of primary data on the places of entry and exit of passengers with stopping points can be carried out either at the vehicle level (by integrating the onboard software of two subsystems), or on the server side of the navigation data processing system (by comparing the time of entry and exit of passengers from the passenger travel accounting system with the exact time of vehicle's presence at stopping points obtained from the navigation system).

As a result of video processing, the software generates anonymised data on passenger trips with the following parameters:

- Stopping point, date, and time of boarding the vehicle.
- Stopping point, date, and time of exiting the vehicle.

This information is recorded in the logbook as a text file. Such a file, containing, for example, information about 1000 passenger trips, will occupy no more than 50 kB in computer memory. After the vehicle completes its operation on the route, this data array must be transferred to a stationary computer (or to a server platform), where a passenger trip origin-destination correspondence matrix will be formed using the data. In addition, using the same data array, it will be possible to obtain traditional reporting on passenger traffic.

The solution to this problem is based on the use of neural networks, machine learning and various methods of image processing. In this

regard, the following tools were used for software development:

- Programming language Python.
- Specialised libraries for building neural networks and machine learning (Keras [9], PyBrain, Scikit-learn, TensorFlow, PyTorch with torchvision, etc.).
- Libraries for image and matrices processing (OpenCV [10], ImageAI [11], NumPy).

To simplify creation of similar applications and reduce the program code, we have developed our own Postoperative Library for Image Transformation – PostoLIT.

To date, using this toolkit, some basic modules of the computer vision system have been implemented to solve the problem, in particular:

- R-CNN neural networks for object recognition.
- Image segmentation and clustering modules based on Haar cascades.
- Modules for recognition and segmentation of object instances based on Mask R-CNN networks.
- Modules for recognising key points of the image (based on technologies for finding facial landmarks and face elements).
- Modules for constructing digital models of images based on a histogram of oriented gradients.
- Modules for matching images based on homography and HOG detectors.

Who might be interested in systems of automated data collection on trips with fixing the place of entry and exit of each passenger? First, these are passenger motor (bus) transport enterprises. According to the analytical agency Avtostat, as of January 1, 2020, there are about 409,9 thousand buses in Russia¹, more than 8 thousand trams² and 4 thousand trolleybuses³. This sufficiently large fleet of vehicles can use this system. Such systems are of interest to city and regional authorities, which provide and organise transport services for the residents. Today in the Russian Federation there are 85 constituent entities and 1117 cities, of which 173 cities have a population of over 100 thousand inhabitants⁴. There are 43

¹ Russian bus fleet: key indicators at the beginning of 2020 [*Rossiiskiy park avtobusov: osnovnie pokazateli na nachalo 2020 goda*]. [Electronic resource]: <https://www.avtostat.ru/infographics/43090/>. Last accessed 25.02.2021.

² The state of the tram system in Russia [*Sostoyaniye tramvaynoy sistemy v Rossii*]. [Electronic resource]: <http://www.ipem.ru/news/publications/914.html>. Last accessed 25.02.2021.

³ Trolleybus cities in Russia [*Trolleibusnye goroda Rossii*]. [Electronic resource]: <http://trolleibcity.narod.ru/stat.htm>. Last accessed 25.02.2021.

⁴ Federal structure of Russia [*Federalnoye ustroystvo Rossii*]. [Electronic resource]: <https://mnogofactov.ru/goroda-i-strany/skolko-sub-ektov-v-rf-na-2019-god.html>. Last accessed 25.02.2021.



largest domestic suppliers of information systems for transport companies, which, among other software products, develop and implement systems for accounting for passenger traffic⁵. They will be able to use the developed software modules to integrate them into their existing passenger traffic accounting systems and automated fare collection systems, thereby expanding their functionality, as well as to create new products based on the proposed software and technological solutions.

Besides, the proposed technological approach and software may be in demand not only in the transport industry, but also in other sectors of production activity, where it is required to fix movement of objects with external individual characteristics, where it is necessary to estimate time of customer service, as well as to assess the effectiveness of service personnel, e.g., in systems for determining the time spent by customers in retail outlets, assessing the time of customer service in the municipal centres providing services to residents, in clinics, in banks and other organisations. All this favours the prospects for the development and the demand for computer vision systems.

CONCLUSIONS

Computer vision and artificial intelligence are, perhaps, the most demanded areas of information technology development.

Existing automation systems for collecting data on passenger trips do not allow fixing the place of entry and exit of each passenger; accordingly, it is not possible to build a trip origin-destination correspondence matrix using these data.

The level of achievements in the field of artificial intelligence and computer vision makes it possible to automate the collection of data on passengers' trips with public transport while fixing the place of entry and exit of each passenger. Considering the fact that currently there are no

such solutions in the software market, they have significant competitive advantages and a good prospect for implementation.

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⁵ The largest IT providers for transport companies 2019 [*Krupneishie postavshchiki IT dlya transportnykh kompanii 2019*]. [Electronic resource]: https://www.cnews.ru/reviews/it_v_transportnoj_otrasli_2020/review_table/bf149373aea1d048bd7ffb7edc98bda8b29f7245. Last accessed 25.02.2021.

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Performance of Base Stations in Railway Digital Radio Communication Networks



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ABSTRACT

Base station (BS) is a terminal device of a radio communication network, while railway radio communications play an important role in ensuring safety of passenger and cargo transportation.

A proposed method for calculating the performance of base stations in railway digital radio communication networks is intended to calculate for the BS the probabilities of being in certain state.

BS was decomposed and such functional elements as circuit groups and a radio frequency path were identified, as well as the central module ensuring the exchange of information with elements of this BS and with other BSs. A detailed study of each element has increased accuracy of the proposed method. Following the Markov model, BS is presented as a system in which all possible states are considered. Models for BS with two and three circuit groups have been constructed.

The parameters of each functional element of the model can be obtained through observation over a certain period. The solution of the system of equations for each of the models presented in the article will allow obtaining the values of the system being in a certain state. The obtained characteristics can be used to calculate the reliability of the entire radio communication network, and then to assess quality of service provided to the users of this network.

Conclusions are made about the possibilities of using the obtained models when designing new railway communication networks and when calculating quality indices of existing ones. The proposed models can be applied not only to railway radio communication networks but also to mobile communication networks of commercial operators.

Keywords: digital radio communication network, railway telecommunication systems, call quality, train traffic safety.

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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

Radio communication as a type of telecommunications has been widely used on railways. Initially, it was used only for exchange of voice information between mobile and fixed subscribers. Considering development of high-speed traffic, as well as rapid growth of telecommunications and information technologies, emergence of new generations of mobile communications, radio communications began to significantly increase the functionality. Now it is used for transmission of telemetric information, automatic control of rolling stock (auto-driving), video conferencing. The newest systems of interval regulation of trains' traffic (radio blocking) are being built over the radio channel, which are replacing the track circuits. Such positioning systems are described in [1].

Several works [2; 3] consider the issues of choosing the best standard and topology of the railway digital radio communication network. The work [4] should be considered an important contribution in the field of effective use of communication network elements, while the results of measurements of some characteristics are presented in ITU-R report [5]. The latest mobile technologies (for example, LTE and 5G) described in detail in [4; 6] are gaining popularity in some countries.

Digital train radio communication networks within the railway network of the Russian Federation are organised based on TETRA, GSM-R or DMR standards, while the probability of good communication at any place and time must be at least 95 %¹, the availability of radio communication networks for high-speed transport must be at least 99, 95 % [7]. Therefore, at present, sufficient attention is paid to the issues of stable and reliable operation of radio communications. They are considered in [8; 9], and the issues of calculating survivability of a digital radio communication network are described in [10].

While designing a communication network, several tasks are posed: quality indicators are calculated for each class of service for subscribers considering changes in the load, gravity structure, channel capacity, as well as failure of network components; the load of equipment and

communication channels, the need for redundancy are estimated. These tasks are solved through modelling and subsequent system analysis [11]. The models in this study will simplify finding some characteristics of the communication network.

The *objective* of the study was to develop a method to calculate the performance of base stations within railway digital radio communication networks and the probabilities for BS of being in certain states. The main *method* of the study was analytic modelling used in the theory of telecommunication traffic to solve similar problems.

RESULTS

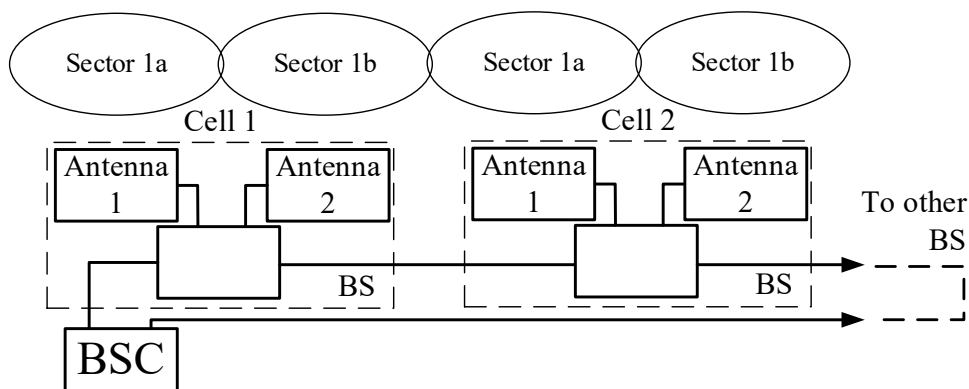
Let us consider a simplified diagram of a digital radio communication network of railway transport on a given section of the railway. No radio coverage redundancy exists. The radio communication network contains a certain number of base stations (BS), interconnected by a terrestrial communication channel (Pic. 1).

The BS connection scheme is sequential, since, according to the requirements [5], they must be connected to the Base Station Controller (BSC) according to the «spatial ring» principle. Each antenna serves a specific sector of the cell. All requests for connections from mobile terminals are transmitted from BS through communication channels to BSC. It connects the required BS to operation, which connects the terminal of the called subscriber through the radio communication channel. Radio coverage of the required area is provided through the antennas of each sector.

A functional model of a base station of a digital radio communication network is shown in Pic. 2. The numbers 1 and 2 denote the radio frequency path of the base station (antennas, antenna-feeder devices, etc.) of the left and right sectors, number 3 – the switching, control and connection modules that provide information exchange with other base stations over circuit groups (numbers 4 and 5), as well as interaction with the RF path. For simplicity, component 3 will be called further-on a switch.

It is proposed to consider BS as a system with several functional elements. To obtain the dependences of the required characteristics on all parameters of the system, analytical modelling is used, which is widespread in the theory of telecommunications traffic when solving such problems. Description and examples of some

¹ GOST R [Russian State Standard] 54959-2012. Railway electric communications. Train radio communications. Technical requirements and control methods. Date of enactment: April 1, 2013. [Electronic resource]: <https://docs.cntd.ru/document/1200095030>. Last accessed 12.01.2021.



Pic. 1. Simplified diagram of railway digital radio communication network (compiled by the authors).

models are given in [12], and the solution of such problems is described in [13], and regarding the railway transport [14].

For our functional model of BS (Pic. 2), we will construct a graph of possible transitions between operability states (Pic. 3). Let λ be the failure flow intensity of each element of the model, μ – recovery flow intensity, P_i – probability of the system being in the state $i = [0, 10]$.

The scheme of the model's functioning makes it possible to distinguish ten discrete states in which the system could be:

0 – Both sectors of the base station are operational, all circuit groups are operational, switching is in progress.

1 – Both sectors of the base station are operational, one of the circuit groups is faulty, switching is in progress.

2 – Both sectors of the base station are operational, both circuit groups are faulty, switching is in progress.

3 – Only one of the sectors of the base station is operational, all circuit groups are operational, switching is in progress.

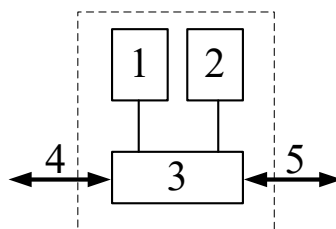
4 – Only one of the sectors of the base station is operational, one of the circuit groups is faulty, switching is in progress.

5 – Only one of the sectors of the base station is operational, both circuit groups are faulty, switching is in progress.

6 – Both sectors of the base station are inoperative, all circuit groups are in good order, switching is in progress.

7 – Both sectors of the base station are inoperative, one of the circuit groups is faulty, switching is in progress.

8 – Both sectors of the base station are inoperative, both circuit groups are faulty, switching is in progress.



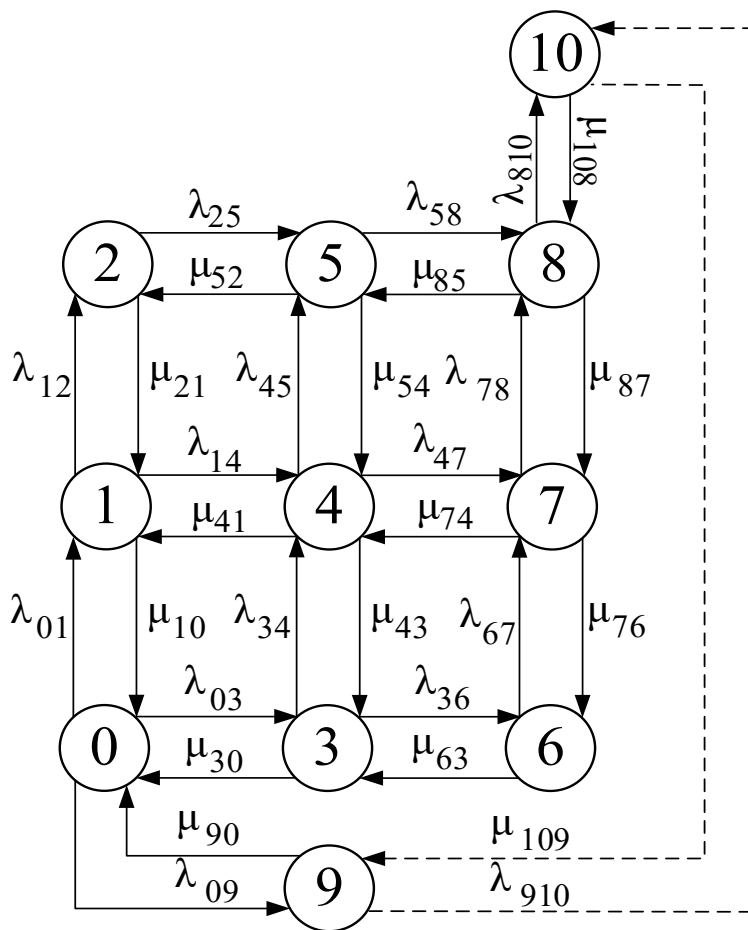
Pic. 2. A functional model of a base station with two sectors, two circuit groups and a switch (compiled by the authors).

9 – Both sectors of the base station are operational, all circuit groups are operational, switching is not performed.

10 – Both sectors of the base station are inoperative, all circuit groups are faulty, switching is not performed.

State 0 indicates that the system is fully operational. States 1, 3 and 4 indicate that the base station has received serious damage but it is functioning as intended with a deterioration in quality of service. In states 2, 5–9, the system is considered inoperative, even when its individual components are functioning. End state 10 indicates complete failure of base station components.

Let's compose a system of equations according to the following rules: the probability of the base station being in state P_i is to the left of the equal sign. To the right of the equation there is the sum of the products of the probabilities of all transitions entering (incoming arrows in Pic. 3) into state i of the system by the intensities of the states from which these flows originate, minus the probability of the considered state i , multiplied by the total intensity of transitions that remove the system (outgoing arrows in Pic. 3) from the given state i . To solve such a system, it is necessary to add one more equation that



Pic. 3. The graph of states of the operability model of a base station with two sectors, two circuit groups and a switch (compiled by the authors).

determines the normalisation condition, since the sum of the probabilities of all states is equal to one.

Let us write the system of equilibrium equations according to the graph:

$$P_0(\lambda_{01} + \lambda_{03} + \lambda_{09}) = P_1\mu_{10} + P_3\mu_{30} + P_9\mu_{90};$$

$$P_1(\mu_{10} + \lambda_{12} + \lambda_{14}) = P_0\lambda_{01} + P_2\mu_{21} + P_4\mu_{41};$$

$$P_2(\mu_{21} + \lambda_{25}) = P_1\lambda_{12} + P_5\mu_{52};$$

$$P_3(\lambda_{36} + \mu_{30} + \lambda_{34}) = P_6\mu_{63} + P_0\lambda_{03} + P_4\mu_{43};$$

$$P_4(\mu_{41} + \lambda_{45} + \lambda_{47} + \mu_{43}) = P_1\lambda_{14} + P_5\mu_{54} + P_7\mu_{74} + P_3\lambda_{34}; \quad (1)$$

$$P_5(\mu_{54} + \mu_{52} + \lambda_{58}) = P_4\lambda_{45} + P_2\lambda_{25} + P_8\mu_{85};$$

$$P_6(\mu_{63} + \lambda_{67}) = P_3\lambda_{36} + P_7\mu_{76};$$

$$P_7(\mu_{76} + \lambda_{78} + \mu_{74}) = P_6\lambda_{67} + P_8\mu_{87} + P_4\lambda_{47};$$

$$P_8(\mu_{85} + \mu_{87} + \lambda_{810}) = P_5\lambda_{58} + P_7\lambda_{78} + P_{10}\mu_{108};$$

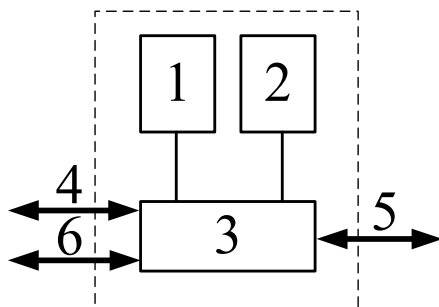
$$P_9(\mu_{90} + \lambda_{910}) = P_0\lambda_{09} + P_{10}\mu_{109};$$

$$P_{10}(\mu_{109} + \mu_{108}) = P_9\lambda_{910} + P_8\lambda_{810}.$$

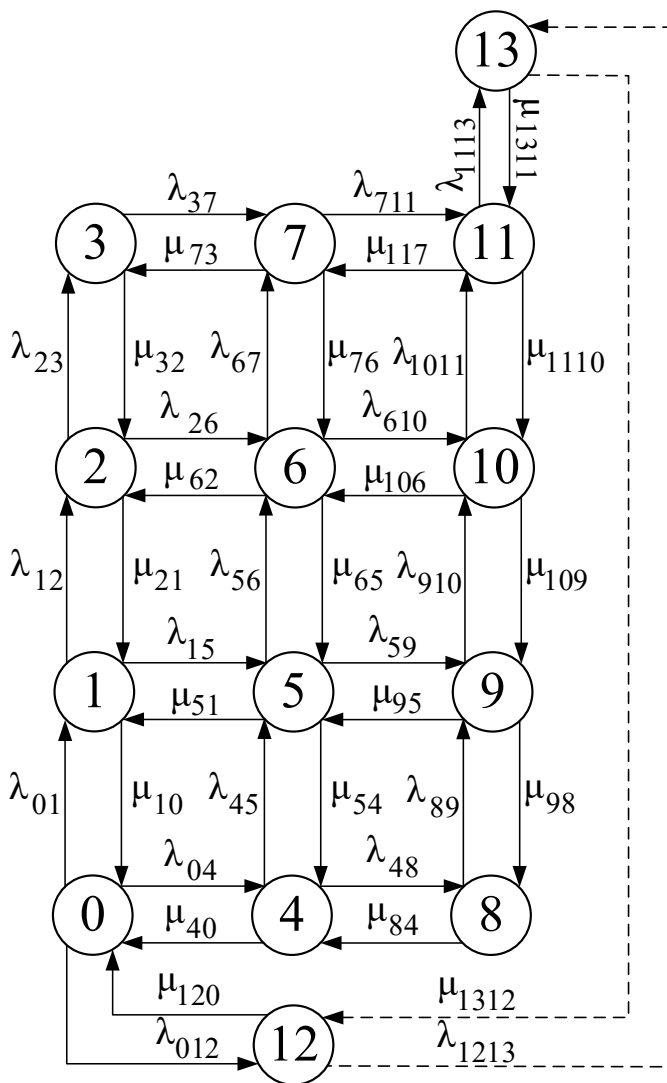
Let us indicate the normalising condition:

$$\sum_{i=0}^{10} P_i = 1.$$

Let us set the following numerical values of the model parameters – failure and recovery intensities: $\lambda_{01} = 0,009 \cdot 10^{-6}$, $\lambda_{12} = 0,008 \cdot 10^{-6}$, $\lambda_{25} = 1 \cdot 10^{-6}$, $\lambda_{58} = 1 \cdot 10^{-6}$, $\lambda_{78} = 1,89 \cdot 10^{-6}$, $\lambda_{67} = 1,29 \cdot 10^{-6}$, $\lambda_{36} = 0,0011 \cdot 10^{-6}$, $\lambda_{03} = 0,011 \cdot 10^{-6}$, $\lambda_{34} = 0,9 \cdot 10^{-6}$,



Pic. 4. A functional model of a base station with two sectors, three circuit groups and a switch (compiled by the authors).



Pic. 5. The graph of states of the operability model of a base station with two sectors, three circuit groups and a switch (compiled by the authors).

$\lambda_{14} = 0,115 \cdot 10^{-6}$; $\lambda_{45} = 0,205 \cdot 10^{-6}$; $\lambda_{47} = 0,145 \cdot 10^{-6}$; $\lambda_{09} = 0,0019 \cdot 10^{-6}$; $\lambda_{910} = 0,01 \cdot 10^{-6}$; $\lambda_{810} = 0,122 \cdot 10^{-6}$; $\mu_{10} = 9,99 \cdot 10^{-6}$; $\mu_{21} = 9,77 \cdot 10^{-6}$; $\mu_{32} = 2,63 \cdot 10^{-6}$; $\mu_{85} = 3,45 \cdot 10^{-6}$; $\mu_{87} = 2,21 \cdot 10^{-6}$; $\mu_{76} = 1,01 \cdot 10^{-6}$; $\mu_{63} = 4,56 \cdot 10^{-6}$; $\mu_{30} = 9,99 \cdot 10^{-6}$; $\mu_{43} = 4 \cdot 10^{-6}$; $\mu_{41} = 9 \cdot 10^{-6}$; $\mu_{54} = 1,01 \cdot 10^{-6}$; $\mu_{74} = 5 \cdot 10^{-6}$; $\mu_{90} = 9,89 \cdot 10^{-6}$; $\mu_{109} = 1,11 \cdot 10^{-6}$; $\mu_{108} = 2 \cdot 10^{-6}$. The choice of the model parameters is due to achievement of the maximum value of the probability of the operational state of the BS (state 0).

Next, the resulting system of equations is calculated by the Gauss–Seidel iterative method.

The obtained values are presented below:

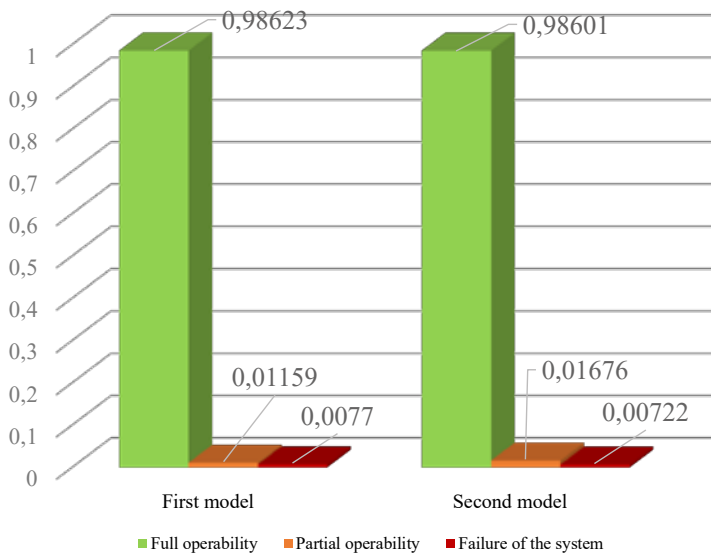
$P_0 = 0,98623$; $P_1 = 0,00496$; $P_2 = 0,00066$; $P_3 = 0,00663$; $P_4 = 0,00445$; $P_5 = 0,00270$; $P_6 =$

$0,00019$; $P_7 = 0,00107$; $P_8 = 0,00079$; $P_9 = 0,00189$; $P_{10} = 0,00037$.

Thus, the probability of operability of all components of the base station will be $P_0 = 0,98623$. The probability of the base station operability with deterioration in quality of service will be $P_1 + P_3 + P_4 = 0,01159$. The probability of the base station not performing its functions will be $P_2 + P_5 + P_6 + P_7 + P_8 + P_9 = 0,00733$, and the worst outcome is possible with the probability $P_{10} = 0,00037$.

Next, we will consider a functional model of a BS of a digital radio communication network of a different type, the model of which is shown in Pic. 4. This model employs three circuit groups which are designated by numbers 4–6.





Pic. 6. Diagram of BS operability (compiled by the authors based on the results of the proposed calculation).

Let's construct a new graph of possible transitions between the states of BS operability (Pic. 5).

In this model, we select 13 discrete states:

0 – Both sectors of the base station are operational, all circuit groups are operational, switching is in progress.

1 – Both sectors of the base station are operational, one of the circuit groups is faulty, switching is in progress.

2 – Both sectors of the base station are operational, both circuit groups are faulty, switching is in progress.

3 – Both sectors of the base station are operational, all circuit groups are faulty, switching is in progress.

4 – Only one of the sectors of the base station is operational, all circuit groups are operational, switching is in progress.

5 – Only one of the sectors of the base station is operational, one of the circuit groups is faulty, switching is in progress.

6 – Only one of the sectors of the base station is operational, both circuit groups are faulty, switching is in progress.

7 – Only one of the sectors of the base station is operational, all circuit groups are faulty, switching is in progress.

8 – Both sectors of the base station are inoperative, all circuit groups are in good order, switching is in progress.

9 – Both sectors of the base station are inoperative, one of the circuit groups is faulty, switching is in progress.

10 – Both sectors of the base station are inoperative, both circuit groups are faulty, switching is in progress.

11 – Both sectors of the base station are inoperative, all circuit groups are faulty, switching is in progress.

12 – Both sectors of the base station are operational, all circuit groups are operational, switching is not performed.

13 – Both sectors of the base station are inoperative, all circuit groups are faulty, switching is not performed.

State 0 indicates that the system is fully operational. States 1, 2, 4, 5 and 6 indicate that a significant failure of its components has occurred in BS, but it functions as intended with a deterioration in quality of service. In states 3, 7–12, the system is considered inoperative, even when its individual components are functioning. End state 13 indicates complete failure of base station components.

For the new model, the system of equations will look like this:

$$P_0(\lambda_{01} + \lambda_{012} + \lambda_{04}) = P_1\mu_{10} + P_{12}\mu_{120} + P_4\mu_{40};$$

$$P_1(\mu_{10} + \lambda_{12} + \lambda_{15}) = P_0\lambda_{01} + P_2\mu_{21} + P_5\mu_{51};$$

$$P_2(\mu_{21} + \lambda_{26} + \lambda_{23}) = P_1\lambda_{12} + P_6\mu_{62} + P_3\mu_{32};$$

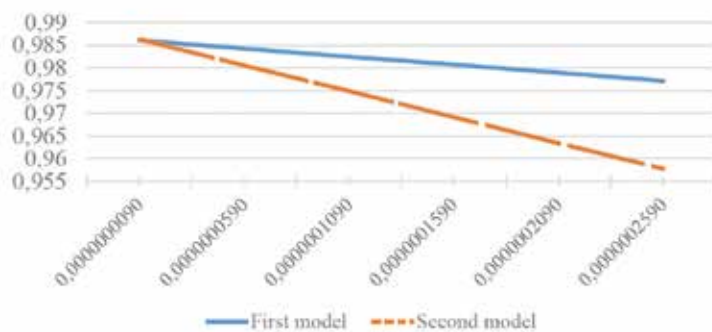
$$P_3(\lambda_{37} + \mu_{32}) = P_7\mu_{73} + P_2\lambda_{23};$$

$$P_4(\mu_{40} + \lambda_{45} + \lambda_{48}) = P_0\lambda_{04} + P_5\mu_{54} + P_8\mu_{84};$$

$$P_5(\mu_{54} + \mu_{51} + \lambda_{56} + \lambda_{59}) = P_4\lambda_{45} + P_1\lambda_{15} + P_6\mu_{65} + P_9\mu_{95};$$

$$P_6(\mu_{65} + \mu_{62} + \lambda_{67} + \lambda_{610}) = P_5\lambda_{56} + P_2\lambda_{26} + P_7\mu_{76} + P_{10}\mu_{106}; \quad (2)$$

$$P_7(\mu_{76} + \lambda_{711} + \mu_{73}) = P_6\lambda_{67} + P_{11}\mu_{117} + P_3\lambda_{37};$$



Pic. 7. The graph of dependence $P_0 = f(\lambda_{01})$ (compiled by the authors based on the results of the proposed calculation).

$$P_8(\mu_{84} + \lambda_{89}) = P_4\lambda_{48} + P_9\mu_{98};$$

$$P_9(\mu_{98} + \mu_{95} + \lambda_{910}) = P_8\lambda_{89} + P_5\lambda_{59} + P_{10}\mu_{109};$$

$$P_{10}(\mu_{109} + \mu_{106} + \lambda_{1011}) = P_9\lambda_{910} + P_6\lambda_{610} + P_{11}\mu_{1110};$$

$$P_{11}(\mu_{1110} + \mu_{117} + \lambda_{1113}) = P_{10}\lambda_{1011} + P_7\lambda_{711} + P_{13}\mu_{1311};$$

$$P_{12}(\mu_{120} + \lambda_{1213}) = P_0\lambda_{012} + P_{13}\mu_{1312};$$

$$P_{13}(\mu_{1311} + \mu_{1312}) = P_{11}\lambda_{1113} + P_{12}\lambda_{1213};$$

$$\sum_{i=0}^{14} P_i = 1.$$

For the model with three circuit groups, let us set the following values of failure and recovery intensities, which practically do not differ from the parameters of the model with two circuit groups: $\lambda_{01} = 0,009 \cdot 10^{-6}$, $\lambda_{12} = 0,008 \cdot 10^{-6}$, $\lambda_{37} = 1,5 \cdot 10^{-6}$, $\lambda_{711} = 1,11 \cdot 10^{-6}$, $\lambda_{1113} = 0,111 \cdot 10^{-6}$, $\lambda_{67} = 1,29 \cdot 10^{-6}$, $\lambda_{1011} = 1,11 \cdot 10^{-6}$, $\lambda_{23} = 1,24 \cdot 10^{-6}$, $\lambda_{89} = 2,14 \cdot 10^{-6}$, $\lambda_{48} = 1,11 \cdot 10^{-6}$, $\lambda_{45} = 0,205 \cdot 10^{-6}$, $\lambda_{04} = 0,011 \cdot 10^{-6}$, $\lambda_{15} = 1,67 \cdot 10^{-6}$, $\lambda_{910} = 0,01 \cdot 10^{-6}$, $\lambda_{59} = 1,222 \cdot 10^{-6}$, $\lambda_{56} = 1,246 \cdot 10^{-6}$, $\lambda_{26} = 2,456 \cdot 10^{-6}$, $\lambda_{012} = 0,01 \cdot 10^{-6}$, $\lambda_{1213} = 0,111 \cdot 10^{-6}$, $\lambda_{610} = 2 \cdot 10^{-6}$, $\mu_{10} = 9,99 \cdot 10^{-6}$, $\mu_{21} = 9,77 \cdot 10^{-6}$, $\mu_{73} = 2,12 \cdot 10^{-6}$, $\mu_{117} = 0,1 \cdot 10^{-6}$, $\mu_{1311} = 5,55 \cdot 10^{-6}$, $\mu_{76} = 1,01 \cdot 10^{-6}$, $\mu_{1110} = 8,76 \cdot 10^{-6}$, $\mu_{32} = 1,11 \cdot 10^{-6}$, $\mu_{98} = 1,234 \cdot 10^{-6}$, $\mu_{84} = 9,99 \cdot 10^{-6}$, $\mu_{54} = 1,01 \cdot 10^{-6}$, $\mu_{40} = 99 \cdot 10^{-6}$, $\mu_{51} = 1,5464 \cdot 10^{-6}$, $\mu_{109} = 1,11 \cdot 10^{-6}$, $\mu_{95} = 2,1453 \cdot 10^{-6}$, $\mu_{65} = 8,76 \cdot 10^{-6}$, $\mu_{120} = 9,99 \cdot 10^{-6}$, $\mu_{1312} = 900 \cdot 10^{-6}$, $\mu_{106} = 5,67 \cdot 10^{-6}$.

The obtained values are presented below:

$P_0 = 0,98601$; $P_1 = 0,00875$; $P_2 = 0,00414$; $P_3 = 0,00311$; $P_4 = 0,00032$; $P_5 = 0,00213095$; $P_6 = 0,00140$; $P_7 = 0,00119$; $P_8 = 0,00013$; $P_9 = 0,00105$; $P_{10} = 0,00053696$; $P_{11} = 0,00017$; $P_{12} = 0,00098$; $P_{13} = 0,00002$.

Thus, the probability of operability of all components of the base station will be $P_0 = 0,98601$. The probability of the base station operability with deterioration in the quality of service will be $P_1 + P_2 + P_4 + P_5 + P_6 = 0,01676$.

The probability of the base station not performing its functions will be $P_3 + P_7 + P_8 + P_9 + P_{10} + P_{11} + P_{12} = 0,0072$, and the worst outcome is possible with the probability $P_{13} = 0,00002$.

Next, let's compare the results. The probabilities of operability of each model are shown in the diagram (Pic. 6). In the results obtained, we admit an error inherent in iterative methods for solving a system of equations.

Now let's consider how the full operability of BS will change with a change in intensity of the flow of failures λ_{01} . The results obtained for each model are shown in Pic. 7.

Based on the results obtained, the following conclusions can be drawn:

- The model with 3 circuit groups is less reliable with a difference of 0,02 %.
- The probability of partial operability of BS is higher in the second model.
- The probability of complete BS failure in the second model is less than in the first model.
- With an increase in intensity of the flow of failures λ_{01} by 2 times, full operability of BS for the first model decreases by about 0,18 %, and for the second model by 0,05 %. From this we conclude that the presence of the third circuit groups reduces the probability of BS not performing its functions.

It can also be assumed that with radio coverage of neighbouring cells, the probability of operability of the entire digital radio communication network will increase.

CONCLUSIONS

The developed models are of practical value and can be used for designing railway digital radio communication networks, as well as for calculation of quality characteristics of the existing network. To improve the accuracy of calculations, the obtained values of full or partial



operability can be used together with the first Erlang formula, which determines the probability of blocking calls for a given specific load and the number of channels. The product of two probabilities will represent the final result.

When using various architectures of GSM-R standard networks described in the recommendations [5], the obtained characteristics of BS operability are supposed to be used in calculating the structural reliability of the communication network. By changing the parameters of the developed model, it is possible to choose an architecture that will be cost-effective and will provide the specified operability of the digital radio communication network.

In general, it can be assumed that the emergence of new technologies and high speeds described in [15; 16] will result in the emergence of new architectures of railway communication networks and methods for calculating their operability.

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Solutions to logistics problems under conditions of stochastic time and demand.



Documents and electronic document interchange.





Classification of Objects of Supply Chain Management to Ensure Their Sustainability



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ABSTRACT

Classifications of objects of supply chain management create the basis for managing their sustainability. The author proposes a hierarchy of priorities regarding managed objects – systems, processes and relations, which implies creation of adequate anti-crisis measures for operational management of resource flows.

The objectives of the study are to clarify and supplement classifications of supply chain management objects based on their qualitative characteristics. The tasks of the study are to identify the problems of classification of objects of supply chain management, to determine the prerequisites and to determine ways to solve these problems.

The methodological basis of the research is formed by the provisions of logistics as a science of resource flow management

and supply chain management as a science of managing systems and processes of creating value for end users of products and/or services.

Logical-structural methods and tools of binary matrices have allowed to develop classifications of flows of the first (A) and second (B) levels, creating basis for adoption of codes of those flows indicating types of systems and processes and ensuring thus their sustainability. The proposed hierarchy of prioritisation of managed objects reveals the dependences that govern the anti-crisis measures of operation management of resource flows. The research results make it possible to eliminate the contradictions between the goals of the supply chain links (suppliers) and requirement chains (consumers) and, on this basis, to organise their effective interaction.

Keywords: flow, integrated flow, flow sustainability, process, supply chain, value.

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INTRODUCTION

The term «supply chain» refers to terms, the essence and content of which are still not entirely clear. On the one hand, the supply chain is defined as «a group of independent organisations connected together through the products and services that they separately and/or jointly add value on in order to deliver them to the end consumer» [1]. On the other hand, a supply chain is «a complex network of relationships that organizations maintain with trading partners to source, manufacture, and deliver products. It encompasses all activities associated with flow and transformation of goods and services from the point of origin, through to the end user, as well as the associated information and financial flows» [2]. The ambiguous interpretation of the term «supply chain» imposes serious restraints on the theory and methodology of sustainable supply chain management (hereinafter – SSCM).

The *objective* of the study is to clarify and supplement classifications of supply chain management objects, such as flows, enterprises, relationships between them and processes based on their qualitative characteristics, formed based on the components of the logistics complex, which include quality, quantity, costs, time, territory, and trajectory. Achievement of the set goals is ensured through binary matrices formed based on a set of actual qualitative features and their dichotomies which are two opposite states of these features.

This makes it possible to clarify the content of the management system for supply chain management components based on a systematic approach, as well as to create necessary theoretical

prerequisites for increasing its efficiency in highly competitive markets.

The *methodological* basis of the research is made up of logical-structural methods, such as analysis and synthesis, induction and deduction, grouping, typology and classification, and binary matrices are used as a research tool, which makes it possible to unambiguously characterise the objects of supply chain management.

RESULTS

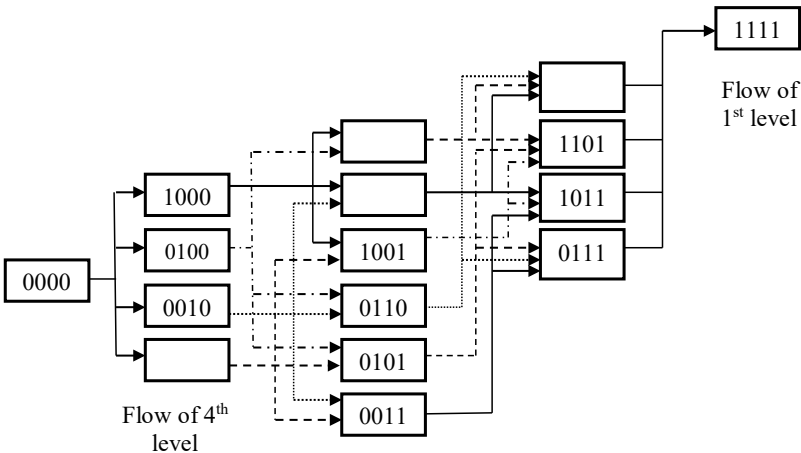
Clarifying and Supplementing Classifications of Objects of Supply Chain Management

A very significant aspect contributing to achievement of the research objective is the definition of SSCM as management of material, information and capital flows, as well as cooperation between companies along the entire supply chain, considering the goals... of three dimensions of sustainable development, i.e., economic, environmental and social factors, taking into account the requirements of customers and stakeholders [3].

In the above definition, the term «flow» is used, which, according to a number of authors, is the object of logistics research [4].

Thus, classification of supply chain management objects can be used to ensure sustainability of resource flows.

The specificity of managing stability of resource flows is determined by their type. Various classifications of flows have been proposed [5–9]. Nevertheless, within the framework of sustainability management, it is advisable to refine these classifications using the following qualitative characteristics:



Pic. 1. Sequence and variants of formation of an integrated flow of resources (developed by the author).



**Classification of variants of the integrated flow of resources
(developed by the author)**

Material flow (not taken into account – 0, taken into account – 1)	Information flow (not taken into account – 0, taken into account – 1)	Financial flow (not taken into account – 0, taken into account – 1)	Human flow (not taken into account – 0, taken into account – 1)	Code of resource flow
0	0	0	0	0000
0	0	0	1	0001
0	0	1	0	0010
0	0	1	1	0011
0	1	0	0	0100
0	1	0	1	0101
0	1	1	0	0110
0	1	1	1	0111
1	0	0	0	1000
1	0	0	1	1001
1	0	1	0	1010
1	0	1	1	1011
1	1	0	0	1100
1	1	0	1	1101
1	1	1	0	1110
1	1	1	1	1111

• Type of resource flow object: real; not material.

• Factors of activity of links of the supply chain: economic, managerial ones.

These signs of classification (type «A») make it possible to distinguish four types of resource flows: material, information, financial, and human flows. The use of human flows as flows (Pic. 1) is due to the opinion of A. Halley, A. Guilhon [10] that «logistics is based on sustainable human resource management».

If we imagine the process of forming the structure of an integrated flow as a sequential combination of flows of the same level (jets), then on the basis of four types of flows identified above, 16 variants of the integrated flow can be obtained (Table 1).

As follows from Table 1, based on the fourth level of flows with codes 0001, 0010, 0100, and 1000, six third-level flows, four second-level flows and one first-level flow (integrated flow) can be obtained. The sequence and options for formation of an integrated flow are shown in Pic. 1. The formation of an integrated flow can occur in parallel, bypassing one or another level [11]. It is expedient to consider the flows of the lower level in relation to the flows of the higher level as jets. When managing resource flows, each of flows is characterised by a level of stability, which can change under the influence of the internal and external environment, which implies establishment and monitoring of priorities for

managing certain jets of resource flows. The priorities of jets of flows imply their classification of type «B» using the attributes: the relation of the flow to the value of the end user (creation; accompaniment); type of link forming the flow (absorbing link; generating link); the influence of the flow on quality of the value (determining; secondary impact) (Table 2).

Data of Tables 1 and 2 create the prerequisites for creation of resource flow codes that are convenient for the use with the help of computer support within the digitalisation of supply chain management. So, for example, the code «1100–010» means an auxiliary integrated flow (third level), which includes material and information flows (jets). For a detailed understanding of types of flows of Table 2 Table 3 was developed, specifying their types using the example of «the value of clean clothes for the end user».

Let's define these parameters and characteristics of the flow using the example of the flow of material resources.

First, it is necessary to identify objects of the flow of this type based on the following classification features: purpose of the flow object (maintaining value; value delivery); relation of the flow object to the value (creation; accompaniment). It is possible to differentiate the following objects of material flow: products (value carriers), containers (packaging), vehicle and loading-unloading devices.

Based on the modern works developing the model of marketing mix whose foundations have

Table 2

Classification «B» of flows of resources (developed by the author)

Ratio of the flow to the end user value (creation – 0, maintenance – 1)	Type of the link that forms the flow (absorbing link – 0, generating link – 1)	Influence of the flow on quality of the value (determining impact– 0, minor impact – 1)	Flow type
0	0	0	Main
0	0	1	Optional
0	1	0	Auxiliary
0	1	1	Indirect
1	0	0	Accompanying
1	0	1	Side
1	1	0	Supportive
1	1	1	Utility

Table 3

Components of the flow with the code «1100–010» using the example of «The value of clean clothes for the end user» (developed by the author)

Flow type	Example of an object	
	Material flow	Information flow
Main	Washing machine	Instruction manual
Optional	Houses for water and its drain down the drain	Recommendations for installation of houses for water
Auxiliary	Vehicle to move a washing machine and washing powder to the place of their sale	Information about the location of the purchaser of the washing machine and washing powder
Indirect	Loading-unloading devices of the manufacturer and the consumer	Safety instruction for operation of loading-unloading devices
Accompanying	Washing powder	Data on consumption of washing powder
Side	Dispenser for washing powder	Price data for dispenser for washing powder
Supportive	Fuel and lubricants for a vehicle and loading-unloading devices	Fuel consumption standards for a vehicle and loading-unloading devices
Utility	Pull attachments	Load limit information and checking of pull attachments

been created in the works of E. J. McCarthy devoted to 4P's [12], it is possible to reveal several enlarged quantitative parameters of flows (Table 4).

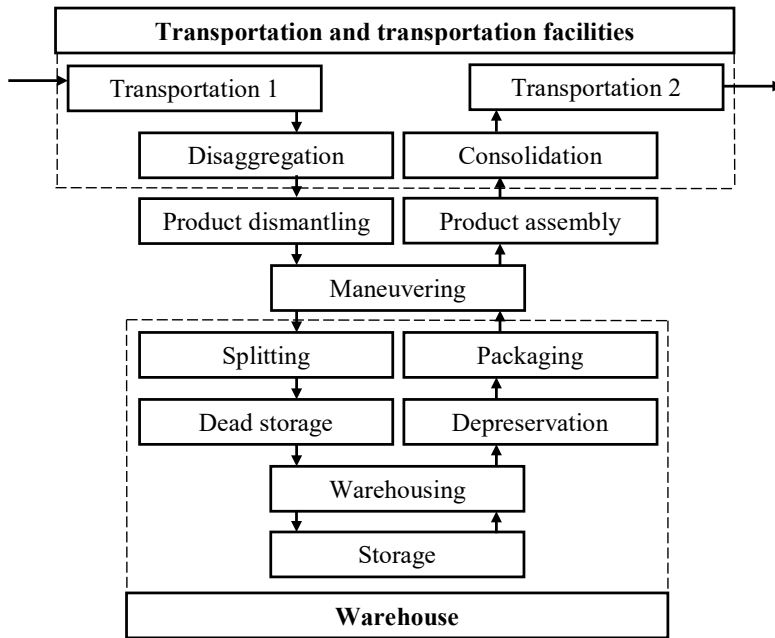
As can be seen from Table 4, in addition to the parameters «quantity», «quality», «costs» and «time», it is proposed to use the parameters «trajectory» and «territory». It is easy to see that these parameters concretise the «place» component of the marketing [13]. The parameter «trajectory» is used in trajectory-based management to generalise, update and implement the description of transport processes at all stages of strategic and tactical coordination and operation [14]. The «territory» parameter assumes focus on economically justified boundaries of the activity of the supply chain link. For example, when the growth in sales of products and/or services is constrained by an increase in transportation costs for their delivery to the end consumer [14].

SUSTAINABILITY MANAGEMENT

Flow sustainability management is provided by enterprises which are links in the supply chain. These links form systems of various configurations depending on the requirements of end consumers. The type of links and their geographic locations form the trajectories along which resources move. Classification of the links in the supply chain, based on such classification features as tasks of the links in the supply chain (value creation and maintenance), priority type of goods (product; service), allows us to highlight the technological, trade, logistics links and infrastructure links [15].

The movement of resource flows is provided by processes (operations), which can also be assessed from the standpoint of their sustainability and impact on management of resource flows. These processes can be distinguished using the classification features: state of resource flow objects (rest and movement); stability of resource





Pic. 2. Sequence of processes (operations) of management of material resources flows (developed by the author).

flow parameters (parameters do not change and do change). Based on these features, the following resource flow management processes are formed: transportation, storage, packaging (picking), and consolidation/unbundling. In some cases, it is advisable to move from processes (Pic. 5) to operations. If we use such classification signs as location of the product (outside the storage area (vehicle) and in the storage area (vehicle)), type of flow object (product and loading and unloading device), it is possible to distinguish operations that link storage and transportation of products: depreservation (removal from long-term storage)/preservation, storage (manoeuvring), installation/dismantling and waiting.

The totality of the processes and operations highlighted above allows us to draw the following conclusions. Only logistic processes (operations) are considered. If necessary, technological and other types of processes (operations) can be added to them. Evaluation of flow sustainability management should be carried out over a time interval that assumes that several processes are performed by supply chains. If we take the warehouse form of movement of resources according to the scheme «transportation–storage–transportation» as a basis, then it is possible to form a sequence of processes (operations) for managing resource flows (Pic. 2).

During movement of the material flow (if it is the main one), the accompanying flows are also moving (Table 1). The stability of accompanying flows can significantly affect stability of the main flow. By analogy with the above classifications of processes related to material flow management, the processes accompanying information, financial and human flows can also be identified (Table 5).

Analysis of the contents of Table 5 allows us to draw the following conclusions. Each of the processes (operations) of resource flow management can be structured into components. When controlling an integrated flow, at a certain point in time, several processes (operations) can be performed with flows (jets) entering it, differing in parameters and characteristics, which requires their joint analysis. Each of flows can be denoted by a code similar to the code used for a material flow. The flow code is constantly changing during its movement, including due to changes in the parameters of the accompanying flows. An integrated flow can be designated by a four-level code, depending on the types of flows (jets) included in it, identified according to the classifications «A» and «B». Moreover, each of flows (jets) includes flows (jets) of the lowest level with their corresponding codes. The topic of coding resource flows and the methodology for its use is the topic of a separate study.

Table 5

**Classification of processes accompanying information, financial and human flows
(developed by the author)**

Flow types	Classification features	Processes
Information	• type of link in the information supply channel: sender, recipient. • aspect of work with information flow: managerial and technical.	• structuring information, preparing a message. • choice of information transmission method and its coding. • transmission of information and its decoding. • processing of the received information.
Financial	• type of link in the supply chain of financial resources: the sending bank; beneficiary bank (1). • aspect of work with financial flow: economic; technical.	• writing off by the consumer's bank of financial resources from the consumer's account. • transfer of financial resources by the consumer's bank to the supplier's bank. • crediting financial resources to the supplier's account. • receipt of financial resources by the supplier.
Human	• stage of human flow formation: analytical and practical. • levels of coordination of the parameters of the human flow: process operations. • knowledge, skills, and abilities – human resources.	• research of the content of operations of the process and determination of the list of resources for its implementation. • justification of knowledge, skills and abilities of human resources to carry out the operations of the process. • training and/or attracting human resources of the relevant profession and qualifications. • formalising relationships with human resources and familiarising them with the operations of the process.

Table 6

Parameters of managed objects (developed by the author)

Parameters of managed objects	Managed objects		
	Resource flow	Resource supply chains	Processes (operations) of resource flow management
Quantity	+	+	+
Quality	+	+	+
Costs	+	+	+
Time	+	+	+
Territory		+	
Trajectory	+		

Table 7

Hierarchy of priorities of managed objects (developed by the author)

Quality (Q)	Quantity (K)	Costs (Z)	Time (T)	Priority of managed objects (code)
0	0	0	0	Usual (5)
0	0	0	1	Actual (4-T)
0	0	1	0	Actual as per costs (4-Z)
0	0	1	1	Significant (3-ZT)
0	1	0	0	Actual as per quantity (4-K)
0	1	0	1	Significant (3-KT)
0	1	1	0	Significant (3-KZ)
0	1	1	1	Important (2-KZT)
1	0	0	0	Actual as per quality (4-Q)
1	0	0	1	Significant (3-QT)
1	0	1	0	Significant (3-QZ)
1	0	1	1	Important (2-QZT)
1	1	0	0	Significant (3-QK)
1	1	0	1	Important (2-QKT)
1	1	1	0	Important (2-QKZ)
1	1	1	1	Especially important (1)



Thus, sustainability of resource flows is a criterion for sustainability of supply chains, requirement chains, value chains, and the processes that these chains perform. By analogy with the data in Table 4, each of the managed objects listed above can be assessed by six basic quantitative parameters (Table 6). Each of the objects of management presented in Table 6 (first of all, the flow of resources) has a priority, which is formed on the basis of stability of their parameters. These priorities form a hierarchy both at the stage of preparation for creating value for the final consumer of products and/or services, as well as at the stage of operational management of facilities. Based on four parameters of managed objects, five levels of priorities can be distinguished: usual, actual, significant, important and especially important (Table 7).

CONCLUSIONS

As a result of the research carried out, classifications of flows of the first («A») and second («B») levels have been developed that seem to be of research novelty/ The classifications create the basis for using the codes of these flows indicating the types of systems and processes that ensure their stability.

The hierarchy of priorities of managed objects has been suggested depending on which anti-crisis measures of operational management of resource flows are implemented.

The developed approaches allow to eliminate contradictions between the links of the supply chain and the requirement chain that achieve their own goals and are interested in reducing the lost profit, to organise their interaction within the framework of managing relationships with suppliers and consumers, to create and maintain a system for monitoring sustainability of the flow of resources, as well as introduce anti-crisis measures to prevent a decline in the values of end consumers.

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Modelling and Optimisation of the Business Process of Documentary Support of Cargo Transportation for Building a Digital Document Management System



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ABSTRACT

The objective of the work is to analyse the examples of optimisation of documentary support system regarding rail cargo transportation based on the transition to the electronic form of documents.

The theoretical concept of modelling the business process of documentary support of cargo transportation is developed using the ARIS (Architecture of Integrated information Systems) software, which is used for development of an integrated process model of the activities of many manufacturing and transportation companies in Russia and in the world [1].

The subject of the research is modelling of the document circulation system supporting cargo transportation to eliminate losses in a significant part of the processes of interaction with

customers. The objective of business process modelling is to use all the advantages and functionality of case tools to eliminate duplication of actions and operations that do not add value to the customers of the transport company but reduce their loyalty to the products and services of railway transportation. The studied business processes ensure formation of an application for transportation and its transformation during the transportation process.

The study reflects the results of modelling business processes for documentary support of transportation in digital form. A comparative analysis of these models is followed by description of the advantages of the electronic documents in comparison with their paper form considering a possibility of using a digital signature.

Keywords: electronic document management, digital technology, modelling, business process, railway transportation, cargo transportation support.

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

INTRODUCTION

Modelling of processes in any type of business, and especially in the transport sector of the economy with a predominant character of end-to-end technologies, is aimed at improving business processes and indices that serve as indicators and drivers for improving organisation performance. Modelling is one of the *methods* for analysing and improving movement of documents in an enterprise. Modelling is a description, identification, simulation and analysis of business processes, design of new processes for the purpose of their subsequent optimisation.

The cargo transportation is among core railway business processes having significant impact on economic indices of the companies in this industry. Hence, it is quite natural that cargo transportation have become one of the first fields for testing and implementing digital technology, modelling many processes including those related to document management that plays an important role in formalising relationships with cargo owners, regulatory bodies, as well as immediately during the transportation.

Research and design of information support processes for cargo transportation using modelling tools allows to:

- Represent visually, graphically the structure of the information support system for interaction with shippers.
- Describe in detail the functions of the document management system.
- Identify potential opportunities for development of document management technologies regarding railway customers.
- Identify and to analyse information links with internal and external participants in the documentary support of the transportation process.
- Optimise the technological operations of working with documents, their sequence, using the technology of describing workflows.

Modelling allows us to simplify the electronic document management system as much as possible, reflecting its most important properties and resources, which helps to eliminate losses in the business process of document circulation when using the instrumental environment as a means of optimisation and forecasting. The model, drawn up in a standard form, makes it possible to design a future process before it is reproduced in the form of software and hardware systems, which will reduce the cost of its creation

[2]. A visual representation of processes of receiving and processing information on formation of an application for transportation and its approval will eliminate the losses in efficiency and time while processing transportation documents [3].

Business modelling uses mathematical methods based on operations research (OR). The purpose of OR is to find a rational way of acting in solving organisational and managerial problems under various constraints. These problems include many linear and dynamic programming problems, inventory management, queuing theory, etc. Modern concepts of business modelling are based on a process approach to management. A huge number of publications of the theoretical nature are devoted to the process approach and implementation experience [4; 5]. The publications contain samples of business modelling, which use tools for various types of production systems and technologies [6; 7]. Thanks to the process approach and business modelling methodology, a business can be described as a set of processes, each of which can be optimised based on quality management standards, as well as on approaches allowing to eliminate losses and operations that do not add value to the customer.

The instrumental modelling tools are implemented with numerous software packages that are designed for various fields of activity. In the field of «software development and software engineering, one of the ways to represent processes is CASE (computer-aided software engineering) method» [8], which includes a set of methods, software engineering tools for software design, helping to ensure high quality support of software information systems and products [9; 10].

CASE-tools are tools designed for optimal automation of design and development processes not only for software from the standpoint of the developer's labour costs, but also for processes in other areas of activity, in particular, for describing the technologies of transportation processes. At first, CASE tools were considered only as tools that were designed to simplify the most complex and time-consuming processes of analysis and design of information systems. However, after introduction of ISO/IEC 14102 standard, CASE tools began to be defined as software tools to support the life cycle processes of digital services and software products [11].

This concept, «as a rule, is determined by the list of tasks that can be solved, as well as by set of methods and means» [12, p. 44], or, in other words, by the algorithms and formats used for describing processes for automation. CASE technology is «the totality of methodology of analysis, design, development and maintenance of complex software systems, supported by a set of interconnected automation tools» [12, p. 44].

The functional purpose of software products that are used to automate business processes of enterprises can be divided into three types: integrated corporate systems, electronic document management systems and software products for formalised presentation of business processes.

Electronic document management systems perform the functions of accounting, transfer, and storage of documents, which is of particular importance in the transport sector, where shipping documents are the basis for paying for a special type of product which is transportation, that cannot be saved or returned to the contractor.

Business process modelling software is commonly used in an organisation's reengineering projects. The same products can be used for reengineering an electronic document management system.

Process modelling starts «at the stage of analysing the requirements and constructing the relationships and structure of operations that make up the value stream in the process. These are the most poorly formalised and time-consuming stages in development of management and control systems. When any management system is being developed, the task of choosing a design tool arises, which should allow to effectively and competently solve the assigned tasks and meet all the requirements of the designers» [13]. The choice of a CASE tool largely depends on the methods of analysis and design of intelligent systems.

To support the point, we can refer to extended quotation of K. S. Myshenkov's work [13]: «Functional models perform the functions of a structured image of the environment or system, information and objects that connect these functions. These models are used when designing a new system, when analysing system requirements, when making decisions about reengineering a management system for analysing business processes.

Data flow models are needed for graphical structural analysis that describes processes external to the system, data receivers and sources,

data flows and data storage devices that are being accessed.

Business process models contain a description of workflows, business functions, departments, resources, processes, roles, media, information systems, positions. In this case, the models can be both static and dynamic since they describe the sequence and conditions for implementation of business processes. Business process models are used in implementation of management systems in enterprises, in description and reengineering of the company's activities, in analysis and definition of system requirements.

Event data models reflect the functioning of the system as of a set of states of business units or objects of labour, including significant system events aimed at their transformation. Information models of a specific subject area or its objects reflect the data structure of the systems being designed» [13].

Static models of business systems do not reflect dynamics over time. Such models have forms of presentation that at all stages of reengineering refer to classes, diagrams, components or objects of the system and their relationships with each other. Dynamic models are used for analysis, reflect the sequence of performance of system functions over time, as well as the process of changing the states of a real or projected system [13].

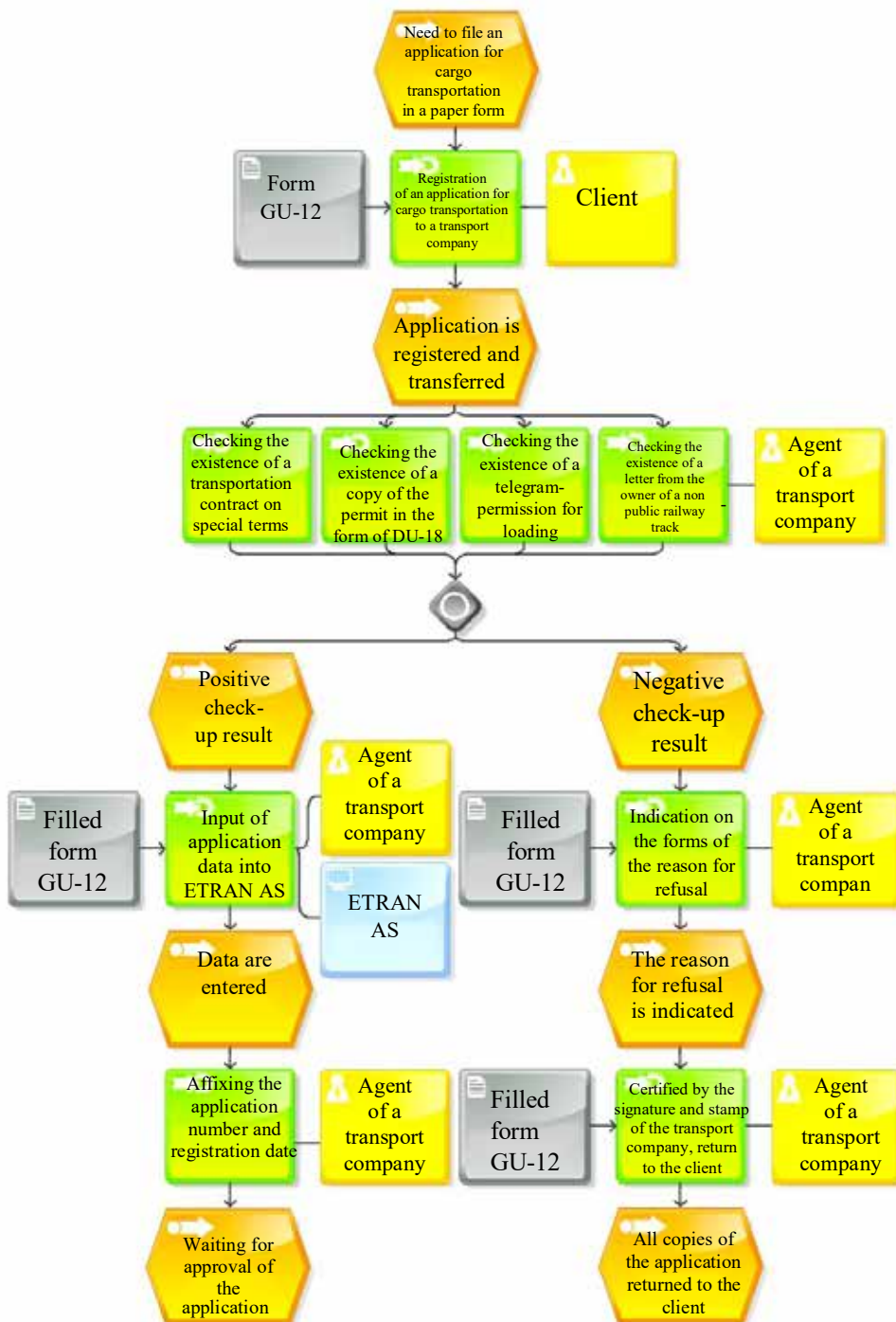
If we consider the example of Russia, then the most common software products for «modelling business processes according to the research company Gartner, which specialises in analytics of the information technology market, are the Corporate Modeler Suite and ARIS¹ systems provided globally by Casewise and IDS Scheer AG respectively. Corporate Modeler Suite occupies a leading position in a number of countries, but this tool, unlike ARIS, is not yet popular in the Russian market» [14].

The *objective* of the study described in the article is to consider an example of optimisation of the process of documenting cargo transportation.

The research *method* is based on ARIS (Architecture of Integrated information Systems) toolkit. ARIS has a set of software services for building a process map; several notations for describing models, namely: eEPC (extended event driven process chain) and «business

¹ Official website of ARIS Community. [Electronic resource]: <https://www.ariscommunity.com/>. Last accessed 12.03.2021.



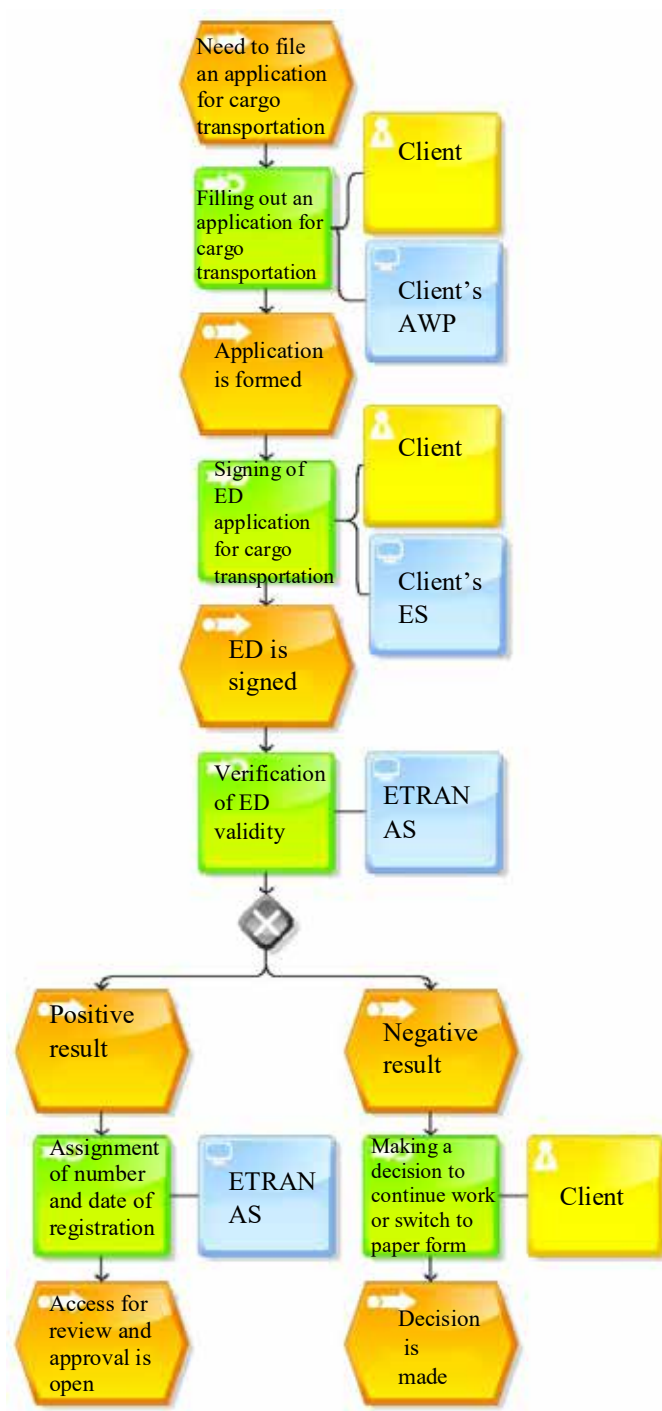


Pic. 1. The process of filing an application for transportation of goods with paper documents (compiled by the authors).

process models in BPMN notation (Business process model and notation). As part of the business capabilities of ARIS product, Smart Design function is also included, which allows us to quickly enter the necessary data for the automated creation of models» [5].

RESULTS

The main purpose of applying the methods of modelling the business process of workflow is to increase its operational efficiency, to organise data transfer in the most optimal way, resulting in decrease in time, labour, and material



Pic. 2. The process of filing an application for transportation of goods using electronic signature (ES)(compiled by the authors).

losses, and in an increase in the level of transportation and logistics services and competitiveness.

ARIS workflow business process modelling toolkit considers the organisation from the following five aspects: «products and services,

processed data, functionality, organisation, structure of business processes. These aspects are further subdivided into three sublevels: specification description, requirements description, implementation description. When describing business processes, about 80 types of



models are used, each of which refers to one of the aspects. The main principle in ARIS is the ability to integrate models of different types within one repository by detailing objects. As a result, any organisation can be described using a hierarchy of models»: from, i.e., top-level processes to the «level of procedures and resource environment of functions» [15].

Models of the application process for transportation of goods are presented below, developed using the ARIS toolkit (Pics. 1 and 2). Comparison of business process models of document flow clearly shows the effectiveness of the electronic form of shipping documents in comparison with the paper one. To make the examples more detailed, we used some of the procedures and forms of documents used on JSC Russian Railways network.

The electronic form of documents neutralises several repetitive iterations in the course of approvals and corrections of documents, while significantly reducing time for processing documents and simplifying the approval procedure. In particular, registration of an application for transportation of goods, with paper document circulation, is reduced by eight operations performed by the agent of the transport company when filling out an application in electronic form. The entire process of approval, including five outcome options (transfer of an application with the result of approval, refusal of a partially agreed application, withdrawal of an application for transportation of goods, refusal to fulfil an agreed application, refusal to fulfil a part of an agreed application) is reduced to one client's action: entering information into the AWP (automated workstation).

The obvious advantage of electronic document interchange is the absence of the need for a customer to visit the company to confirm each operation for filing and correction of the document. The current level of technology does not allow interacting with shippers in any other way from the point of view of the client-oriented strategy of railway transport.

ETRAN (Automated System «Electronic Waybill») AS is intended to electronic document interchange in an organisation that provides for an electronic signature. Form GU-12 indicated in Pic. 1 is an application for railway transportation of goods submitted by the consignor for transportation of goods; form DU-18 is an application for transportation of goods.

The electronic document interchange system allows us to completely abandon such operations as:

- Filling of paper copies of the document.
- Unnecessary travelling of the client's representatives associated with the need to deliver paper forms.
- Correction of errors that occur when filling out forms.
- Processing associated with affixing of stamps and written filling of paper forms of documents.
- Automatic entry of data and printing of documents using a system of centralised preparation and execution of documents for transportation.
- Checking the correctness of filling and availability of the necessary documents.
- Affixing stamps and filling out the paper form in writing.
- Storage of copies of documents.
- Unnecessary travelling of the transport company employees associated with transfer of the document to the responsible agent.
- Verification by the agent of the transport company of the authority of the consignee's representative.

CONCLUSIONS

As a result of abolition of the paper form of shipping documents, time of all the participants in the transportation process, labour and material resources of the companies are saved.

Graphical reflection and comparison of existing models of the system is not an end task itself. The analysis of presented models allows planning further adaptive transformations and forming the architecture of the digital document interchange system, which should ensure the efficiency the use of resources, processes, as well as the market efficiency of the company.

The choice of ARIS tools in building these models is due not only to its ability to create an organisation model, but also to the ability to conduct a sufficiently in-depth analysis of business processes. ARIS allows us to look at the organisation and understand where the bottlenecks of the processes have arisen, which resources are inefficiently used, and which business process chains need to be changed. Various ARIS modules allow us to dynamically consider all kinds of scenarios for execution of business processes without changing the real structure of the organisation.

Through the analysis of business processes and the definition of a conceptual scheme, it is possible to determine the main goals of the business, and before that, to identify new business processes that will need to be designed, as well as to identify weaknesses. In addition, using strategic analysis of business processes, it helps to calculate what new information technologies are possible and appropriate for implementation in the company's activities [16].

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Optimisation of Inventory Levels as Logistics Challenge



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ABSTRACT

Inventory ensures stability of the production technical system. Production facilities have warehouses for workpieces to create final output parts, and warehouses for finished products to meet customer demand. Stocks of workpieces avoid manufacturing downtime. Stocks of finished products make it possible to meet demand in a timely manner and avoid penalties for late deliveries of finished products to consumers.

On the other hand, the objects that make up the inventory are «dead» material resources that do not bring profit and negatively affect economic efficiency and competitiveness. According to published data, in economically developed countries, such as the USA, Japan, Germany and others, up to 30–40 % of

production is in stocks. All this indicates the relevance of the issue of optimising the level of reserves, of solving the problem of establishing and maintaining the optimal level of the stock, its timely replenishment, considering time required for execution of applications of end users.

The objective of the work is to propose a solution to a stochastic logistic problem of inventory management with a random time delay and random demand, obtained by the authors using the methods of mathematical statistics, mathematical modelling, and production logistics for unknown and arbitrary form of distribution functions of demand and time delay. The work provides specific examples of approaches to implementation of suggested solution.

Keywords: logistics, spare parts, inventory management systems (IMS), management strategy, stochastic demand, stochastic time delay, technical and economic functions, targeted functionality, algorithms, dynamics of spare parts inventory levels.

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

INTRODUCTION

There is a need to improve the efficiency of management systems governing spare parts inventory for transport and special vehicles by building models and optimising them. The problem of inventory management has arisen for a long time. In transport mechanical engineering, inventories play the role of a shock absorber in conditions of a mismatch between the rates of production and the rate of receipt of raw materials. The presence of reserves at an industrial enterprise is an objective reality and an economic necessity. In this case, material resources concentrated in stocks are diverted from the production sphere. The largest share in the working capital of industrial enterprises is made up of funds invested in inventories. The structure of stocks consists mainly of raw materials, basic materials, components and purchased semi-finished products.

Scientific theories of inventory management emerged in the late 19th century. The first mathematical models of inventory management systems (IMS) were deterministic in nature. The economic and mathematical functions used and the criteria for effectiveness of inventory management systems built on their basis were linear and often unimodal. This, in turn, dictated the choice of the optimisation method for the proposed IMS models. Attempts have been made to solve the problem analytically. Later, methods of linear and dynamic programming were used. Improvement of industrial production technologies, complication and development of relations and cooperation of enterprises, including the structures of the material and technical supply, has resulted in the understanding of the need to consider the influence of many factors on operation of IMS. Deterministic models had to be abandoned as inadequate to real conditions. Time has come for stochastic IMS models. The development of industrial logistics as a system for managing flows of material resources and finances led to sophistication of IMS, required development of qualitatively new mathematical models of IMS, an in-depth study of their mathematical properties. For example, in the USA, the share of reserves in gross domestic product for almost 35 years is about 28 %. By abandoning the traditional approaches to managing supply, manufacturing, and sales processes since each of these processes was not managed comprehensively, but separately and independently of each other, American firms have

achieved a significant reduction in the costs of maintaining and servicing inventories and their share in the annual volume of costs. The transition to logistics approaches of IMS in American firms has reduced the share of working capital invested in inventories to 18 % in the US gross domestic product [1; 2].

The overwhelming majority of recent publications seem to give preference to logistics and stochastic models as to the most adequate description of real conditions [3; 4].

Hence, the *objective* of the study is to propose a solution to a stochastic logistic problem of inventory management with a random time delay and random demand, obtained using the *methods* of mathematical statistics, mathematical modelling, and production logistics for unknown values and arbitrary form of distribution functions of demand and time delay.

RESULTS

Let us consider the mathematical model of IMS corresponding to the most common conditions of functioning of an industrial enterprise. Demand is usually random, and applications are processed with a random delay. The distribution functions of demand and time delay are a priori arbitrary and unknown, and often not unimodal. In this setting, the problem has not been solved. Under these conditions, to achieve the goal, it is natural to use modern methods of production logistics, including methods of mathematical statistics, mathematical modelling, information technology and, in particular, identification algorithms.

Let the inventory management system be characterised by the cost function Z for stock storage, delivery, shortage, etc. Inventory management is carried out by choosing a management strategy. One of the sufficiently effective and flexible strategies is (s, S) -strategy according to which an order of size $S - y$ is formed by reducing the level of stock y below the level s , $s < S$. For random demand and delay $Z = Z(y(s, S, x))$, where, according to Yu. I. Ryzhikov [5], $y(s, S, x)$ is current stock level, x is random demand, s, S are levels in (s, S) -strategy. Then the criterion of optimality of the system J is some averaged function of the costs Z :

$$J(s, S) = Mx \{F[y(s, S, x)]\} \rightarrow \min s, S. \quad (1)$$

Applying to (1) the method of stochastic approximation, which is a method of information technology, we obtain a self-consistent system of adaptive algorithms [6–8]:





$$\begin{aligned} S[p+1] &= S[p] - \gamma_\alpha(S[p+1]) \cdot f_s \cdot \\ &\cdot F(Z(y(s[p], S[p], x[p+1]))); \\ s[p+1] &= s[p] - \gamma_\alpha(s[p+1]) \cdot f_s \cdot \\ &\cdot F(Z(y(s[p], S[p], x[p+1]))), \end{aligned} \quad (2)$$

where gradient in α is a derivative in the direction;

$\alpha \cdot \gamma_\alpha \cdot [p+1]$ are coefficients;

f_s, f_s are functions that consider constraints for s and S .

It is assumed that the functions F and Z are differentiable, otherwise search algorithms can be applied. Sufficient conditions for convergence (2) are given in numerous monographs on methods of stochastic approximation. In the process of calculating in (2), it is necessary to know the explicit form of the function $y(s, S, x)$ to find the derivatives with respect to s and S . Let us write an equation that simulates the dynamics of inventory and uses the (s, S) -strategy for the control. It is known that within the framework of (s, S) -strategy for $y \geq s$, the system does not require replenishment of stocks, and for $y < s$, an order for replenishment of stock is sent in the amount of $(S - y)$. Unsatisfied applications do not leave the system but wait until the stock shortage is eliminated by the next order. All research is done for discrete demand.

Let's renumber applications as they enter the system. We can assume that their number is infinite. The obvious relationship holds:

$$\begin{aligned} y_k(x[i]) &= y_{k-1}(x[\eta_k - 1]) + \\ &+ (S - y_k(x[i]) \operatorname{sgn}(s - y_k(x[i - 1]))) - x[i], \end{aligned} \quad (3)$$

where $i = 1, 2, 3, \dots$;

$y_0(x([\eta_0]))$ is initial stock level;

k is period number by order;

η_k is number of the last application in the k -th period, determined from the condition:

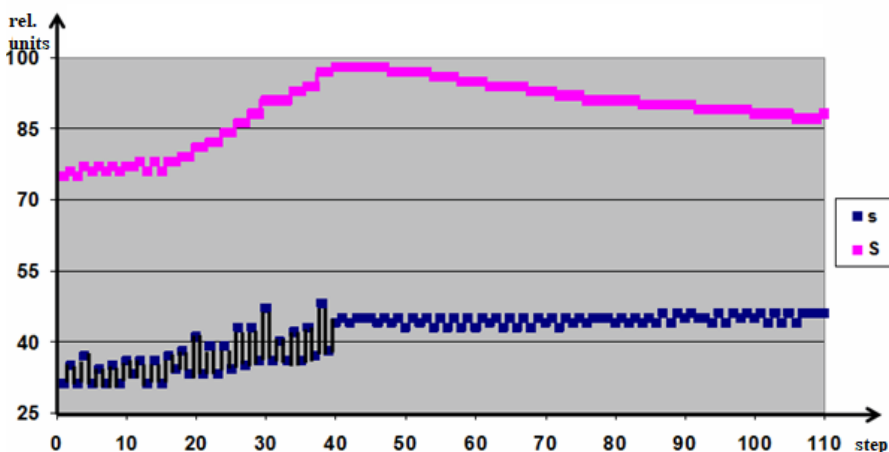
$$\operatorname{sgn}(s - y_k(x[i - 1]) - x[i]) = 1 \rightarrow i = \eta_k. \quad (4)$$

It should be noted that in (1)–(4) time does not occur explicitly. The time dependence is essential for objects, the cost functions of which change over the considered period. As a rule, the type of the cost function for mechanical engineering objects does not change during the optimisation period.

Nevertheless, the problem of optimisation of stocks of spare tools and accessories (spare parts) for road, railway transport and for special vehicles is of considerable practical interest.

Special equipment is a large class of special vehicles in construction, industry, cargo transportation, and military field. Road special vehicles is subdivided according to its functional purpose into civil construction, roadbuilding, agricultural, fire-fighting vehicles, railway special vehicles, etc., which require optimal number of spare parts for good operation.

Time factor in IMS often plays an auxiliary role. In fact, the level of stock in the warehouse is important at the moment of receipt of the next order, while the time itself of receipt of orders is not so important. A deficit is possible only for $s < 0$. If there is a delay in the system, then a deficit may appear for $s > 0$ as well. In this case, when obtaining the initial information and with an equation similar to (3), it is possible to apply the algorithms without using time in an explicit form, despite the fact that delays have the



Pic. 1. Graphs of changes in stock levels of spare part (plate 1) for the automotive industry enterprises (compiled by the authors).

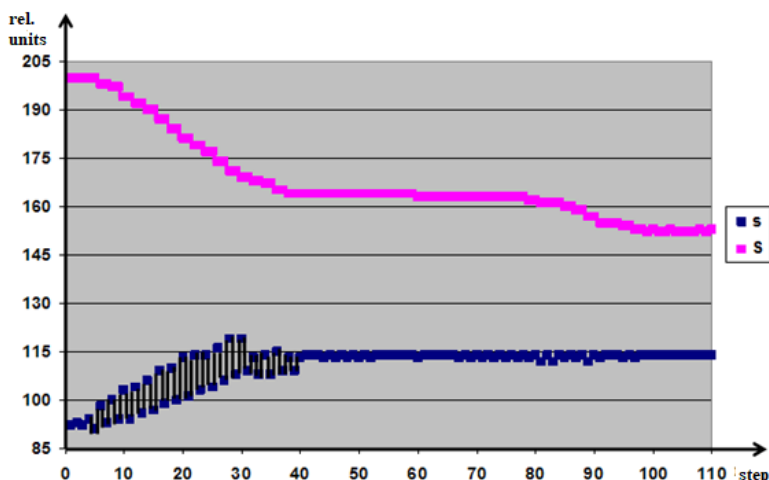
meaning of a time interval. When modelling the dynamics of the stock level, we will consider a random delay through a random number of applications arriving during this time interval. With this approach, it is possible to abandon timing of the change in the level y , which significantly reduces complexity of obtaining the initial information. All that is needed is data on the size and sequence order of individual applications, not on their temporal distribution. Information about the size and sequence order of applications in the examples under consideration was established by accounting documents.

Since the methods using the first derivative (gradient) are a necessary condition for an extremum, we will compare the values of the criterion in the process of calculating $s[p]$, $S[p]$

for different p . For functional (1), we use an algorithm of the type (2):

$$\begin{aligned} J_e[p] &= J_e - 1[p] - f_e[p] \{F(Z(y(s[p], \\ S[p], x[c]))) - J_e - 1[p]\}, \\ \text{where } J_e[p] &= J_e(s[p], S[p]). \end{aligned} \quad (5)$$

As a possible conditional example, a mathematical model of the problem of optimising the level of stocks of plates 1 and 2 (Pics. 1, 2) is considered for the automotive industry with random demand and random time delay. The authors checked efficiency of the computation program developed by them according to the system of algorithms (1)–(7) on the given model of stocks movement. To avoid discussion that is not related to the content of the work, the authors provide data in relative units, while the mode of operation



Pic. 2. Graphs of changes in stock levels of spare parts (plate 2) for the automotive industry enterprises (compiled by the authors).

of a real warehouse was simulated. Initial input information about movement of material objects can be obtained from the reporting data directly at the warehouse. Technical and economic functions can be obtained from financial reports with subsequent approximation of the initial data using orthogonal Chebyshev polynomials according to well-known techniques [9–11].

The results of calculations carried out by the authors using relations (1)–(5) for conditional examples are shown in Figs. 1, 2. Along the horizontal axis, the numbers of demand applications are plotted in the sequent order of reception by the control system, along the vertical axis, the changes in the levels s and S are plotted as compared with the initial values established by experts. The converged values of s and S are taken as optimal, as corresponding to the minimum of the objective functional.

CONCLUSIONS

The paper presents a mathematical model of a stochastic IMS developed by the authors based on production logistics methods and proposes an implicit method for accounting for delay in ordered delivery aimed at replenishment of stock in a warehouse through accounting for orders received during the time of delay of applications (demand), which was the objective of this publication. Recurrence relations (2) were obtained by methods of identification theory [6]. Thus, the use of modern methods of production logistics made it possible to construct a scheme for optimising the level of material resources in the warehouse, which can increase the efficiency and competitiveness of the activities of specific enterprises.

It should be noted that digital technologies, which are also classified as IT technologies, are currently widely used in management of industrial production and technological processes. In particular, research on application of digital technology is currently being carried out in the Russian The Central research and development

automobile and engine institute NAMI, in many other Russian transport organisations and associations.

The model proposed by the authors can be useful for adoption and implementation in inventory management.

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*Neutralization of transport documents:
reasons and risks.*



URBAN TRAFFIC 221

*Example of integrated approach
to solving a problem at a single street
in a single city.*

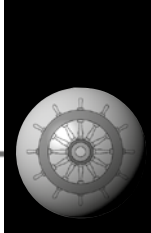
ADMINISTRATION, MANAGEMENT AND CONTROL



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*Practical significance and importance
of harmonisation of the term.*





ORIGINAL ARTICLE

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Neutralization of Transport Documents in Road Transport



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ABSTRACT

In 1956 there was a significant step in international road freight transport – conclusion of Convention on the contract of carriage in international road freight transport (CMR Convention), the basic purpose of which was to unify the rules in the international transport of goods and thus promote the development of international trade. From a practical point of view, this was very important for both carriers and transporters. The Convention describes the most important document in the carriage of goods – the CMR consignment note.

Recently, the term «neutralization» has been used in connection with the CMR consignment note, which is considered as an interference with the system of functioning of transport documents, which aims to obscure the actual movement of the consignment during transport. At the same time, neutralization of the consignment note is not so much contrary to legal norms as it can lead to undesirable consequences for carriers. For this

reason, the question of whether it is possible to neutralize the CMR consignment note in accordance with the current rules and whether the neutralization of the CMR consignment note does not violate the functionality of the existing system is relevant. Therefore, the objective of this work is to study the reasons and methods for neutralizing CMR consignment notes, as well as options for handling neutralized consignment notes.

Considering that neutralization of the consignment note has become a relatively common practice and means the exchange of original consignment notes or transport documents with other consignment notes or transport documents, canceling the actions of the first consignment note, in the article the authors, based on their own research, identified the possibilities of using the neutralization of the CMR consignment note in practice for certain types of goods, routes of the most frequent use, as well as the risks of these procedures in road transport.

Keywords: transport, contract, document, Convention on the contract of carriage in international road freight transport (CMR Convention), document neutralization, parallel trade.

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INTRODUCTION

Obviously, in the modern world is an important need for mankind and is also a prerequisite for normal functioning of trade. Within the EU, road transport has gradually gained a dominant position, mainly due to reasons such as a quality and dense road network, flexibility, speed, convenience, adaptability, and many others [1; 2]. Transport of goods in the framework of international trade is possible only based on the conclusion of the transport contract [3; 4]. Concluding such a contract would be significantly more complicated if there were no Convention on the contract of carriage in international road freight transport (CMR Convention). Carriers would have to proceed according to the particularities of the national regulations of the countries where the transport would take place. In 1956 in Geneva CMR Convention was concluded. The purpose of the Convention is to standardize the conditions governing the contract of carriage of goods in the cross-border carriage of goods. The CMR consignment note plays an important role in such transportation. It is a document of the conclusion of the contract of carriage and at the same time, it is a document of acceptance of the consignment by the carrier [5].

Neither the CMR Convention, no other legal documents knows the term neutralization of transport documents.

The *objective* of this article is to identify what procedures, in terms of transport documents and the responsibilities of the contracting parties, take place in the neutralization of documents. There is a presumption that in the neutralization of documents one of the contracting parties is harmed or one of the contracting parties assumes a greater risk in the standard contractual relationship. In the article the authors, based on own research, formulated proposals that would help the contracting parties to identify and prevent the neutralization of documents if the neutralization could harm the rights of the person.

Analysis of the Current State

Concluding a contract of carriage for international transport would be significantly more complicated for the carrier in the absence of the CMR Convention. In this case, the carrier would have to know all the national transport regulations of the countries where one would like to carry the goods [6]. There would be misunderstandings in the conclusion of contracts, including claims on the carrier, due to differences

in legislation between countries and due to their inconsistent interpretation [4]. Therefore, in Geneva on May 19, 1956, CMR Convention was adopted. The basic purpose of this Convention is to unify the rules in the international carriage of goods by road, thereby promoting the development of international trade. From a practical point of view, this is of great importance for both carriers and transporters, since in the absence of such a convention everything would be governed by national regulations [7]. In 1978, a Protocol to the Convention was amended in Geneva, regulating Article 23 describing compensation for damage [8]. Later in 2008, the Convention was supplemented by an Additional Protocol, the amendment relating to the electronic consignment note.

International transport is a transport where the place of loading is in a country other than the place of unloading [9]. The CMR Convention may be used for the international carriage of goods only if the place of loading or the place of unloading is in a State Party to the CMR Convention [10; 11]. There are three exceptions where it is not possible to conclude a contract of carriage under the CMR Convention, even though it is an international carriage [12; 13]. The Convention does not apply to the carriage of postal items, dead persons and migratory uppers. The main reason why these consignments cannot be transported under the CMR Convention is the fact that it is not possible to objectively determine the value of the consignment and thus to identify the carrier's liability for carriage [14]. The Convention has been gradually ratified by individual European countries, but non-European countries are also contracting parties. Currently, 56 countries have signed the CMR Convention, of which only 45 have ratified the Protocol to the Convention [15]. The member countries are listed in the Table 1. The first column lists the countries that have adopted the Convention as well as the Protocol to the Convention. In the second column are countries that are only members of the CMR Convention.

The CMR Convention governs the rules, rights, obligations, and responsibilities of the carrier and the transporter. It regulates the conclusion and implementation of transport contracts as well as the procedures for claiming damages [16]. It further describes what the accompanying documents for transport must contain [17]. It describes the most important document in the international transport of goods, which is the



Table 1

States Parties to the CMR Convention*

CMR Convention and CMR Protocol	Only CMR Convention
France, Austria Netherlands, Germany Italy, Poland Belgium, Luxembourg Denmark, United Kingdom of Great Britain and Northern Ireland Norway, Sweden Portugal, Switzerland Hungary, Romania Finland, Spain Greece, Russian Federation Ireland, Slovenia Croatia, Lithuania Belarus, Estonia Republic of Moldova, Slovakia Czech Republic, Latvia Tunisia, Turkey Uzbekistan, Turkmenistan North Macedonia, Kyrgyzstan Iran, Georgia Cyprus, Lebanon Armenia, Albania Malta, Jordan, Pakistan	Bulgaria Bosnia and Herzegovina Morocco Kazakhstan Tajikistan Serbia Mongolia Azerbaijan Montenegro Ukraine Syrian Arab Republic

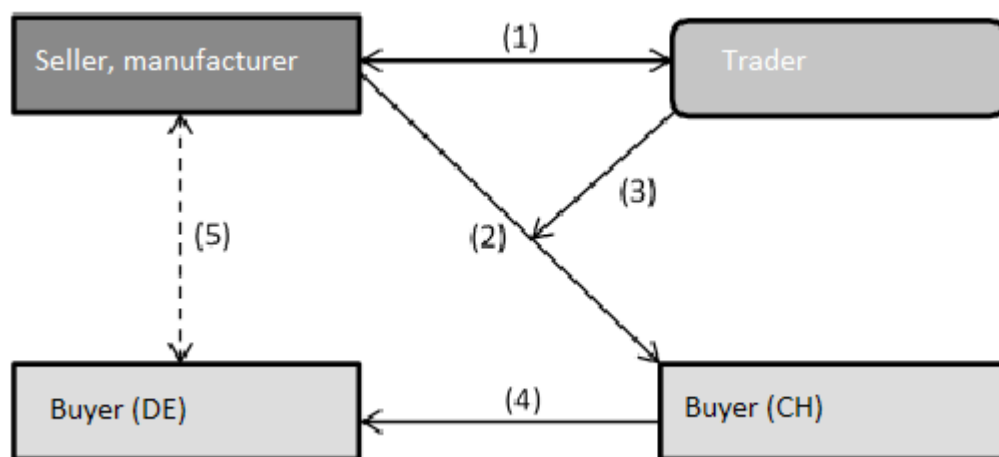
Compiled by the authors based on the UNTC.

* The text of the Convention: https://unece.org/fileadmin/DAM/trans/conventn/cmr_e.pdf.

CMR consignment note (an official document that has a standardized form and is usually written in two languages) [18–20]. The consignment note shall be drawn up in three original copies signed by the consignor and the carrier [21]. The first red copy shall be addressed to the consignor and shall be a proof to the consignor that the goods have been handed over to the carrier for carriage. The second blue copy shall be handed over to the consignee of the goods so that he knows how many goods to take over from the carrier. The third green copy shall remain with the carrier and shall also constitute proof that the goods have been handed over to the consignee [22]. Unless proven otherwise, the consignment note shall be credible proof of the conclusion and content of the contract of carriage as well as the acceptance of the consignment by the carrier. If the consignment note does not contain the carrier's statement of reasons, the legal presumption is that the consignment and its packaging were in good condition at the time of acceptance by the carrier and that the number of packages, their marks, and numbers corresponded to the information on the consignment note [14; 23].

The carrier's liability shall commence at the moment of acceptance of the goods for carriage and end at the moment of delivery of the goods to the consignee [24; 25]. The carrier is responsible for damage or loss of the goods during

transport and also for exceeding the delivery time. The Carrier has to, by the provisions of the CMR Convention, compensate for any loss of the consignment arising from the moment of its acceptance for carriage to the moment of its delivery [26]. The refund shall be calculated based on the value of the consignment at the place and time of its acceptance for carriage. The value of the consignment is determined by the exchange price, if not the exchange price, by the current market price, and if neither the exchange price nor the market price, by the general value of goods of the same nature and quality [27]. The CMR Convention provides that damages may not exceed a fixed amount per kilogram of missing gross weight. In the original version of the CMR Convention, damages may not exceed 25 francs per kilogram of missing gross weight. Franc means a golden franc weighing 10/31 grams and a purity of 0,900 [15]. This limitation of liability currently applies in eleven countries that have not ratified the CMR protocol. Other countries have significantly reduced the liability of carriers by replacing the gold franc with a unit called Special Drawing Rights (SDR). The carrier is obliged to compensate the owner of the transported goods in the amount of 8.33 SDR for each kilogram of damaged, destroyed or lost goods. The specific value depends on the SDR and EUR exchange rates [28–30]. The carrier



Pic. 1. Scheme of neutralization of CMR consignment note at parallel trade (compiled by the authors).

must also cover the transport, customs and other expenses involved in the carriage of the consignment. This value is also covered by the liability insurance of the carrier. However, if the CMR consignment note states the price of the consignment or the consignor's particular interest in delivery, in this case, the carrier is liable for the full value of the goods thus indicated. In the event of the total loss of the consignment, the carrier must pay the full value of the goods as well as import charges, customs duties, VAT, excise duties, etc. If this value is higher than the amount of the insurance coverage of the carrier's liability arising from the CMR Convention, the carrier should insure such goods [31]. This applies in particular to light and expensive goods. If the delivery time is exceeded and the consignee proves that he has suffered damage, the carrier is obliged to pay only the amount of the delivery charge.

The above analysis confirms that the CMR Convention is an important legal standard for both the carrier and the transporter. The CMR consignment note constitutes a credible document for both the carrier and the transporter. CMR consignment note is also a credible document for third parties, eg. customs offices, insurance companies, etc. For this reason, further consideration should be given to whether the CMR consignment note can be neutralized under the rules currently in force and whether the neutralization of the CMR consignment note does not jeopardize the functionality of the existing system.

Research of the Concept of Neutralization of the CMR Consignment Note and its Reasons

The neutralization of document is a process known only to the transport sector. The authors of this article have failed to get the definition of this term in any legislation or standards. Nevertheless, this term in road freight has been known and used for some years now. The word neutralization has several meanings. Generally, it also means revocation [32]. In transport, neutralization means the exchange of original consignment notes or transport documents with other consignment notes or transport documents. It is, therefore, the annulment of the effect of the first consignment note [33].

The neutralization of transport documents is in most cases linked to illegal logistics activity called «'parallel trade'». Parallel trade is defined as a trade-in product that takes place outside official distribution and is created by a particular company [32; 34]. Through their distribution, companies can cause price differences in different countries, exploiting national differences in consumer behaviour. Parallel merchants buy products in countries where they sell them at lower prices and then sell them in countries with a higher price. The product is not forged but imported from the country without the permission of the owner of the intellectual property.

The neutralization of consignment note in the parallel trade can be explained in the following Pic. 1.

The explanations to the scheme are as follow.

(1) The trader agrees with the seller (manufacturer) that he will distribute his product to a country where his product is not currently sold (for example Switzerland) if he is offered a lower price than his original sale price. Lower



sales price because of promotion in the new market.

(2) The CMR consignment note is written, whereas a consignor is mentioned the manufacturer and as the buyer is listed company in Switzerland.

(3) After the goods begin to be transported, the driver receives a command to neutralization CMR. He stops the vehicle for example at the gas station and neutralizes the CMR consignment note.

(4) This consignment note lists Switzerland's company as the consignor and the recipient is a German company. The trader sells these goods in Germany at a much higher price than the one he bought, (5) while the manufacturer does not know that his goods are sold in Germany, where he already sells these goods.

The purpose of neutralizing the consignment note should be to ensure business secrecy, where the trader wants to prevent the recipient from knowing the manufacturer and purchasing terms. Based on theoretical research the following can be identified reasons for neutralizing the consignment note:

Reason A – when the trader does not want the manufacturer to find out who is buying the product. In this case, the driver loads the goods in the vehicle and writes out a CMR consignment note indicating the consignor and the original consignee. After a while, the driver will be instructed to neutralize and writes out new documents indicating another consignee.

Reason B – when the trader does not want the customer to know where the goods are produced. The driver loads the goods into the vehicle and the consignment note is sent to the consignee's warehouse indicating the place of loading other than the actual one. In the event of a roadside check, the driver shall draw up a consignment note indicating the actual place of loading and unloading of the consignment. However, the end customer will receive documents in which the place of loading is different from the actual one, so he will not know who the actual producer of the goods is.

Reason C – Nobody knows anything, that is, the manufacturer does not know where the goods are and the final customer does not know where the product comes from. This is the case when the driver loads the goods into the vehicle and writes out a consignment note which is stored in the warehouse of departure. Later, the driver will be instructed to neutralize and will issue a new

consignment note indicating the actual consignor but the new consignee. Subsequently, before approaching a new consignee, the driver shall write out a third consignment note in which the consignor is different from the actual consignor and the new consignee listed in the second consignment note.

Based on this, it can be argued that there are up to three ways of neutralizing transport documents. We conducted our research in the next part which is based on the theoretical identification of the problem of neutralization of transport documents.

RESULTS OF THE OWN RESEARCH

For acquiring information about the neutralization of consignment note of CMR, a survey was conducted electronically, in software called «Google Forms». After the creation of a survey, the pre-test was done to confirm that questions are understandable enough. Later, this survey was sent to the public on discussion forums, then it resented through the social sites and added into groups including members of the road freight transport (transporters). There were 190 respondents who filled the survey.

The questionnaire contained 3 questions. The first question aimed to determine whether carriers (drivers) have experience in neutralizing CMR consignment note. The second question aimed at identifying the type of goods in which the CMR consignment note was most neutralized. As a final question, we wanted to find out on which transport routes the consignment note was used (the country of dispatch and the country of destination). The questionnaire survey was carried out to obtain basic information on the possibility of using the neutralization of the CMR consignment note in practice and for what kind of goods it is most often performed. We also wanted to find out that if carriers have real experience with the neutralization of transport documents, what countries are in such cases indicated in the shipper and consignee boxes in the CMR consignment note.

Survey output confirms the assumption that carriers have experience with neutralizing the CMR consignment note. The results of the survey show that up to 66 % of the interviewed carriers (drivers) already have experience with neutralization, 34 % have no experience or have never encountered the concept of CMR neutralization. Although no special literature describes the neutralization of the CMR consignment note, it

Table 2

**Share of transported consignments in Slovakia and neutralized consignments
(compiled by the authors)**

Type of goods	Share in total transportation in Slovakia (%)	Share in total neutralized transportations (%)	The ratio of the share of transportations of a particular commodity to that of transportations with neutralized documents
Secondary materials; municipal waste and other waste	3,50	21,25	6,0714
Wood, articles of wood and cork; articles of straw and plaiting materials; pulp, paper and paper products;	3,52	8,75	2,4858
Textiles and textile products; leather products	0,59	1,25	2,1186
Food, beverages and tobacco	8,82	17,50	1,9841
Chemicals, chemical products and man-made fibers; rubber and plastic products; nuclear fuel	5,51	7,50	1,3612
Furniture; other industrial goods	2,11	2,50	1,1848
Machinery and equipment; office machines and computers; electrical machinery and apparatus	5,32	6,25	1,1748
Metal ores and other mining and quarrying products; products thereof; turf; uranium and thorium	36,62	27,50	0,7510
Transport equipment	4,67	2,50	0,5353
Equipment and material used in the carriage of goods	3,89	1,25	0,3213
Products of agriculture, hunting and forestry, fish and other fishery products	13,18	3,75	0,2845
Other non – metallic mineral products	9,35	0,00	0,0000
Coke and refined petroleum products	2,44	0,00	0,0000
Coal and lignite; oil and natural gas	0,23	0,00	0,0000
Goods transported during the moving of household and office; luggage	0,14	0,00	0,0000
Unidentifiable, other goods	0,12	0,00	0,0000
Total	100 %	100 %	–

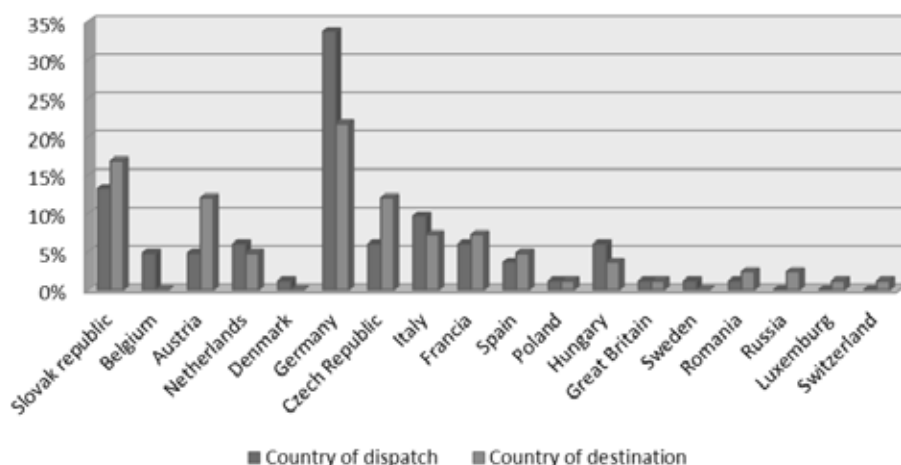
should be noted that carriers are commonly encountered with these practices.

The second part of the research dealt with the question of what kind of goods usually requires the consignor or consignee to neutralize the transport documents. The results of the research are expressed in Table 2, which describes the different categories of goods reported by the carriers as transported goods that were entered in the CMR consignment note in box 9 Labeling of goods in case the consignment note was neutralized. It may be noted that the documents are neutralized for different types of goods. The table also contains information on the percentage of individual categories of transported goods in Slovakia (information from EUROSTAT). However, this survey shows that the most neutralization is associated with the transport of metal ores and metal products (27,50 %), which represents the most transported category of goods in the Slovak Republic (36,62 %). Furthermore, in the

volume of 21,25 % of all neutralized documents were related to the transport of waste. In the Slovak Republic, it is not often transported type of goods, only 3,5 %. On the third place is the transport of food and beverages, which represents almost 18 % of the total neutralized transported quantity of goods, the fourth most frequently transported type of goods in Slovakia. On this basis, it can be said that neutralization does not, therefore, apply to specific transported goods and is not related to the total volume of transported goods in Slovakia (both high and lower share of transported goods).

However, if we observe the importance of neutralizing transport documents to the share of transport of a particular commodity, then the highest share is achieved by secondary materials, municipal waste and other waste. These shipments account to share for only 3,5 % of total transport but up to 21,25 % of total transport with an identified neutralization of tickets (the ratio





Pic. 2. Country of dispatch and destination at neutralizing transport documents (compiled by the authors).

between the percentages reaches a coefficient of up to 6,0714). Furthermore, the following items are also important from the neutralization of transport documents: wood, articles of wood and cork; articles of straw and plaiting materials; pulp, paper, and paper products with a coefficient of 2,4858 and textiles and textile products; leather products with a coefficient of 2,1186.

The last part of the research was aimed at obtaining information on transport routes where neutralization is used. We wanted to find out from the carriers on what transport routes they received a request from the customer to carry out the neutralization of the consignment note. As different transport routes were mentioned, these routes were divided into countries of dispatch and destination. The results are shown in Pic. 2, which shows that Germany is the country where neutralization is most used. Germany accounts for almost 35 % of the replies as the country of dispatch and 22 % than the country of destination. Furthermore, neutralization is mainly used in connection with the Slovak Republic. The other countries mentioned were not listed as much as Germany and Slovakia.

This survey also showed that neutralization is used not only for international transport but also for national (cabotage) transport. 87 % of carriers carried out the neutralization of the consignment note for international transport, the remaining 13 % for domestic transport.

Risks Associated with the Neutralization of Transport Documents

With the neutralization of the transport documents, which in practice exists and which is

described above, some risks arise not only on the part of the consignor but also on the part of the carrier. To neutralization, we identified the following risks:

- *Fraud risk* occurs when someone enriches someone else's property or otherwise by misleading someone or using someone else's mistake, causing damage to someone else's property. The carrier cannot know in advance whether neutralization will be used to conceal fraud on the consignor. Fraud is circumventing a regional pricing policy or getting rebates that are not eligible. For example, if the consignor requests a lower price from the manufacturer for deliveries to the Baltic States, so that the goods can be placed on a new market. The goods will be transported to Germany. The Sender will mislead the manufacturer, and there will be a lie and a violation of the Criminal Code. This type of trading is known as «Parallel trade».

- *Damaging foreign rights* occurs when someone else causes serious harm to rights by misleading someone or making use of someone's mistake. According to Article 12 of the CMR Convention, the seller has the right to change dispositions until the moment of delivery and if the holder of the first copy of the CMR. For example, if the consignee is found to be insolvent, it has the right to require the carrier to return the goods. However, if the consignment note is neutralized immediately after loading, this right is difficult to assert.

- *Risk of insurance of the carrier's liability.* The carrier in the event of a loss event must prove to the insurance company the original transport documents related to the carriage in which the

consignment or its part was damaged. The carrier, who on the order of the customer exchanges the transport documents during the carriage, carries out the carriage according to other conditions than originally agreed in the contract of carriage. According to the opinion of several insurance companies, they would not realize insurance benefits when the transport documents were neutralized. In this situation, there is a risk on the part of the carrier that it carries out the transport without insurance coverage.

In addition to these risks, there are other risks in the area of tax law or cabotage operations, which we will not discuss in detail because they are either on the side of the transport customer or on the side of the carrier who is aware that the transport documents have been neutralized.

CONCLUSIONS

The CMR Convention, which governs the contract of carriage for international road freight transport, is today the most important instrument of sharing responsibility between the carrier and the customer. The CMR Convention also defines credible documents that are necessary for the execution of the carriage and which constitute proof of the carriage not only for the parties but also for third parties. In the absence of credible research into the neutralization of the transport documents, the paper aims to confirm the hypothesis that the documents are neutralized. Research by the authors confirmed that in practice the transport documents were neutralized. Up to 66 % of the surveyed carriers confirmed that they had neutralized the transport documents at the request of the client of transport. From further research, it can be concluded that neutralization does not only apply to the transport of a particular type of goods. However, we can say that our research shows that documents are most neutralized when transporting secondary materials, municipal waste, and other waste. We have also concluded that the consignment note exchange is used on different transport routes. It is mostly connected with the transport of goods from/to Germany and further from/to Slovakia. Neutralization is used not only in international freight transport but also in national freight, where there may be problems of non-compliance with cabotage conditions.

Since neutralization of the consignment note is not a technical term and is not defined in any legislation or the CMR Convention, the neutralization procedure needs to be specifically

addressed. In this article, we identified some risks on the shipper and carrier side. These are mainly risks related to fraud and infringement of the sender's property rights but also risks related to insurance of the carrier's liability. The authors are aware that there are other risks, for example in the tax area. This paper presents a proposal to prevent the neutralization of the CMR consignment note from the position of the sender. In case the sender has access to data from the transport route – according to the unique CMR consignment note number, the neutralization of the transport documents will be limited. Similarly, in terms of tax risk, it would be appropriate to provide this information to the financial administration. Further research would need to be devoted to this issue.

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The Project of Organizing Non-Stop Traffic at T-Intersections (Tyumen Case Study)



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ABSTRACT

The constant growth in the number of cars and trucks in single industry towns is forcing road design engineers to find ways convenient for all road users and pedestrians to move at intersections. Fulfilling such conditions is a difficult task but it can be solved, especially if there are many T-shaped intersections along the entire length of the road. Most often they are located along the line of railways, heating mains, river or lake banks, parks, etc. Since there are no adjacent roads, it is possible to ensure continuous movement of cars, but only in one direction.

The objective of this work is to substantiate the project aimed at ensuring unhindered traffic at T-intersections of vehicles following 50 let VLKSM street in the city of Tyumen.

To achieve this objective, the method of observation and recording, as well as the analysis of operation of optical devices

that regulate passage of cars at intersections were used. With newly designed travel mode, there is no infringement of rights in relation to other motorists and pedestrians since the traffic light mode for the rest of segments keeps the same counting in seconds. A system of safe pedestrian crossing is envisaged along with an improvement in the environmental component of the whole city.

For initial adaptation of motorists to new conditions, it is proposed to use a side green vertical arrow attached to the traffic light and signal columns that delimit traffic lanes for a «slow merge» into the flow of those leaving the secondary road. An undeniable advantage of this type of design is the minimum cost of reconstruction of intersections. Based on author's own observations, it can be argued that this project increases traffic of vehicles moving from the central part of the city to the eastern part by 1,5–1,8 times.

Keywords: transport, T-shaped intersection, traffic lights, road marking, traffic organisation.

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INTRODUCTION

The number of vehicles sold and registered in Russia is growing steadily from year to year. Basically, this increase occurs in regional centres and large cities of the country. Both passenger cars and trucks are registered by individuals and organisations. Unfortunately, transport interchanges, overpasses, roads in most cities of the Russian Federation do not have time to cope with the constantly growing number of vehicles [1]. Even after construction of new interchanges, which were supposed to increase traffic capacity, motorists still often experience difficulties when driving through this or that intersection. Sometimes inauguration of new interchange is expected for years due to calculation errors during construction, lack of funding, etc. And all this aggravates the situation even more. Obviously, an option is needed that would combine minimum cost estimate, minimum construction or reconstruction time at road segments, and will ensure a safe crossing for pedestrians, but under all these conditions, road capacity for vehicles would increase [2].

For the most part, the transport infrastructure of the city of Tyumen is a balanced traffic of vehicle and pedestrian flows. The markings have been applied, delimiting traffic lanes, traffic light switching has been correctly adjusted, there are smooth road surfaces, new pedestrian crossings and those under construction, etc. Despite the well-developed concept of traffic flows, the city still suffers problems with congestion at intersections, mainly in city's central parts. Based on the experience of other cities [3–6; 10; 15], these problems, as a rule, are proposed to be solved by increasing the number and expansion of carriageways, additional construction of second-level roads (above the main road), using reverse traffic, regulated depending on the growing traffic flows at different times of the day.

But what if the carriageway is expanded to its maximum limit, and the construction of second-level roads and reverse traffic is not possible due to the fences on the carriageway? The answer to this question is that it is necessary to develop such a traffic project that will increase road traffic capacity with the minimum amount of road works and estimated costs.

The *objective* of this article is to create a typical project for T-shaped intersections, with the possibility of increasing car traffic in one of the directions. The objective is studied using the case of one of the central streets of the city of Tyumen.

As research *method*, the study of automatic operation of traffic light control and of the number of vehicles moving at T-shaped intersections from the central part of the city to the eastern part is applied.

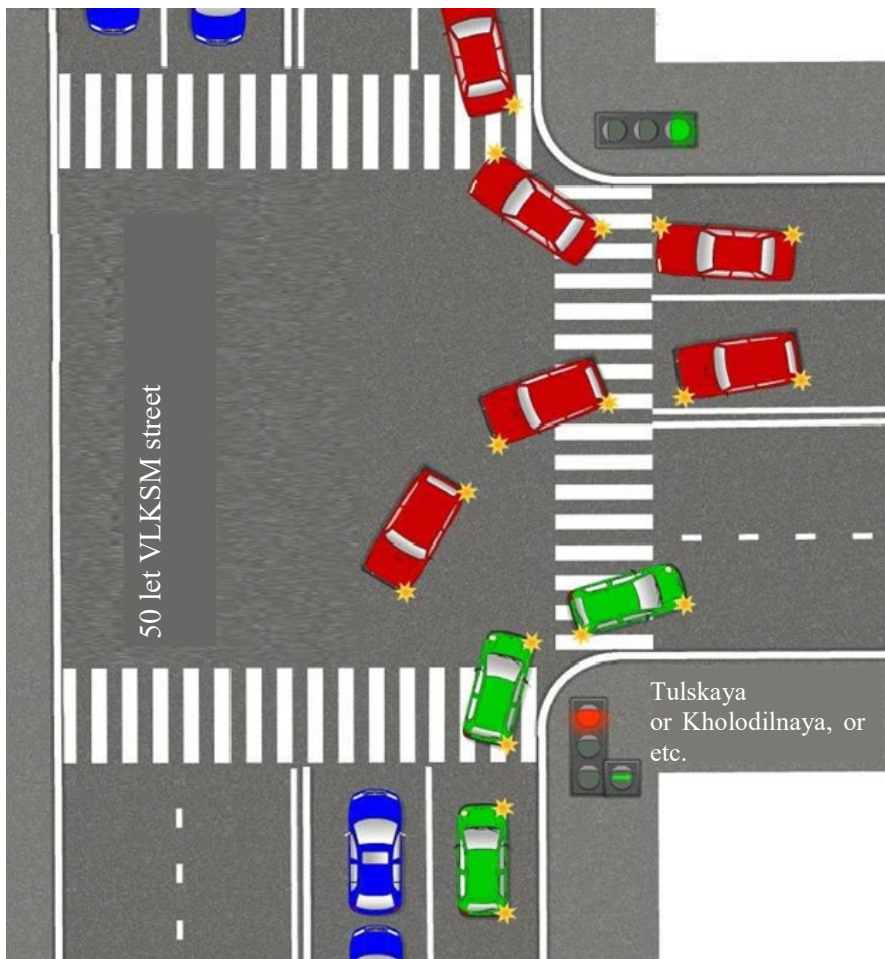
RESULTS

Input Conditions

It is proposed to consider the example of 50 let VLKSM street, coming from Zapolnaya street and ending at the intersection with Montazhnikov street. The fact is remarkable that this street connects the city centre with its eastern part. It is in the eastern part of the city that new residential neighbourhoods are being actively built, and universities, shopping centres, recreation areas, etc. are concentrated in the central part. Hence, the emphasis is put on this road-and-street section.

50 let VLKSM street in Tyumen is a duplicate of another central street, Respubliki street, therefore, increasing traffic capacity in this area is extremely important for the entire city. The traffic congestion at the 50 let VLKSM street is sometimes even more than that of its backup since vehicles with a permitted maximum weight of more than 3,5 tons are prohibited from moving along Respubliki street in its central part. When carrying out work on recording time of traffic light operation (in the direction from the centre to the eastern part of the city) on weekdays from 7:30 to 19:00, it was found that the green traffic light was on at all T-sections for the period from 50 to 60 seconds. During this period, 45–50 units of vehicles pass in the forward direction, the rest stop in front of the prohibiting traffic light. The red signal lights up from 35 to 40 seconds, and during this time 2 to 6 more cars join the standing cars, approaching from the secondary road.

Most of the intersections on this section of the road are T-shaped, as shown in Pic. 1. With minor amendments, the intersection of 50 let VLKSM street with Maksim Gorkiy, Kholodilnaya and Permyakova streets can also be attributed as being T-shaped. Their difference is that, moving from west to east, there is an additional lane for turning left or making a U-turn. Also, at these intersections there are turns to the right (crossing Maksim Gorkiy street), where the car service is located, and to the gas station (crossing Kholodilnaya and Permyakova streets). Based on the observations of movement of vehicles at these intersections, it can be noted



Pic. 1. Scheme of T-shaped intersection at the street 50 let VLKSM (compiled by the author).

that the number of vehicles leaving them on 50 let VLKSM street is so small that it is possible to remove the traffic light near a car service, gas stations and make an exit as «from the adjacent territory when it is allowed to turn only to the right».

Design Proposals

To implement the design solution for development of unhindered traffic along the 50 let VLKSM street in one of the directions, it is proposed to do the following:

- To install signs allowing only left turn from the left lane and right turn from the right lane only at all the T-shaped intersections entering the 50 let VLKSM street.

- To keep the same mode for traffic from east to west, namely for vehicles driving in the extreme right lane to install signs allowing going straight and to the right, for those moving in the left lane there will be sign allowing going only straight forward.

- When driving from west to east of the city in the extreme left lane, it is possible to make a left turn and a U-turn, and the extreme right lane can be intended for driving straight, except for right turns (e.g., to car services and gas stations), if there are any.

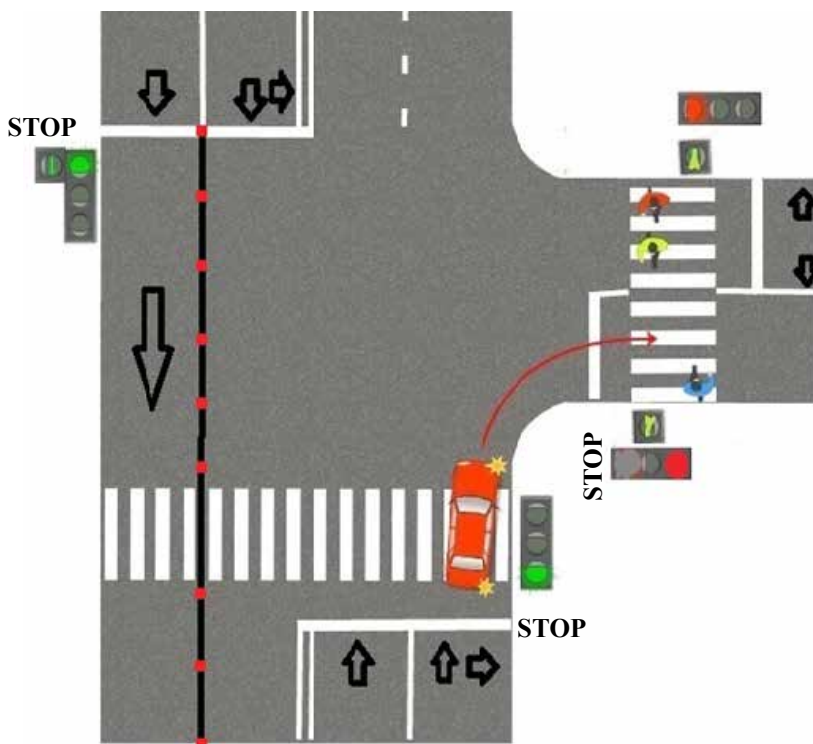
- To carry out markings for a pedestrian crossing across the 50 let VLKSM street on only one side of the intersection.

- To equip the installed traffic lights with special buttons for manual switching on for pedestrian crossings, after a certain time interval, and it is proposed to leave the same time for passing and waiting for vehicles.

An approximate design option will look as shown in Pic. 2.

For initial introduction of this project, so that motorists can develop a habit, it is possible to install additional signs [12] before entering the intersection and to separate the far right lane, for example, with signal identification posts (Pic. 3).





Pic. 2. An approximate typical design of a T-shaped intersection for unimpeded movement in one of the directions (compiled by the author).



Pic. 3. Signal identification posts.

CONCLUSIONS

When implementing the project of a T-shaped intersection along its entire length of 50 let VLKSM street at the intersection with secondary roads, it is possible:

- To ensure unimpeded movement from the city centre to its eastern part, thereby increasing average speed of movement of vehicles, including freight vehicles with a maximum permissible weight of over 3,5 tons.
- Not to infringe on other road users in delaying traffic lights.

- To stay in the limits of minimum cost estimate for reconstruction.
- To avoid global construction works.
- To increase car traffic by 1,5–1,8 times.
- To create convenient schemes for operation of pedestrian crossings.
- To organise safe conditions for pedestrian crossings.
- To reduce downtime of vehicles at intersections, which will entail a decrease in emission of harmful gases and improve the environmental situation.

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Editor's note. Even though the research is of applied and local nature and does not pretend to generalise the conclusions, it seems that precisely because of its specific focus, its results can be of interest and might be useful due to the similarity of the problems experienced in many cities with comparable traffic congestion.





ORIGINAL ARTICLE

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Structural and Content Characteristic of the Object of Combined Transport

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ABSTRACT

The article presents the results of a comparative analysis of equivalence of structural and content characteristics of individual terms used in combined transport contained in various official regulatory documents. Differences in definitions of individual terms in that subject area often impede effective integration of transport systems at interregional or international level. This study focuses on the analysis of characteristics of structural components of the

objects of combined transport, which are contained in definitions of this term in a number of international agreements, national regulations and interstate standards. The results of the study have allowed to formulate proposals aimed at unification of structural and content characteristics of the object of the combined transport as well as recommendations for improving certain regulatory documents.

Keywords: transport, multimodal transportation, intermodal transportation, combined transport, international agreements on combined transport, objects of combined transport.

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INTRODUCTION

Transport plays a decisive role in ensuring sustainable social and economic development of any state. Moreover, this thesis is of particular importance for the countries of Europe and Asia. Since ancient times, reliable and efficient communications implemented with different modes of transport have been the main condition for expanding international and interregional trade and humanitarian cooperation between the countries of the Eurasian continent. A striking example of the key role of land transcontinental routes in establishing such cooperation is demonstrated by the Great Silk Road, which was actively used in ancient times and is rapidly reviving in recent years on a new modern technical, technological, and organisational basis.

At the same time, more and more countries of the continent are interested in development of predominantly land international transport communications using several modes of transport with dominant participation of railways. It is sufficient to note that there is demand for new railway routes of the revived Silk Road for foreign trade relations as evidenced by high growth rates of traffic volumes and of the number of container trains in transit through the countries of the Eurasian Economic Union, primarily through Russia, Kazakhstan, and Belarus.

The most important condition for further improving of the efficiency of international land transportation is facilitation of cross-border trade, customs and transport procedures based on application of a system of uniform national and interstate standards and rules, which should use professional concepts and terms unified in content and meaning [1]. At the same time, the terminology introduced into circulation should identify and interpret as correctly as possible the essence of the phenomena and processes being determined in relevant fields of activity: economics, technology, law, etc.

The need to unify transport terminology at the interstate level is also due to the fact that the legal categories enshrined in relevant agreements are then implemented into the legislation of individual states or interregional associations. An example is the Convention on International Multimodal Transport of Goods, which was adopted by the UN in 1980 (hereinafter referred to as the Convention) but has not yet entered into force [2]. Nevertheless, the Convention, albeit

nominally, that is, not legally, but only in fact, secured a certain meaning and semantic content for certain professional terms. Then the corresponding terminology began to be actively used by the expert and professional community in business and scientific research, and in some countries, it has already been integrated into legislation. In particular, ASEAN countries have adopted the Framework Agreement on Multimodal Transport, which is largely based on the provisions of the above-mentioned Convention. Therefore, improvement of the terminology of combined transport should be carried out in conjunction with improvement of the modern international system of sectoral regulatory and legal regulation of such transportation.

In this regard, it should be recognized that the work on improvement and unification of the terminology for combined, intermodal and multimodal transportation is carried out by experts of the Organisation for Co-operation between Railways (hereinafter – OSJD) in cooperation with experts from the UN Economic and Social Commission for Asia and the Pacific (hereinafter – ESCAP) and other organisations participating in OSJD. This initiative of OSJD experts is gaining special relevance against the background of active digitalisation of the transport industry. In modern conditions, a computer must not only record electronic signals, but also understand the meaning of text and words as well as a person does. That is why, in the era of digital transformation of the economy and social sphere, the international expert community should focus on standardising terms and definitions used by public authorities and the business community. According to experts from the UN Centre for Trade Facilitation and Electronic Business (UN/CEFACT), the use of a single conceptual format increases the efficiency of business processes, reduces the risk of errors, and diminishes the cost and time for execution of international trade transactions [3].

The use of a common terminology in the field of combined, intermodal, and multimodal transportation provides the following effects:

- Semantic compatibility of data in trade and transport contracts.
- Implementation of the principle of a «single form» for documents.
- Development of a methodological basis for classifiers and standards for various types of transportation.



For a number of years, the combined method of delivery of foreign trade goods has been actively used in the EU countries, which has positively affected the dynamics of traffic volumes and freight turnover of railway transport and made a significant contribution to improving the environmental situation in the EU countries [4]. At the same time, in countries from the eastern part of the continent, combined transport has not yet been sufficiently developed. One of the main reasons for the low demand for combined transport for servicing transcontinental cargo flows is associated with terminological differences in individual international and national transport agreements, standards and rules governing the peculiarities of this type of transportation.

In this regard, the *objective* of this study is to identify structural and content differences in the definitions of combined transport and to develop recommendations for their unification for further improvement and harmonisation of transport legislation in the Greater Eurasia.

METHODOLOGY

Combined transport is one of the progressive ways of implementing the so-called mixed (combining different modes of transport) cargo transportation, which is carried out mainly in interregional and international traffic [5–10].

Mixed transportation on most main routes, as a rule, has significantly higher economic, social and environmental efficiency compared to direct transportation, which is carried out by any single mode of transport. The main source of formation of these effects are the intra-system mechanisms of formation of new properties that are not inherent in individual parts of the transport system (in different modes of transport), which are manifested in lean management (interaction) of all system components: transport and logistics infrastructure, traction and rolling stock, loading, and unloading equipment, specialized devices for placing cargo, etc. [11].

The sustainability of the mixed transportation system is based on the assumption that all the participants in the supply chain are interested in making a rational choice in favour of maximising the economic and environmental benefits of each mode of transport through their integration into a single transport and logistics chain. The organizers of mixed transportation analyse advantages and disadvantages of individual modes of transport, considering specific operating

conditions (they are compared according to relevant criteria: price, speed, weight and size restrictions, compliance with specific conditions, etc.) and select the most suitable mode of transport for each section of the route [12].

The selection of mixed transportation as of a separate species category is of scientific interest for development of a unified methodological basis for organisation and implementation of such transportation, and has also an important organisational, technological, and practical importance.

In mixed transportation, so-called intermodal transport units (ITU) are often used to increase the efficiency of interaction between participants in the transport and technological system. The use of ITU can significantly reduce time and money costs for performing transshipment operations when changing the mode of transport. ITU include containers, swap bodies, semitrailers, and other equipment, structurally adapted to accommodate cargo and to transport it in rolling stock of various modes of transport from the point of departure to the point of destination. At intermediate points, when changing the mode of transport, not the actual cargo is reloaded, but ITU with cargo. Mixed transportation using ITU is called intermodal transportation.

According to the UNECE Glossary «Terminology on Combined Transport» (hereinafter referred to as the Glossary), intermodal transportation also includes carriage of goods in a car, which is transported by other modes of transport on adjacent sections. Moreover, intermodal transportation with participation of road transport is a subspecific category, on the basis of which such a species as combined transport is distinguished. The main feature (difference) of combined transport from other types of intermodal transportation with participation of road transport is that most of the voyage through the territory of the EU countries falls on rail, inland waterway or sea transport, and any initial and (or) final segment of the route where road transport is used, is as short as possible.

According to UNCTAD experts, as a rule, in very rare cases, delivery of foreign trade goods is carried out in the form of a direct transportation, i.e., only by any single mode of transport [13].

In international deliveries, mixed transportation predominates, which has a much more complex structure of transportation and technological operations, uniting a larger number

of participants within the trade and logistics chain. For reasons of efficiency, it is advisable for all the participants in the supply chain, including supervisory authorities, to use a single terminology both in relation to the operations performed and in terms of information characterising the items transported, settlement, customs, and other operations. It is worth noting that regarding the data identifying the customs characteristics of cargo and goods, unity has been achieved at the international level through UN/CEFACT and the World Customs Organization. The use of a unified terminology contributes to harmonisation of customs legislation, transparency of the relevant procedures and, as a result, to an increase in the efficiency of international trade. When organising the process of collecting, rationalising and harmonising transport terms, the UNECE and UN/CEFACT model guidelines on simplification and standardisation of data for international trade can be used [14].

When carrying out a comparative analysis of the terminology of combined transport, the wording from official international and national documents related to this type of transportation was used. First of all, the study referred to the terminology contained in the documents having an interstate status: «European Agreement on Important International Combined Transport Lines and Related Installations (AGTC)» (hereinafter – «European Agreement»), «OSJD Agreement on organizational and operational aspects of combined traffic between Europe and Asia» (hereinafter – «Europe–Asia Agreement»), and Council Directive 92/106/EEC of 7 December 1992 on the establishment of common rules for certain types of combined transport of goods between Member States (hereinafter – EU Council Directive No. 92/106/EEC, Directive), as well as in the above-mentioned UNECE Glossary and interstate standards in force in individual OSJD member countries. Analysing and discussing the content of transport terms consider also theoretical and methodological developments of domestic and foreign representatives of academic science in the field of improving the terminology of mixed transportation.

The study of terms on combined transport based on the listed sources made it possible to generalise official and scientific approaches to determining the meaning and sense of the corresponding terms. This process was

accompanied by a comparison of the content of terms with the technological, organisational, and legal aspects of the subject area characterised by them (by those terms). Then the differences in the content of the studied terms were identified using the methods of semantic and structural and content analysis. Further, feasibility of using distinctive characteristics to identify relevant terms was assessed. With a positive assessment, reasonable recommendations were developed for correcting existing or introducing new terms.

The structural and content characteristic of terms is considered as the definition of the composition of lexical elements of the definition and interpretation of the essential meaning attributed to them. Regarding transport terminology, the following structural components can be distinguished in the structure of the term: used modes of transport and types of rolling stock, equipment, technologies, and infrastructure facilities, taking into account their specialisation, transported objects, legal framework, supervisory procedures, features of document interchange, etc. This research puts the emphasis on structural and content characteristics of the object of combined transport, which, due to technological peculiarities of this method of transportation, has a complex component composition.

RESULTS

It was noted above that to improve the efficiency of international transportation with participation of different modes of transport, many countries of the Eurasian continent have entered into a number of multilateral agreements, which enshrine obligations of the parties to bring operational characteristics of national infrastructure facilities into compliance with uniform requirements (standards) established in the agreements. At the same time, the analysis of definitions of key terms in these Agreements revealed the presence of certain differences, primarily regarding the object of combined transport.

As a general rule, the object of transportation is cargo. In combined transport, the object is not the actual cargo, but various types of equipment (container, swap body, etc.), trailed rolling stock (semitrailer, trailer, etc.) or vehicles (universal trucks with a fixed body), which directly accommodate cargo, and changing the mode of transport implies not the cargo transshipment but the transshipment of a corresponding object with the cargo.



The «European Agreement» contains, in our opinion, an insufficiently specific definition of the term «combined transport», which in the document means carriage of goods in the same «transport unit» using several modes of transport («The term «combined transport» shall mean the transport of goods in one and the same transport unit using more than one mode of transport»). At the same time, the «European Agreement» does not comprise any additional clarification of what should be understood by the corresponding transport unit.

Some explanations of the characteristics of a «transport unit» which is the object of combined transport under the «European Agreement» are given in the Glossary «Terminology on Combined Transport». The third chapter of the Glossary, which is called exactly «Transport Units», describes various types of vehicles related to road, rail, and sea transport. However, not all types of transport units listed in this section of the Glossary can perform the function of «one and the same transport unit», as prescribed by the «European Agreement» for an object of combined transport. Considering the technological features of implementation of combined transport, the following types of transport units from the Glossary can be attributed to the objects of combined transport: articulated vehicle, road train, trailer, semitrailer, bimodal semitrailer. These types of «transport units» are intended for operation in combination with motor vehicles (trucks with a fixed body or tractor units or «motor vehicles» as described in the English version of the term in the Glossary). Moreover, the actual trucks with a body that do not use trailed rolling stock, according to the formal characteristics of the Glossary, do not belong to «transport units» and, as a result, do not form a part of the object of combined transport according to the definition of the «European Agreement». In our opinion, such a characteristic of the object is not without its drawbacks, and therefore it is desirable to specify the wording of the term «combined transport» in the «European Agreement».

The «Europe–Asia Agreement» provides a comparatively detailed description of the object of combined transport, to which the so-called cargo units are assigned, and their species are listed in parentheses: container, swap body, semitrailer, motor vehicle. It is worth noting that this structure of components of a combined transport object is complex in its composition

since it contains not the same type of objects if we refer to the classification of the Glossary.

The first category comprises containers, swap bodies and semitrailers, which are referred to as so-called «intermodal transport units» (ITU) and are a kind of «cargo units». As it is known, ITU are structurally unsuitable for autonomous motion. Therefore, ITU for combined transport (loaded or empty) are located on the vehicle, and when changing the mode of transport, it is not the cargo, but the ITUs that are transhipped. At the same time, semitrailers in the Glossary simultaneously refer to both ITU and «transport units», but do not refer to «cargo units», a variety of which are ITU, which, in our opinion, introduces contradictions in the structure of the terms of this document.

The second category comprises motor vehicles, which, as noted above, include motorised trucks with a fixed body, adapted to transport various types of goods, including ITU and trailers. It is worth noting that, according to the formal characteristics from within the Europe–Asia Agreement, road trailers do not belong to the objects of combined transport, although in fact they are such and their transportation in railway wagons is provided for by the provisions of SMGS [OSJD Agreement on International Railway Freight Communications].

Summarising the results of the analysis of definitions of combined transport from the «Europe–Asia Agreement» and the «European Agreement», it is possible to highlight the main structural and content differences in the used objects of combined transport. The text of the «Europe–Asia Agreement» explicitly states that the number of objects of combined transport includes both cargo units and vehicles, which are understood as vehicles with fixed bodies. In turn, the text of the «European Agreement» mentions the «transport unit» only as the object of combined transport, while cars do not belong to the «transport unit».

It should be noted, however, that with regard to the structure and content of these terms, there are certain differences between the Glossary, the Europe–Asia Agreement and the OSJD Agreement on International Railway Freight Communications (SMGS), for example, see SMGS Article 2. It is also worth noting that the rolling stock classification system from the Glossary, the Europe–Asia Agreement and SMGS is not fully consistent with the structure of those categories contained in «OK



034-2014 (CPA 2008). All-Russian classifier of products by type of economic activity)», i.e., in its subsection 29 «Motor vehicles, trailers and semitrailers» of section C «Manufacturing products», though the latter document has a lower status in the legal hierarchy. However, a detailed study of these issues is beyond the scope of this study.

The information provided on the existing structural and content differences in the Agreements and Glossaries gives grounds to assert that the formulations of the «combined» transport object contained in them can be interpreted in a sufficiently broad sense, which does not contribute to harmonisation of the industry's legislation between the countries of the continent.

A more detailed description of the «combined transport» object is contained in the EU Council Directive, which was adopted about a year after the signing of the European Agreement and applies only to EU countries. The Directive, in contrast to the European Agreement, provides specific criteria for «combined transport», including the detailed structure of the transport object:

1) The object of transportation refers to vehicles or intermodal transport units in which cargo is actually placed during transportation:

- truck (lorry – in the English version of the term in the Directive),
- trailer, semitrailer with or without a tractor,
- removable body, container.

2) Road transport is used at the initial and (or) final section of the multimodal route.

3) The length of railway or water sections of the multimodal route exceeds 100 km in a straight line.

4) Cargo must be delivered by road to or from the nearest railway station in relation to the places of departure or destination of multimodal transportation, respectively.

5) The length of the road section to or from the sea (river) port relative to the places of departure or destination of multimodal transportation, respectively, should not exceed 150 km in a straight line.

The adoption of the EU Council Directive and implementation of state support measures for combined transport provided for in it (as a rule, refund, or reduction of the transport tax) ensured a reduction in the volume of direct (unimodal) road transportation, which led to redistribution of freight traffic to other more «environmentally friendly» modes of transport, such as rail transport, inland waterway, and sea transport. These measures have made a significant contribution to reducing emissions of harmful substances and greenhouse gases into the atmosphere, as well as reducing road accidents, noise and congestion rates. At the same time, experts note that the definition of the term «combined transport» in the Directive has not either avoided drawbacks that prevent many carriers from using economic support measures [15]. In this regard, the EU is discussing amendments to Directive 92/106/EEC. In particular, it is planned to change the procedure for calculating the length of the sections of combined transport, on which road vehicles are used. For intra-European routes, the carriage on which is regulated by the Directive, this norm, of course, should be the same for all the EU countries. However, for transcontinental supply chains, it may be more rational if each of the parties (states) to the Combined Transport



Agreements will independently establish separate criteria for combined transport, which will consider geographical features of the regions, the actual configuration and density of the transport network. At the same time, it is important that the structural and content characteristics of the combined transport object be uniform in the regulatory documents of all parties to the agreements. Otherwise, the legal regulation of the combined transportation of goods in the same type of transport or cargo units in different countries will differ, and then, perhaps, when changing the mode of transport, the cargo itself will be transhipped, and not cargo or transport units with cargo.

Terminological differences can be seen not only in legislative acts, but also in interstate standards and national rules. For example, in GOST [State Standard] 34530-2019 «Interstate standard «Railway transport. Basic concepts. Terms and definitions» (clause 2.4.19) and in GOST 34056-2017 «Interstate standard Railway transport. Rolling stock. Terms and definitions» (p. 3.3.21) the definition of the term «platform for combined transport» is given, which is understood as a flat wagon intended for transportation of containers, road trains, caravans, semitrailers and swap bodies. As we can see, the number of objects for transportation of which the corresponding platform is intended does not include actual vehicles that transport cargo in a fixed body, and not in a trailer or semitrailer. It can also be noted that in the new Russian rules for transportation of certain types of rolling stock of road transport by rail (approved by order of the Ministry of Transport of the Russian Federation in January 2020), vehicles are not included in the list of transported objects, while Appendix 3 to SMGS provides for the possibility of their transportation along with road trains, semitrailers, trailers, swap bodies, etc. These rules are not related to combined transport but considering the prospects for development of combined transport, there may be a need for a more detailed discussion of the Russian rules for transportation of vehicles in freight wagons.

Most likely, this issue will be raised after adoption of a new law on direct mixed-mode (combined) transport, the draft of which is being actively discussed in the professional community. Article 788 of the Civil Code of the Russian Federation defines the fundamentals of relations between transport organisations in implementation of direct mixed transportation carried out under

a single transport document. This article states that the procedure for organising such transportation is determined by agreements between carriers of different modes of transport and is regulated by a special law on direct mixed (combined) transportation. It is noteworthy that in the title of the future law the terms «direct mixed» and «combined» transportation are used as equivalent, which, in our opinion, is not fully consistent with the meaning of the corresponding concept.

The terms «direct mixed» and «combined» transportation are varieties of a broader concept of «mixed transportation». At the same time, these terms refer to various taxonomic groups within a superspecific class: «direct mixed transportation» characterises the organisational and technological features of implementation of mixed transport under a single transport document, and «combined transport» characterises the type of non-transferred (intermodal, without transshipment) transportation performed with participation of road transport on the initial and (or) final sections of the mixed route. Accordingly, equalisation of meanings of the concepts of «direct mixed» and «combined» transportation and, as a consequence, application of the same regulatory requirements to them can complicate regulation of these types of mixed transportation. Therefore, it makes sense to discuss feasibility of changing the title of such a law in the Civil Code, excluding combined transport from it.

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

To ensure a real and effective integration of transport systems of the Eurasian continent, it is important to ensure generality of the conceptual apparatus of combined transport intended for their regulation at international and national levels, so that all market participants use equivalent formulations of professional terms. This is important to ensure harmonisation of transportation rules, shipping documents and other regulatory legal documents on combined transport in international traffic, which, in turn, will contribute to the growth of international trade, reduce the delivery time of goods, and increase their safety and, ultimately, reduce consumer costs on the Eurasian continent.

It is worth recognising the rational idea and successful practice of using the Glossary as a reference document with detailed formulations

and detailed explanations of professional terms that are used in sectoral international agreements. At the same time, it is advisable to clarify, supplement and systematise individual definitions in the Glossary. For example, the Glossary categorises semitrailers as «transport units» and at the same time they are part of ITU, which are a kind of «cargo units». In turn, trailers, which are also classified as «transport units», are not part of ITU objects. Of course, trailers have structural differences from semitrailers, but technological differences in terms of organising the transportation process with their participation are not so significant.

The Glossary, when describing the content of many terms, uses the term «Motor vehicle», which in this document does not have its own definition. The meaning of this term, of course, can be established from the context of its use in defining other concepts. For example, in the definitions of certain types of «transport units» (such as an articulated vehicle, trailer, semitrailer, road train), the concept of «motor vehicle» is used as a superspecific category. Considering the content and meaning of the definitions of these terms, «motor vehicle» is understood as the actual «car». Three important conclusions follow from this thesis.

Firstly, the definition of the term «Intermodal transport» from the Glossary uses two transport objects only: «cargo unit» and «motor vehicle». Then it turns out that if a vehicle (actually a car) does not belong to the objects of the group of «transport units», then transportation of cargo in a semitrailer, trailer and even a wagon in mixed traffic using technologies excluding transshipment (for example, cargo in a wagon is transported on a sea ferry) does not belong to the category «intermodal transport». Therefore, the content of the term «intermodal transport» in the Glossary is controversial and it seems appropriate to supplement the list of objects transported using technologies without transshipment also with «transport units». For example, trailers, road trains, articulated vehicles, wagons, and other rolling stock suitable for traffic without transshipment. If this is not done, then it will be necessary to select a new term to characterise intermodal (seamless, without transshipment) transportation with participation of «transport units».

Secondly, in the «European Agreement» only «transport units» are included in the composition of combined transport objects. Consequently, according to this document, it does not apply to



transportation without transshipment involving road vehicles and other «cargo units» such as a container. While other regulatory documents, including the «Europe–Asia Agreement», Council Directive of the EU No. 92/106/EEC, regulate transportation with such objects. Therefore, it is desirable to expand and specify the objects of combined transport in the «European Agreement» to ensure harmonisation of regulatory requirements with other documents regulating similar transportation. General recommendations for adjusting the combined transport object will be formulated using the example of the «Europe–Asia Agreement», the content of which also needs to be clarified in terms of the composition and structure of the corresponding object.

In the current version of the Europe–Asia Agreement, only one object is actually indicated as an object of combined transport: a «cargo unit», the structure of which is then presented in brackets as its four types (container, swap body, semitrailer, vehicle). The work showed that these varieties belong to different taxonomic groups: a container and a swap body are «cargo units», a semitrailer is a «transport unit», while the Glossary and SMGS mean quite different objects under the term «vehicle». At the same time, trailers were not included in the list of combined transport objects in the Europe–Asia Agreement.



In this regard, the following structure of the combined transport objects is proposed. It is logical to distinguish three structural parts in it: «cargo units», «transport units» and «road vehicles (automobiles)». The first two groups can be further characterised by specific species. For example, it is advisable to represent the group of «cargo units» as «intermodal transport units»: containers and swap bodies. The group of «transport units» can be represented by trailers, semitrailers, road trains, articulated vehicles.

Thirdly, the «Europe–Asia Agreement» has a higher legal status than interstate standards, therefore it seems appropriate to consider the issue of changing two interstate standards mentioned above (GOST 34530-2019 «Interstate standard «Railway transport. Basic concepts. Terms and definitions» (p. 2.4.19) and GOST 34056-2017 «Interstate standard «Railway transport. Rolling stock. Terms and definitions»») in terms of correcting the definition of the term «platform for combined transport» considering the structure of the object of such transportation proposed above.

The above recommendations for improving transport terminology are due to objective changes in transportation technologies. It is quite natural that for several decades since the adoption of the «European Agreement» and the «Europe–Asia Agreement» innovations have appeared in the regulation and implementation of combined transport. It would be advisable to reflect them in both Agreements. To ensure synchronisation of the process of discussion and development of new rules for regulating combined transport by all parties to the Agreements, it may be easier to return to the idea of concluding a new, comprehensive Eurasian Agreement on the most important combined transport lines based on the existing Agreements. The new agreement would reflect successful accumulated experience of the parties to these Agreements, the developed proposals for improving requirements for organisation of international combined transport, as well as update the transport terminology, which is developing in the wake of rapidly

changing technologies of combined, multimodal, intermodal and other types of transportation.

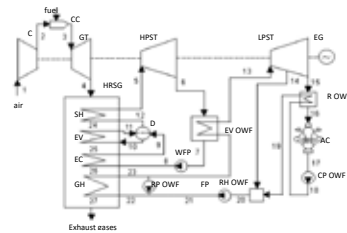
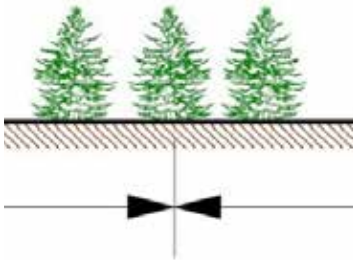
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Living Snow Fences: International Practices

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Moscow, Russia.*✉ daria.korneeva@list.ru**Daria Yu. MISHINA****ABSTRACT**

In winter, in the countries with snow covered regions, one of the main tasks of road maintenance is to combat snow deposits, snowpacks and snowdrifts on the roadway. Living snow fences consisting of tree and shrub plantings are among known world practices to protect roads against effects of snow deposits. They are environmentally friendly, durable and have great snow retention capacity. However, there are several constraints regarding application of those practices.

The analysis of the design, spacing and planting schemes refers to Russian and foreign living snow fences used to protect highways, considers the features, advantages, and disadvantages of living fences in different countries. Japanese and American designs are reviewed as international experience. The influence of the state of trees on the efficiency of their snow-retaining function has been determined. As a result, the need for monitoring and proper maintenance of existing living snow fences throughout their life cycle was confirmed using the examples of surveys of forest plantations

in Kazakhstan and in Volgograd region of the Russian Federation.

The author presents promising directions for improving the structures and planting schemes of snow storage living fences, namely, an integrated approach to their design as of a protection not only against snowdrifts, but also against pollutants. Such solutions include the design of protective living fences using only tall shrubs, providing the best blowing of roadside areas and dispersion of contaminants. Another solution is to complement the species planted within living fences with willow and corn. Besides, referring to global climate changes, an important task for modern science has been identified, that is to update the current standards for the design of living fences under the current meteorological conditions.

Recommendations on the use of mathematical modelling with the help of computer software are suggested regarding development of new configurations of living fences, assessment of their effectiveness, as well as on the adoption of modern technologies such as video cameras and drones during field tests.

Keywords: *transport, living snow fences, snow protection, snow transport, snow fighting, winter maintenance of highways.*

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INTRODUCTION

To provide safe and uninterrupted traffic on roads in winter, many countries with cold climates fight snowdrifts on the roadway. The snow element is mainly typical for areas of very difficult and especially difficult snow fighting according to the zoning of the territory of Russia [1; 2]. Globally, Canada, Japan, Kazakhstan, Scandinavian countries, the USA, and others face the same challenge.

For more than a century of use, snow-retaining plantation forests have proved to be the most effective tool of protection against snowdrifts. The design of living snow fences is carried out based on quantitative assessment of the parameters of blizzard activity and the degree of snowdrift extent on highways. Each country has its own peculiarities of choosing the spacing scheme and the range of species to be planted.

It is important to note that it is at the stage of designing new construction or reconstruction of highways that it is necessary to proceed with planting of living snow fences. At the stage of operation of already built and existing highways, only monitoring and minor adjustments of the adopted design decisions are possible.

The *objective* of the study was to reveal promising direction allowing to improve the design and planting schemes of living snow fences considering an integrated approach to their design as of a protection not only against snowdrifts, but also against pollutants.

RESULTS

The widespread use of tree and shrub plantings is due to their significant snow-retention capacity, they are environmentally friendly and have an unlimited service life. Nevertheless, along with significant advantages, there are some constraints for their use. Those constraints include unfavourable soil and geological conditions, location of a road in vicinity of agricultural land, significant land areas allocated for the plantings (the width of those areas [in Russia], according to the recommendations of ODM 218.5.001-2008¹ and ODM 218.2.045-2014², is from 15 to 100 m from the edge of the roadbed to forest plantations

plus the width of the planting itself, depending on the volume of snow transport). The normative values are approved based on scientific works [1–3], carried out in the second half of the 20th century. Besides, additional snow protection measures must be provided for the period of growth of young seedlings to a state of mature plant during new construction or reconstruction of highways.

Russian Experience of Using Tree and Shrub Plantings

Regulatory schemes for planting living snow fences, rules for reinforcing existing plantings, assortment and requirements for planting material are stipulated in the national recommendations of ODM 218.2.045-2014. The selection of design and schemes is based on the volume of snow transported to the road.

An important factor in effective operation of living snow fences refers to monitoring and maintenance during the period of their operation. Young seedlings, under the influence of negative factors, may not reach the required size or undergo drying out and decay, the shrubs may be non-pubescent. Upon reaching maturity, trees become sparse and can be damaged during the life cycle. Increase in density of trees and shrubs is reached by cutting boughs or increasing the number of rows of trees [3]. According to ODM 218.011-98³, works to strengthen the existing living snow fences comprise soil cultivation, considering regional agrotechnical requirements, the planting (sowing) of plants, the addition of crops, and agrotechnical care of the plantings.

For example, according to [4] field studies of the state of roadside forest plantings were carried out in Volgograd region in 2019 along R-22 «Caspian» (Moscow–Astrakhan) and R-228 (Volgograd–Sykzran) highways, which made it possible to establish their poor condition, stunted growth, degradation. and dry treetops on both road segments.

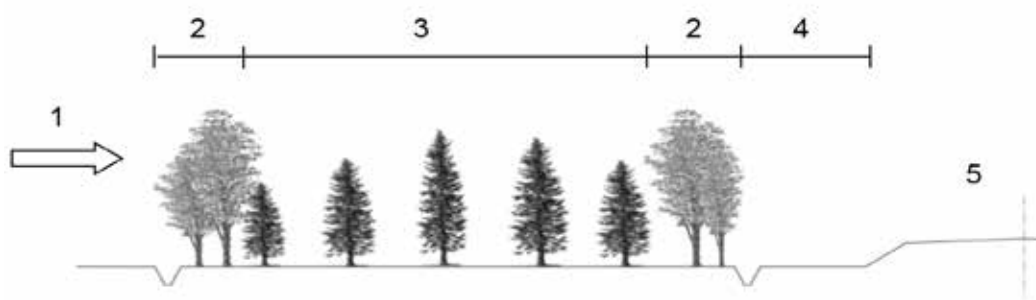
In such cases, tree and shrub plantings are subject to immediate reforestation felling to ensure their renewal and coppice generation. Since living fences, as a rule, are located in the right-of-way of a motor road, the responsibility for performance of these works lies with road maintenance services, which, in turn, do not always have competent specialists in this area on

¹ ODM [Road industry's methodological document] 218.5.001-2008. Methodical recommendations for protection and cleaning of roads from snow.

² ODM [Road industry's methodological document] 218.2.045-2014. Recommendations for design of forest snow-retaining plantations along highways.

³ ODM [Road industry's methodological document] 218.011-98. Public roads. Methodical recommendations for landscaping of highways.





Pic. 1. Standard width woods of living fences in Japan: 1 – direction of the prevailing wind in winter, 2 – fast-growing broadleaf trees, 3 – evergreen trees, 4 – snow-piling area, 5 – road [5, p. 37].

their staff. As a result, living fences are not able to fully function as snow retention instruments.

Foreign Experience of Using Tree and Shrub Plantings

In many foreign countries with a cold and snowy climate, living snow fences snow-retention forest plantations are also used as protection against snowdrifts on highways. The rules for their application in each country are determined based on meteorological and hydrogeological conditions, as well as on the features of the terrain and characteristics of the adjacent territory.

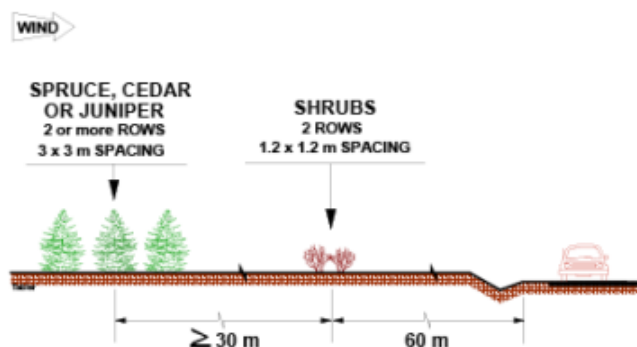
For the purpose of snow fighting in Japan, for example, living snow fences and «snowbreak woods» are very actively used for protection of highways. In 2009, the length of living snow fences on the highways of the island of Hokkaido was about 80 km [5]. However, the standard width of living fences is 10, 20 or 30 m [5; 6] (Pic. 1). Based on the works of Russian specialists [1; 2], it can be assumed that such small distances are possible with small amounts of snow transport since in such cases the snow storage capacity of living fences is small, and

a snow plume may come out onto the carriageway of the highway.

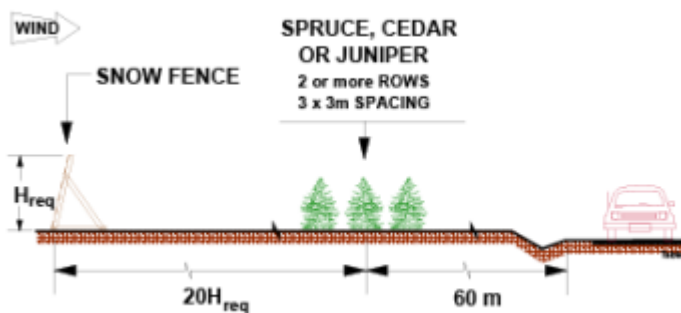
Currently, Japanese scientists continue to study the effectiveness of living snow fences depending on the composition of species, condition of plants during operation, and planting schemes. So, the study [5] comprised the results of a survey regarding, i.e., causes of wilting of the trees, the influence of the direction of winds, of sunshine on plants' growth and, consequently, assessment of the snow storage capacity of the living fence under such conditions.

Living snow fences are also widespread in the northern states of the USA. According to the report of the American scientist Ronald D. Tabler [7], depending on the volume of snow transport, the minimum plant height should vary from 1,2 to 2,8 m, and the distance between the edge of the roadbed and plantings should vary from 30 to 90 m. The author recommends planting additional rows of shrubs during the growth of young seedlings (Pic. 2), or the installation of snow retention devices (Pic. 3).

R. D. Tabler [7] also proposed planting shrub rows in a staggered pattern on steep embankments (Pic. 4). His followers [8; 9] extended this solution



Pic. 2. Temporary scheme for strengthening the planting of young trees with shrub rows [7, p. 234].



Pic. 3. Temporary scheme for placement of temporary snow fence to protect and reinforce young trees [7, p. 233].

for areas with steep slopes (1:1.5), such as approaches to bridge structures. The proposed configuration of trees and shrubs to reduce snowdrifts consists of a row of vegetation at the toe of the embankment followed by one or more rows on the embankment slope (Pic. 5). The number of rows depends on the geometry of the embankment. Obviously, this scheme must be applied with caution, providing visibility on the road.

In the Republic of Kazakhstan, the issue of combating snowdrifts is extremely acute. Climatic conditions and the features of the country's territory determine large volumes of snow transported to the roads in winter (in the steppe zone of Northern Kazakhstan, from 300 to 600 m³/m, and in some areas even up to 800–1200 m³/m of snow are brought to roads). Roadside living snow fences protect from snowdrifts the motor roads (59,7 thousand hectares) and railways (66,8 thousand hectares). The norms and rules for planting living snow fences are generally similar to those in Russia. Existing living snow fences protect 30 % of all the roads. However, according to research [10], in recent years, work on creation of living snow fences is practically not carried out, and the existing plantings due to insufficient care,

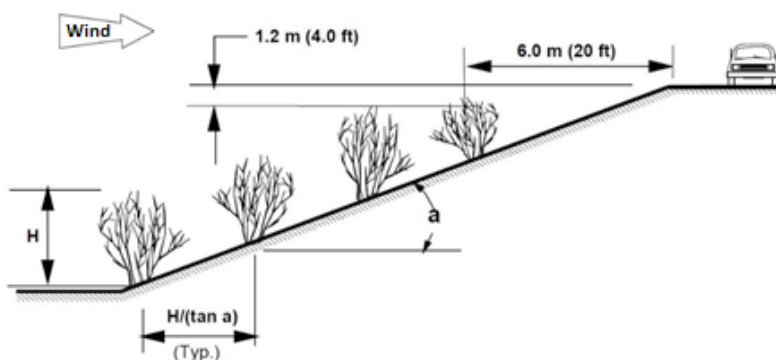
unauthorised felling by the population require reconstruction and restoration. This circumstance, in turn, confirms the need for proper maintenance of plants to ensure their efficiency.

Promising Directions to Improve Living Snow Fences

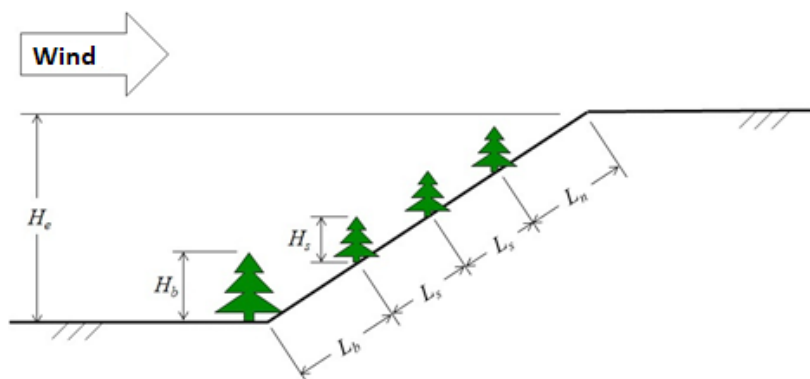
In addition to the retention of snow during the period of blizzard activity, living snow fences can influence the degree of concentration of harmful substances. With an integrated approach to design, living fences are capable of simultaneously ensuring snow resistance of the motorway, reducing concentration of exhaust gases and, as a result, improving the environmental characteristics directly above the roadway [11].

To meet the conditions of snow protection and to reduce concentration of harmful emissions, A. S. Sushkov [12] proposed the design of protective living fences using only tall shrubs (3–6 m) (Pic. 6). In his opinion, such a design will provide the best blowing of roadside areas and will lead to dispersion of contaminants.

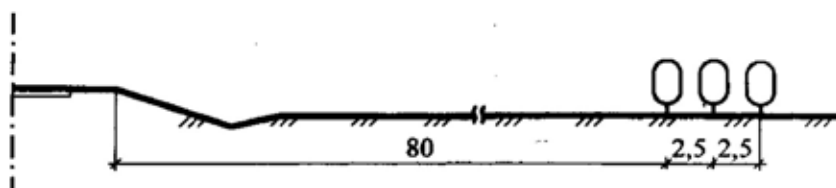
It is important to note the indisputable fact of climate change in general and the need to update the current zoning scheme for the territory of the Russian Federation in terms of the difficulty of



Pic. 4. Pattern of planting shrubs on step embankments [7, p. 235].



Pic. 5. Scheme of plantings at the approaches to bridge structures [8].



Pic. 6. Design of the snow-protective living fence considering dispersion of contaminants [12].

snow fighting on highways. Therefore, another important task of modern science is to clarify the norms for design of living fences at the federal and regional levels, considering the current climatic conditions and relief.

We can also highlight some of the directions of the latest international research. The American scientists have developed the concept of roadside plantings of fast-growing willow [13–15]. The growth rate of willow is several times higher than that of alder, spruce, or pine. In addition to snow retention, willow can perform the protective function regarding water and land resources and to reclaim contaminated soil. The US experience is being considered for implementation in the Republic of Belarus [16].

Another interesting direction of research by American specialists is the inclusion of rows of corn in the composition of living snow fences, as, for example, it is done in the states of Iowa and Wisconsin [17; 18], guided by simplicity and low cost of this method of snow fighting. However, in this case, there can be a higher risk of vandalism by the local population.

Recommendations for Development of Research

When carrying out research on new samples or configurations of living fences, at the first stage, one should resort to mathematical

modelling using computer software, which allows testing in the shortest possible time without limiting the number of samples and testing time, does not require to go to «the field». Such programs are based on the Navier–Stokes system of equations describing the motion of a viscous incompressible fluid [19, pp. 139–142]. Ansys Fluent, which is among world leaders, is a computer program that, with a sufficient degree of accuracy, allows simulating a blizzard flow and snow deposits in the area of snow fences. Among Russian domestic developments, one can single out FlowVision [20].

An alternative research method is physical modelling in laboratory conditions, for example, in wind tunnels. Full-scale tests are extremely time consuming and costly, nevertheless, they are necessary to evaluate the performance of new samples under real operating conditions. In the age of modern technology, video cameras, drones, and computing help to conduct field tests by implementing air and ground photogrammetry with subsequent development of a three-dimensional relief model.

SHORT CONCLUSION

For many years, snow storage and retention living fences have demonstrated their efficiency in combating snow on highways in different

countries and, as a result, they significantly reduce the financial costs of winter highway maintenance. In turn, the efficiency depends on a competent project, implementation of plantings, and further proper care.

At the same time, in the context of a lack of land allocation for placement of living snow fences, of a search for a compromise for their use near agricultural lands, and of an increase in the urgency of the environmental problem, the current situation encourages the scientific community to develop and optimise the composition, assortment, design, spacing and implementation schemes of living snow fences.

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Analysis of the Issue of Recovery of Low-Potential Energy at Small-Scale Energy Facilities



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ABSTRACT

Studying the issues of recovery of low-potential energy at small-scale energy facilities allowed to show the promising character of the organic Rankine cycle (ORC) technology as a technology for recovery or conversion of low-potential energy.

The most promising developments in the field of the use and recovery of waste heat are described regarding application of ORC, which is widely used in geothermal sources, hot water boilers, gas turbine plants. Due to the constantly growing diversity of working fluids, ORC can be used within a wide temperature range from 100°C to over 350°C. Also, developments are underway in the design of ORC generators to increase reliability of its individual system units, such as turbines and expanders. Based on the above factors, it can be concluded that with a deeper study of the problems of adopting ORC technologies, they can become a very promising direction in development of heat power engineering.

It has been determined that the main factor hindering the widespread adoption of the ORC technology is associated with high cost of heat exchange equipment due to increased heat exchange surfaces. It is shown that design of mini power plants and energy centres based on the use of low-potential energy requires improvement of mathematical modelling methods to reliably determine operating modes and characteristics of each of the units. Methods for modelling evaporation and condensation systems, including turbines and expanders using organic low-boiling working fluids, should be considered among the methods that are highly sought after. The methods for selecting a working fluid for ORC devices also have a significant impact on characteristics of the installation determining the range of cycle operating temperatures and pressures. The solution of the above problems can lead to a reduction in the cost of heat exchange equipment, and, consequently, to a decrease in costs for design of ORC generators.

Keywords: low-potential energy resources, organic Rankine cycle, mini electric plant, energy centres, mathematical modelling.

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INTRODUCTION

The need to consider current technological conditions regarding the recovery of low-potential energy at the small-scale energy facilities is determined by the demand for a more economical use of energy resources due to the passed peak of hydrocarbon extraction. In Russia it is due also to implementation of the national Energy Strategy until 2035¹. At the present stage of development of industrial production, it is the adoption of energy-saving technologies that allows to increase efficiency of the use of fuel and energy resources, while the latter is among the main conditions for reducing the fuel component in the cost of production, and, accordingly, for increasing profitability of enterprises. Almost all the enterprises of stationary power engineering in transport and other industries, as well as in agriculture, have «excess» heat of the working fluid in cooling systems that ensure stable and continuous operation of production cycles [1–4].

The last decade has been marked by the widespread of installations operating according to the organic Rankine cycle (ORC) with the use of turbine generators both for producing electricity and operating according to the cogeneration [5]. The main equipment of the generator, as a rule, includes heat exchangers, piping, primary and secondary coolant pumps, a turbine, an electric generator, an automation unit with power equipment. Recently, modular power blocks have become widespread due to the ease of installation and lower transportation costs. In practice, such turbine generators have a fairly wide range of electrical power (50–1000 kW).

The modern scientific literature describes results of analytical reviewing of thermal schemes of power recovery plants, working fluids, methods of thermodynamic evaluation of the efficiency of heat conversion processes [1–13]. In Russia, the first systemic studies were carried out by M. I. Dunaevsky, and then M. M. Grishunin, A. P. Sevastyanov, L. I. Seleznev, E. D. Fedorovich were engaged in development of technological schemes and cycles [14; 15].

¹ Energy Strategy of the Russian Federation for the period until 2035 [in Russian]. Resolution of the Government of the Russian Federation dated June 9, 2020, No. 1523-r. [Electronic resource]: <https://minenergo.gov.ru/node/1026>. Last accessed 09.01.2021.

The *objective* of the article is to consider the current state of the issue on recovery of low-potential energy resources to improve the energy efficiency of small-scale energy facilities and to identify the main problems facing such energy centres.

MAIN RESULTS

Over the past 10 years, much attention has been paid globally to design and development of low-power energy-efficient electrical installations based on closed steam turbine cycles in low-boiling working fluids (LBWF). An energy source of heat is low-potential if its temperature does not exceed 230–300°C (500–570 K). Fundamentally, LBWF determine the type of thermodynamic cycle, the composition of the equipment and technical and economic indicators of power plants. The broadest group includes pure (s opposed to blends) LBWF: hydrocarbons (butane, propane, pentane), freons (R11, R12, R114, R123, R245fa), ammonia, toluene, diphenyl, silicone oil, etc. They are used in power plants, implementing ORC, the essence of the application of which is recovery of secondary energy resources (SER), having a temperature of 80–350°C (waste gases, cooling water and other SER of technological processes) [16].

ORC is mainly used in:

- thermal power plants;
- geothermal power plants;
- landfills for disposal of biological waste;
- industrial enterprises that have waste heat in their production cycle;
- gas turbines, internal combustion engines, etc.

The range of application of working fluids depends on the criteria applied to them: energy properties, low ozone depletion potential, operational safety.

ORC-based power plants have the following advantages:

- lower capital costs for a turbine in comparison with a steam-water analogue;
- there is no need for a water treatment system;
- simple start-stop procedure;
- long service life of turbine equipment (up to 30 years [1]).

Considering these advantages, the use of closed steam turbine cycles in low-boiling working fluids is very promising at the facilities that dispose waste heat.



Use of ORC at Geothermal Sources

A rather interesting example of the use of ORC is its use at geothermal sources. Warm geothermal waters act as a source of heat for ORC at the geothermal power plant. Geothermal waters are pumped from the bowels of the earth to the evaporator, where they give off heat to the LBWF. The world's first geothermal power plant (GeoTPP) using LBWF, or, as it is also called, the binary GeoTPP, was created in the USSR in Kamchatka (Paratunskaya GeoTPP) in 1967. Geothermal waters with a temperature of 81°C served as the heat source. The working agent was R12 freon. The plant generated power of 680 kW. At the same time, practical implementation of binary GeoTPP (USA, Mexico, Argentina, Iceland, Italy, Austria, Germany, Portugal, Israel, Thailand, China, Taiwan, New Zealand, Philippines, Japan) is becoming more active all over the world, with the defining trend to create small, fully automated, modular installations that do not require constant maintenance. ORMAT (Israel) is the leader in their production (up to 1000 installed power modules using pentane with a capacity of 40 kW to 3,5 MW) [9].

Application of ORC with a Hot Water Boiler

The adoption of the ORC technology at the hot-water boiler house makes it possible to create cogeneration: simultaneous generation of heat and electricity. Depending on the consumer, the mini TPP can switch between generation modes both to generate electricity either to supply heat by changing the flow rate of the coolant towards the evaporator of ORC generator or the heating network [12].

Implementation of ORC Technologies in the Circuit of Combined-Cycle Gas Turbine Plants

When using ORC with gas turbine units (GTU) and depending on temperature and volume of exhaust gases, there are two methods of designing ORC superstructure [13]:

- ORC superstructure for combined-cycle gas turbine plant by connecting ORC to heat extraction of the steam turbine;
- ORC superstructure for GTU via waste heat recovery boiler.

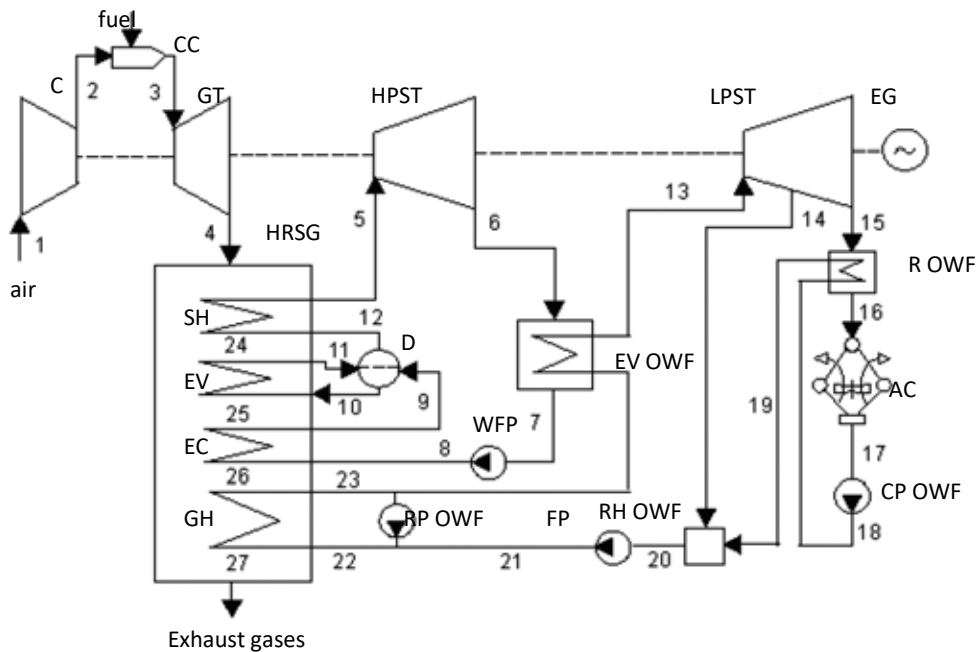
These methods make it possible to generate additional energy from exhaust gases.

Several scientific institutions in Russia have got significant research experience in the study of ORC processes, namely, of working fluids for steam turbine cycles, building thermal circuits and calculating its constituent elements (turbines and heat exchange equipment of various types) [3].

The study [16] performed the analysis and substantiation of the solution of the problem of energy saving on the basis of implementation of closed steam turbine cycles in low-boiling working fluids for industrial facilities with the use of SER. A study was carried out on selection of low-boiling working fluids used in ORC circuits. Calculations have been carried out to assess possible obtained electrical power during the implementation of LBWF turbines using waste gases of a water boiler unit with a capacity of 100 Gcal/h. It is shown that with the maximum use of heat of exhaust gases, electric power of the LBWF installation can reach ~2900 kW. To determine the most effective way of recovery of exhaust gases, a search was made for a rational thermal scheme, considering the characteristics of the existing technological cycle. In [9], based on available operating characteristics maps of the boiler unit, computational studies were carried out to determine possible electric power depending on the operating mode. Calculations have shown that the use of heat of exhaust gases without additional combustion of fuel limits the maximum temperatures of LBWF and does not allow reaching the maximum power of the power plant of ORC circuit through a small heat drop generated by the turbine. A greater amount of heat can be achieved only by increasing consumption of a low-boiling working fluid, which is not always optimal. An increase in flow rate of the working fluid entails an increase in the mass and size characteristics of heat exchange, auxiliary and turbine equipment.

At the present stage of development of closed-cycle steam turbines with low-boiling working medium, it is advisable to choose an option that will cover own needs of a heat-generating installation for electric energy at the level of 5–10 % without additional fuel combustion.

When determining feasibility of adopting the ORC cycle, it is necessary to consider that each individual case requires assessment of the



Pic. 1. Cycle diagram of combined-cycle gas turbine plant [7]: C – compressor, CC – combustion chamber, GT – gas turbine, HRSG – heat recovery steam generator, ST – steam turbine, HPST – high pressure steam turbine, LPST – low pressure steam turbine, SH – superheater, EV – evaporator, D – drum, EC – economizer, GH OWF – gas heater for organic working fluid, EV OWF – evaporator of organic working fluid, WFP – water feed pump, R OWF – recuperator of organic working fluid, AC – air condenser, CP OWF – condensate pump for organic working fluid, EG – electric generator, RP OWF – recirculation pump for organic working fluid, FP OWF – feed pump for organic working fluid, RH OWF – regenerative heater for organic working fluid.

amount and parameters of low-grade heat, as well as a complete feasibility study.

The development and implementation of installations are carried out by well-known companies from the USA, Japan, Belgium, Israel, Italy, Russia and other countries [12; 13; 17; 18].

Currently, the developed installations are intended to use low-potential SER with a temperature of 100–120°C, R142b as a working coolant and to have the efficiency of 0,08–0,10. There is a need to determine the coolant that provides optimal efficiency of the Rankine cycle for each temperature of SER sources. Therefore, for a certain specific source of SER, a thermal scheme of the installation is developed with its proper characteristic parameters and a working coolant. With a decrease in the temperature of the SER source, the cost and complexity of the equipment increases (up to 1500–2000 \$1 per kW of power) [10].

SER sources with a temperature of 150–170°C need recovery by power plants with a isobutane (C_4H_{10}) or a mixture (isobutane/isopentane) working coolants. Thermal circuits with *n*-pentane and hexane

are being developed for recovery of SER with higher temperatures (200–250°C).

Organic heat transfer media have not been studied enough for recovery of SER with temperatures above 300–350°C. Therefore, thermal schemes of installations with water vapour and carbon dioxide (CO_2) were developed.

From the above description of the ways of adoption of ORC installations, it can be concluded that this branch of electrical and heat engineering is sufficiently developed to create industrial designs. Therefore, ORC plants are increasingly being used in energy centres. The main world leaders who have mastered this industry are now ORMAT, Electrathern, Turboden, which have a wide range of capacities, structural solutions, as well as solutions regarding modular blocks that simplify installation and operation of ORC units.

However, despite apparent maturity of approaches to the problem of designing ORC generators, high capital costs due to suboptimal weight and size characteristics of the heat exchange equipment remain limiting factors for widespread introduction of these





Pic. 2. Semi-hermetic twin-screw HSE.85 expander [19].

installations. This negative factor might be overcome by compilation of such mathematical models that most reliably describe the processes in the systems of evaporation, condensation, and gear boxes.

The work [7] inspires interest from the point of view of analysis since it considers a three-stage steam gas plant and proposes a scheme for deep recovery of exhaust gas heat through the introduction of the ORC technology. The scheme is implemented as follows: the topping cycle is expressed by the Brighton cycle, the middle one is the Rankine cycle using water vapour, and the bottoming one is ORC. The schematic diagram of combined-cycle gas turbine plant is shown in Pic. 1 [7].

In the presented combined-cycle gas turbine plant, temperature in front of the high-pressure steam turbine is about 1527°C (1800 K), temperature of exhaust gases of the topping cycle is about 477°C (750 K), the medium steam-water cycle operates in the temperature range of 527°C (800 K) in front of the medium-pressure turbine and 77°C (350 K) in the condenser. The condensation temperature in ORC can be below 0°C (273 K) due to the use of air condensers in the northern regions of the country, where for about 8 months a year the ambient temperature is below 0°C .

The medium steam-water cycle can be replaced by the organic Rankine cycle with a lower condensation temperature of the working fluid than the water has, thereby lowering the condensation temperature limit for a deeper heat recovery in the middle cycle and an increase in efficiency throughout the plant.

The mathematical model proposed in [7], despite a very versatile approach to the method of deep recovery of low-grade heat, is expressed by a mathematical model of the first level, that is, linear equations, with a large number of assumptions and approximations, which may affect reliability of the processes described therein.

Other Applications of OCR Technology

The use of ORC technology is not limited only to stationary power devices. One of the possible options for modernisation of existing piston engines used in sea and railway transport to increase their efficiency is the use of ORC units integrated into the engine operation. The ORC system can recycle either high-grade (exhaust gases) or low-grade (cooling water) heat, or a combination of both, providing an increase in fuel efficiency of up to 12 % [19]. The engine radiator can be replaced, which reduces the capital cost of ORC generator by 30 % of its total cost, with a payback period of

less than five years for diesel engines. So, ElectraTherm company in 2020 presented a commercial model of a semi-hermetic expander operating on 1,1,1,3,3,3-pentafluoropropane, shown in Pic. 2.

The expanders are easier to operate than freon turbines: they work more efficiently at low rotation speeds, they do not need an oil pump, there are no stuffing box seals, it is possible to work under wet running conditions (when the working fluid partially enters the expander in a liquid state) [20].

However, a factor hindering modernisation is weight and size characteristics of non-technological heat exchangers, the calculations of which are carried out, often according to existing simplified engineering techniques with a high margin for the heat exchange surface due to complexity of describing real processes, which leads to an increase in weight and size characteristics of heat exchangers. By constructing various mathematical models, the [21] considered the process of condensation of the working fluid.

It was proposed to pass working fluid through a steel pipeline embedded in the ground to condensate it. The mathematical modelling used tools of engineering calculation methods and ANSYS CFX software package. Using various modelling approaches, when considering this issue, it was proposed to determine the optimal length and diameter of the pipeline. The study found that the divergence of the final length of the pipeline with the same degree of steam dryness (0,00) was more than 30 m. According to the engineering method of calculation, the length was about 107 m, while the length obtained in ANSYS CFX software package was 70 m. The study did not consider the thermal contact of the pipe with the ground, the polytropic nature of the real process, the change in thermophysical properties of the coolant due to hydraulic losses.

As it is known, it is also possible to reduce dimensions of the heat exchanger by forcing heat transfer. The existing methods of intensifying heat transfer are carried out by increasing the turbulence of the flow by means of ribbing, creating hemispherical protrusions along the length of the channel wall, making screw inserts and with other methods. These solutions have found wide application in design [4; 6].

A less studied method for increasing thermal conductivity of the working fluid is associated with the addition of insignificant impurities (less than a fraction of a percent) of nanosuspensions in the form of metal oxides, which increases thermal conductivity up to 60 % [11]. This solution, together with the use of an expander, due to its great simplicity in operation, can contribute to an increase in compactness of the ORC installation.

Despite the fact that the idea of heat recovery at the expense of ORC was proposed a long time ago, adoption of this technology requires solving problems of design optimisation and calculation of all units included in the scheme for recovery of low-potential energy [1–4; 6–8; 16–20].

Research continues to improve the methods for calculating the units of evaporation and condensation of the working fluid of ORC, as well as turbines and expanders [1–4; 6–8; 16–20].

CONCLUSIONS

The analysis performed allows us to conclude that the main factor hindering widespread adoption of ORC technology is high cost of heat exchange equipment due to increased heat exchange surfaces. In this regard, design of such mini electric plants and power centres requires improvement of mathematical modelling methods to reliably determine operating modes and characteristics of each of the units. These popular methods include the methodology for calculating evaporative and condensing systems, as well as turbines and expanders using organic low-boiling working fluids. The solution of the above problems can lead to a reduction in the cost of heat exchange equipment, and, consequently, to a decrease in the costs of designing ORC generators.

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Labour Rate Setting for Transport Company's Managers Based on the Principles of Organisation Design



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ABSTRACT

Analysis and labour rate setting regarding management activities is an important tool in the modern economy, used to improve the corporate efficiency by optimising existing management processes, reducing bureaucracy, and eliminating redundant processes, and, consequently, administrative elements that do not create value, and are an obstacle to normal functioning of the management system. The application of analytical methods to the work of managers is a relevant and powerful tool for increasing productivity and efficiency of corporate management.

The article describes the results of a study of tools for analysis and regulation of management activities implemented in the Russian Railways holding company based on the principles of organisation design.

The subject of the study is management activity as an object of application of modern methods of analysis and labour rates. The objective of the study is to show the possibility and feasibility of using modern methods of analysis and regulation of labour on the

example of a large transport company. The purposes of the study, the results of which are presented in this article, comprise identification of prerequisites for adoption of methods of analysis and regulation of management activities; assessment of possibilities of using the tools of functional analysis of organisation's entities and divisions to increase efficiency of management activities; description of technologies for labour rate setting for management activities using the example of the Russian Railways holding company.

The study is based on the use of methods of process analytics, functional analysis, labour rate setting, and organisation design.

The main result of the study is development of methodological approaches to analysis and standardisation of managerial work in a transport company. These approaches will make it possible to reasonably develop labour standards and rates for managers, staffing plan, and adopt modern management practices in the Russian Railways holding company.

Keywords: organisation design, labour rate setting for managers, process, function, labour rate, method of labour rate setting, transport, railways.

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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

Company's managers tend to be sceptical about the very ability to analyse and standardise their work. The main argument is that, in contrast to simple technological processes, in which all operations in the chain of the production cycle and their sequence are obvious and can be measured, and the labour results in a material, tangible product (service), the work of a manager is intellectual and analytical activity that requires creative, non-standard thinking, which depends on complexity and urgency of the tasks that arise with an indefinite frequency. This approach was widely quoted in different sources, namely in the textbooks intended for training future managers [1–4].

However, as both domestic and foreign practices show, the problem of analysis and standardisation of labour costs for managerial employees: administrative employees, specialists, managers is quite solvable [5; 6].

Today, development of IT and telecommunications, the use of modern technologies for operating big data, artificial intelligence, electronic accounting, business intelligence and office work, technical means of recording and recognising individual operations, as well as various methods and platforms for modelling and simulating business processes, including management processes, offers us ample opportunities for analysis of labour costs and the cost of management personnel. Probably, soon the world will reach such a level of digitisation of processes, when it will be possible to find out the labour costs of any person for any period of time by requesting this information in the global database online.

The *objective* of the study is to show the possibility and feasibility of using modern methods of analysis and regulation of labour on the example of a large transport company.

The tasks of the study, the results of which are presented in this article, are as follow:

- Identification of prerequisites for adoption of methods of analysis and regulation of management activities in an organisation.

- Assessment of possibilities of using the tools of functional analysis of organisation's entities and divisions to further increase efficiency of management activities.

- Description of technologies for labour rate setting for management activities using the example of the Russian Railways holding company.

The study is based on the *methods* of process analytics, functional analysis, labour rate setting, and organisation design.

RESULTS

Russian Railways Holding Company's Experience

The authors of the article carried out a study within one of the largest transport companies in the world, which is JSC Russian Railways, the backbone company of the Russian Railways holding company. A multi-level, multi-profiled, sophisticatedly structured company employs more than 55 thousand managers at various corporate levels. This provides extensive empirical material for the study of the problem of standardisation of management activities.

Currently, the holding company has launched a comprehensive work on implementation of organisation design and process management. The Regulation on Organisation Design in the Russian Railways Holding Company put into effect in 2020 contains the basic rules and requirements for design of organisational and functional models of the company's divisions and entities and for management of organisational change¹.

In conformity with the principles of its provisions, comprehensive application of organisation design tools, such as the analysis of management processes and the analysis of the organisational and functional model of the company constitutes the foundation for measuring and optimising labour costs of employees, including administrative and managerial personnel [7–9].

Analysis and standardisation of management activities is the target of the company. It will be possible to solve it through development of a process model of the holding company, decomposed into an event chain of standardised operations, interconnected with the organisational and functional model based on a single information platform. Today, at the stage of formation of this model, analysis, and measurement of labour costs of management activities is carried out pointwise [10; 11]. First, this work is carried out in relation to problem areas of activity to implement organisational

¹ Regulations on Organisation Design in the Russian Railways Holding Company, approved by the order of JSC Russian Railways dated July 26, 2019 No. 1606r [Polozhenie ob organizatsionnom dizaine v kholdinge RZD, utverzhdeno rasporyazheniem OAO RZD ot 26.07.2019 № 1606r].



Table 1

Organisational unit name	Task	Function	Product (result of function performance)	Consumer (who needs the result of function performance?)
<i>Service of economics and finance</i> (example)	Wording of the task should briefly describe the result that the activity of the structural unit is aimed at	A set of homogeneous specialised work tasks (actions, operations) performed by a structural unit to solve the tasks assigned to it	The most specifically described result of performing a function that has value for the consumer	An external or internal consumer of the result of performing a function (another organisational unit or official, an individual, etc.)

target projects to improve the organisational and functional structure and management system, as well as when creating new organisation's entities.

Functional analysis or analysis of business processes is carried out after preliminary diagnostics of the management system, when the following statements are true with respect to the work of business units [12]:

1. Decision-making is long, or decisions are not taken at all.
2. The function is fulfilled, but it does not create value for the external or internal client.
3. There is responsibility for performance of the function, but the authority is not sufficient to perform it properly.
4. Responsibility for performance of the function is blurred between several organisational units.
5. Responsibilities between managers (departments) are not distributed.
6. An organisational unit (employee) performs work that is not fixed in any organisational document.
7. There is a redundant workflow.
8. The workload of personnel of different organisational units is unevenly distributed. In some cases, there is a regular presence at work outside of working hours, in other cases, there is a chronic underload.

Sources of information for carrying out functional analysis include regulations on divisions, orders regarding distribution of

responsibilities between managers, job descriptions, analysis of products (services), business intelligence, office systems, corporate performance indicators, as well as the results of a survey of the employees.

Many different analytical forms are used to visualise the analysis.

An example of visualisation of a functional analysis of an organisational unit, which makes it possible to identify discrepancy between tasks and functions, «empty» functions that do not create value for the company, is shown in Table 1.

Using RACI matrix

For functional analysis, RACI matrix is also widely used, which makes it possible, through the roles and responsibilities of organisational units (Responsible, Accountable, Consulted, Informed), to visually see redundancy, duplication of functions, imbalance in distribution of powers and responsibilities between participants in performance of these functions, as well as possible uneven workload between organisational units [13–17].

Vertical analysis of RACI matrix allows determining responsibilities and powers of each organisational unit, objectively assessing the level of workload, for example:

1. If many roles for a unit are marked with R (responsible) that «overload» of an organisational unit is possible (Table 2).

Table 2

Function (F)	Organisational unit (OU)					
	OU1	OU2	OU3	OU4	OU5	...
F1	I	I	A	R	–	–
F2	C	R	R	–	A	I
F3	A	R	C	I	C	R
F4	–	R	C	R	I	A
F5	C	R	–	–	C	I
F6	I	R/A	C	R	I	C
F7	I	–	C	R/A	–	C
...						

Table 3

Function (F)	Organisational units (OU)					
	OU1	OU2	OU3	OU4	OE5	...
F1	C	I	R	R	A	C
F2	I	–	A	C	A	I
F3	R	C	C	I	A	R
F4	R/I	C	A	R/C	I	R/I
F5	R	R	A	I	C	R
F6	–	A	R	–	R/C	–
F7	A	–	R	R	–	R/A
...						

Table 4

Function (F)	Organisational units (OU)					
	OU1	OU2	OU3	OU4	OU5	...
F1	I	I	–	R	C	R/C
F2	C	–	A	C	–	I
F3	–	C	C	A	R/C	–
F4	C	C	A	C	I	R/I
F5	C	C	R	–	I	A
F6	–	I	C	I	R/A	C
F7	I	–	C	I	R	–
...						

Table 5

Function (F)	Organisational units (OU))					
	OU1	OU2	OU3	OU4	OU5	...
F1	A	C	R	–	C	C
F2	I	C	C	C	A	I
F3	I	R	C	–	R	R
F4	C	R	R	R	I	A
F5	R	C	C	A	R	R
F6	C	C	A	–	I	I
F7	I	A	–	I	C	R
...						

2. If many roles for a unit are marked with A (accountable) it is recommended to distribute responsibility more evenly (Table 3).
3. There are no roles R and A then there is inappropriateness of existence of this organisational unit within performance of the considered functions (Table 4).
4. If there are no empty cells, then it is possible that all organisational units are overloaded (Table 5).
- Horizontal analysis of RACI matrix reflects quality of organisation of operations, for example:

1. If there are many R (responsible) cells in a row, a duplication of functions is possible (Table 6).
2. If there are many A (accountable) cells in a row, there is a «diffusion» of responsibility (Table 7).
3. If there are many C (consulted) cells in a row, then unnecessary approvals significantly increase execution time of the function (Table 8).
4. If there are no I (informed) cells in a row, then there is an inexpediency of performing this function (there is no consumer of the result of performing the function) (Table 9).



Table 6

Function (F)	Organisational units (OU)					
	OU1	OU2	OU3	OU4	OU5	...
F1	R	R	R	R	R	R
F2	C	R	A	–	A	I
F3	A	C	C	I	C	R
F4	A	–	C	R	I	A
F5	C	I	I	R	R	A
F6	C	A	R	–	I	C
F7	C	R	–	A	R	I
...						

Table 7

Function (F)	Organisational units (OU)					
	OU1	OU2	OU3	OU4	OU5	...
F1	R	I	R	R	A	C
F2	C	A	A	A	A	A
F3	–	C	R/A	I	A	R
F4	A	–	C	R	I	–
F5	C	I	I	R	R	A
F6	C	–	R	–	I	R/A
F7	C	R	–	C/I	R	C/I
...						

Table 8

Function (F)	Organizational units (OU)					
	OU1	OU2	OU3	OU4	OU5	...
F1	R	I	C	R	R/C/A	C
F2	C	R	A	–	C	I
F3	A	K	C	I	I	R
F4	R	–	C	R	I	A
F5	C	C/I	C	C	C	C
F6	C	A	R	–	I	C
F7	C	R	–	A	R	I
...						

Table 9

Function (F)	Organizational units (OU)					
	OU1	OU2	OU3	OU4	OU5	...
F1	R	–	R	C	A	C
F2	C	R	A	–	C	I
F3	A	C	C	I	I	R
F4	–	–	C	C	I	R/C
F5	C	C/I	–	R	R	A
F6	R	A	R	–	I	C
F7	C/I	R	–	A	R	I
...						



RACI matrix is a versatile model. It is used for functional analysis or analysis of processes at any level.

Other Methods and Tools for Managerial Labour Rate Setting

Since administrative and management personnel work mainly with information and documents, a workflow matrix is used as an auxiliary tool for functional analysis. It is formed in any form and must contain information about the name of the organisational unit, the functions performed, the list of documents generated (orders, orders, regulations, reports, etc.) as a result of performance of these functions, information about those involved in approval, consumers and customers of each specific document, a method of transferring information. The workflow matrix makes it possible to identify such manifestations of bureaucracy as formation of unclaimed documents, unnecessary reports, excessive corporate procedures for approving documents, an irrational document flow system between organisational units, and, therefore, to reveal the facts of performing by administrative and managerial personnel of operations that do not create value for the company.

Functional analysis is convenient in that it allows quickly and pointwise identifying deficiencies in organisation design of individual organisational units of the company. However,

it does not provide a full-fledged vision of how management functions are distributed and interconnected in the product creation chain, how they are performed, how their implementation affects creation of this product [18; 19].

For the purposes of analysis and standardisation of labour costs, the company practices a complex application of process and functional analysis, including managerial ones, using ARIS software. This allows identifying «empty» management processes (either separate «empty» functions in the process), duplicating functions, redundant communications in cross-functional interaction (meetings, approvals, etc.), control procedures that do not affect key indicators of the final product, and therefore, revealing excessive labour costs of administrative and managerial personnel.

The sources for construction and analysis of models of management processes are current local documents of the company (standards, regulations, regulations for implementation of processes, as well as regulations for cross-functional interaction between business units of the company, etc.).

This work is carried out on an ongoing basis both by the company's divisions – owners of processes, and by specialised divisions: Centre for Labour Management and Design of Economic Standards and Centres for Improving Personnel Labour Efficiency which are part of regional centres of corporate governance.



Based on the results of the process (functional) analysis for the identified redundant functions or communications, labour costs of managers and specialists are estimated regarding the perform work that does not create value.

To study data on unproductive costs of working time, as well as to determine labour costs for the entire process (function) as a whole, they use a complex data collection by the method of questionnaires, interviewing employees, collecting statistical data over a long period, and requesting expert opinions. To confirm expert assessments, control measurements are carried out to determine the coefficient of confidence in experts.

To standardise (determine the optimal number) of specialists and employees of administrative and managerial personnel, «as it should be» process models (functional models) are designed without considering functions that do not create value. Then the models of processes (sub-processes, functions) are differentiated, which can be standardised. These are the processes that can be decomposed into simple operations, and their execution time can be measured.

To standardise labour costs of a particular organisational unit, it is necessary to have a complete database of models of all processes in which it participates.

The following requirements are imposed on the models of processes for the possibility of their use as a tool in regulation of labour of employees [20–22]:

- All the participants in the process have been identified up to the level of a specific employee.
- Cyclicity and variability of the process is known.
- Statistically significant indicators of operations were selected and, if necessary, differentiated by complexity. For an end-to-end business process, a meter should be used that is single for all participants in the process.
- The loss of working time, which does not depend on the participants in the process, as well as the amount of auxiliary work are determined.

This method is most effective for standardising labour costs of specialists and employees when they perform the functions of typical (standard) processes (for example, planning operating costs, analysing wages, developing business intelligence results, etc.).

Identification of labour costs for implementation of design and rule-making

activities is also carried out in an expert way, based on data on the share of working time spent on performance of certain functions related to development of regulatory documents or work as part of project teams.

Taking into account the peculiarities of the structure of the work of managers, in order to standardise their number, a technology is being developed for determining differentiated standards for the number of managers and management units through finding, considering analysis of influencing factors, the normative limit values of interrelated key indicators of the organisational and functional model: controllability standards, the number of direct subordinates, the ratio of the number of managers and subordinates in an organisational unit.

CONCLUSIONS

The main results of the study include tools for analysis and standardisation of management activities adapted for the companies of the Russian Railways holding company. The prerequisites for introduction of these tools, «triggers» of the work of business units, revealing problem areas of management activities were identified. Forms of visual analysis and interpretation of management information are proposed, allowing systematising and normalising management functions.

Based on the factor rate setting methodology described in the article, methodological recommendations for assessing the balance of working hours are currently being developed for the company's divisions, considering the application of the process approach. This document reflects the main stages of determining labour costs of white-collar employees, as well as ways of solving problems that arise when using the method, and examples of step-by-step research of intellectual occupations.

This will allow the company's divisions to receive the most reliable results on labour costs in the shortest time and to independently develop labour standards.

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Application of Digitalisation in Staffing Planning for Railway Infrastructure Maintenance



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ABSTRACT

Existing and suggested approaches to development of staffing plans regarding infrastructure maintenance are analysed from the point of view of ensuring interests of a railway infrastructure company, using example of JSC Russian Railways.

The existing methodology of planning workforce involved in maintenance of the railway infrastructure is based on the use of average values of parameters resulted from monitoring of the state of infrastructure structures, roadbed and track devices conducted monthly, as well as during autumn and spring continuous inspections and checks of the track. The received values of work to be performed only implicitly reflect the required number of workers, effective involvement in operation, and efficiency of each worker.

The modern trend towards digitalisation and cybernation of all processes, when organising maintenance of the track infrastructure,

provides for maximum social adaptation of production processes to requests of owners, tasks of organisers and interests of performers. Staff planning based only on the volume of work to be performed does not allow digitalisation and social cybernation of an individual performer.

The syntagmatic component of such an algorithm is the monthly total worked time, which is determined by the actual engagement of each performer. The paradigmatic component of such models should be the same daily number of performers. The stage of preliminary assessment of application of the proposed algorithm for digitalisation and social cybernation of workforce planning supposed an increase in labour productivity, approximately by 20–25 %, an increase in quality of work and a more effective assessment of activities of each performer.

Keywords: railway, infrastructure monitoring, maintenance of railway infrastructure, digitalisation and cybernation of infrastructure maintenance, social adaptation of production processes, pattern, syntagmatic model.

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

INTRODUCTION

The existing system of railway infrastructure maintenance is based on monitoring its condition and is carried out in the form of commission inspections, as well as by the use of assessment results by special technical diagnostic tools and equipment in accordance with the standards governing maintenance of tracks and infrastructure facilities¹ [1–5].

In JSC Russian Railways, the methodology of workforce planning regarding maintenance of the railway infrastructure is based on the use of average values of parameters of the infrastructure condition based on the results of monthly, as well as autumn and spring, continuous commission inspections and inspections of the track, infrastructure facilities, roadbed, and track devices².

The works performed by the teams of linear and operational sections for the coming month are planned by the road master together with foremen responsible for current maintenance of the track, roadbed and structures, considering the results of infrastructure monitoring. The developed schedules are approved by the head of the track division in the form of PU-74 schedule³. Development of the current PU-74 schedules considers the work performed during the previous month. When summarising the results of the work performed, the previous and completed current PU-74 schedules are considered.

Technical substantiated standards («TNK»⁴ or «TNV»⁵), as well as other regulatory documents approved by the Central (CDI) or regional (DI) infrastructure directorates, branches of JSC Russian Railways, are the basic normative documents for calculating the standardised scope of work, the standardised

number of employees and workers, the standardised duration of works.

The volumes of work obtained in this way can only implicitly reflect the number of workforce, involvement in operations, and efficiency of each employee.

MATERIALS AND METHODS

By the existing methodology³, the planned tasks for performance of work are calculated according to the dependence (1):

$$N_{\text{worked, hours}} = \frac{V_{\text{works}} \times H_{\text{TNK}} \times K_t}{K_{\text{measure}}}, \quad (1)$$

where V_{works} is amount of work that is assumed based on the results of assessing the state of infrastructure elements by means of diagnostics (based on monitoring described above or on current control);

$N_{\text{worked, hours}}$ normalised time for work performance;

H_{TNK} is standard time to complete a unit of work (as stipulated in TNK or TNV);

K_t – coefficient of the temperature zone;

K_{measure} – a unit of measurement for this work.

The production rate (N_{prod}) per work shift (8,2 hours) is determined by the formula (2):

$$N_{\text{prod}} = \frac{8,2}{N_{\text{TNK}} \times K_t} \times K_{\text{measure}}, \quad (2)$$

where N_{TNK} is time rate from TNK;

N_{prod} – production rate;

K_{measure} – measurement units.

Time for travelling to the work site, for trains traffic and for the time used by signalmen to install necessary signs are determined according to actual data.

The volume of work performed in fact must coincide with the specified amount of work (for a working day, week, month).

The hours that were spent for work may be less than normalised time. Normalised hours must correspond to the work assignment.

The production rates per 1 hour and per 1 person are determined by dividing the measure rate established for this type of work by the time rate, and per shift – by multiplying the result by the duration of the shift.

At present, the trend in production activities and in transport towards digitalisation and cybernation of all processes [6], when organising maintenance of the track infrastructure, provides for maximum social adaptation of production processes to requests of owners, tasks of organisers and interests of performers.

¹ Instructions on current maintenance of the railway track, approved by the order of JSC Russian Railways No. 2288r dated November 14, 2016.

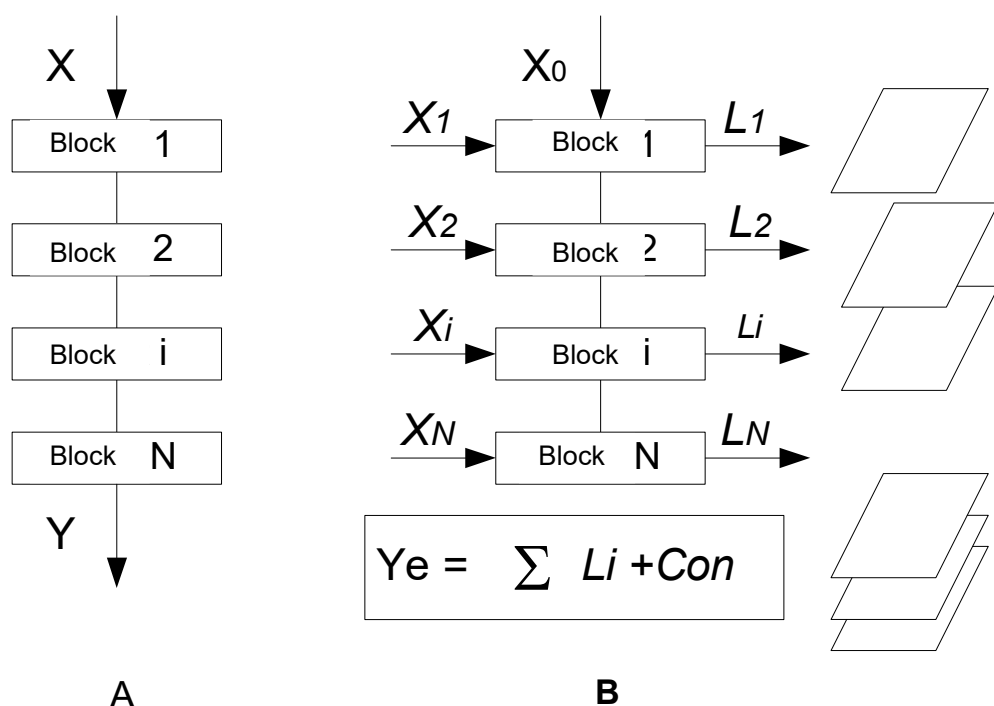
² On comprehensive assessment of the state of the track (as amended by the order of JSC Russian Railways dated January 20, 2012, No. 72r.

³ Journal of accounting of work on current maintenance and assessment of the state of the track and track devices (PU-74), approved by the order of JSC Russian Railways dated May 2, 2012, No. 857 r.

⁴ Technical substantiated standards of time for work on current track maintenance (TNK). Department of tracks and structures of JSC Russian Railways. Moscow, 2009.

⁵ Technical substantiated standards of time for work on current maintenance of the track (TNV) (as amended by the order of JSC Russian Railways dated 05.08.2015 No. 1976r) (7th edition, revised and supplemented) in 2 parts.





Pic. 1. Two types of decision-making models [9].

The existing practices of planning the production labour process of maintenance of the track infrastructure in terms of the volume of work performed does not allow digitalisation and social cybernation of an individual performer.

Social cybernetics is aimed at creating a theoretical basis for assessing and managing systems of cooperative distribution and accounting for activities of each performer [6]. It is based on identifying the share of participation of each performer in the overall production process while detailing the technology of working operations. The paradigm that social cybernetics uses in the analysis of any system is the basic law of social cybernetics. It says that all work teams go through six levels of social contracts for their subsystems:

- aggression $\Leftrightarrow$ survival;
- bureaucracy $\Leftrightarrow$ following the rules and regulations;
- competition $\Leftrightarrow$ my gain – your loss;
- solution $\Leftrightarrow$ disclosure of individual intentions;
- complementarity [7] $\Leftrightarrow$ cooperation in common interests,
- freedom of choice (subsidiarity [8]) $\Leftrightarrow$ the ability to manage own actions and self-control.

The transition through those six phases of relationships provides the basis for a social and cybernetic assessment of any evolutionary system, to which work teams can be attributed. Moreover, these phases manifest themselves in different ways in cybernetics systems of different orders.

The sequential decision-making model is the simplest cybernetic model. It is built according to the principle (3):

$$(A \wedge B) \rightarrow P, \quad (3)$$

In expression (3), A is an event that affects object B , which leads to result P . Expression (3) is a classical expression of succession, in which the symbol $\rightarrow$ is called implication. An expression in parentheses is called a premise or antecedent. P is called a consequence or apodosis. Sequential logical actions and events are well tested with logical expressions. They form a logical sequence in the form of a set of expressions (3), which set logical chains of decision-making. Sequential actions and models are well modelled using graphs. Pic. 1 gives two types of decision-making models [9].

The direct algorithm is a sequential chain of actions, which are shown in Pic. 1a. In the diagram in Pic. 1a, the output of the current stage

serves as the input to the next stage. Such models are called sequences because the inputs/outputs of the stages are consistent in them. However, interrupting a stage interrupts the entire chain. In this model, there is a single general rationality of actions.

RESULTS

A model of the above-mentioned type can be used in development of an algorithm for scheduling the scope of work regarding maintenance of the track infrastructure to eliminate the identified malfunctions by means of diagnostics. When modelling such a process, there is no relationship to specific performers. The digitalisation and cybernation of such processes consists in recording a planned or completed event, as well as the absence of such an event, in the form of a planned or completed one, which should have been based on the results of diagnostics.

Currently, the initial materials for development of such sequential models can be compiled from monitoring data using EK ASUI (single Corporate Automated Infrastructure Management System); KAS ANT (complex automated system of accounting, control of elimination of failures in the operation of technical means and analysis of their reliability); KASAT (integrated automated system for accounting, investigation and analysis of cases of technological violations) systems, commission inspections (autumn, spring, monthly, etc.), data from track measuring and defectoscope control devices and other materials evaluating the state of the infrastructure. The peculiarity of development of such a model for planning the scope of work for maintenance of infrastructure is that if any work operation is not performed in the chain of the sequential model the result is not achieved.

Pic. 1b shows a serial-parallel model of decision-making. This model focuses on producing results at every level of the decision-making stage, but with independent inputs for each stage. Such a stratified model is a collection of particular models in a general decision-making model. We can talk about syntagmatic models along horizontals (levels) and paradigmatic [10; 11] vertical models. In such models, there is one common result and a set of individual approaches.

These models include the labour force planning algorithm. The syntagmatic component of such an algorithm is the monthly total worked time, which is determined by the actual worked

time of each performer. The paradigmatic component of such models should be the same daily number of workers.

Despite the variety of models, there are general rules and principles by which models of social cybernetics are formed. When generating models, the following rules apply:

- The area of interest is fixed as an information situation (A_1), in which management is planned to be carried out:

- In the information situation, conditions (A_2) are fixed, determined by a set of parameters or constraints.

- For the problem areas, known heuristics (A_3) are fixed in the form of patterns [12] or rules by which calculations can be performed.

- If a suitable model based on heuristics is not found, a new model is formed based on analytical studies (A_4).

- For the decision to be made, the conditions (A_5) of its correctness and admissibility are fixed.

- Criteria for evaluating the effectiveness of the solution are selected (A_6).

- Technology is applied (B) and the result is obtained (P).

This technique has a logical form (4):

$$(A_1 \wedge A_2 \wedge (A_3 \oplus A_4) \wedge B \rightarrow (P \wedge A_5) \rightarrow A_6. \quad (4)$$

There are many computational models that can be classified as structural objects, for example, the conceptual model [13], which is a theoretical prerequisite for building a computational model.

Pic. 2 is a diagram of construction of a decision-making model.

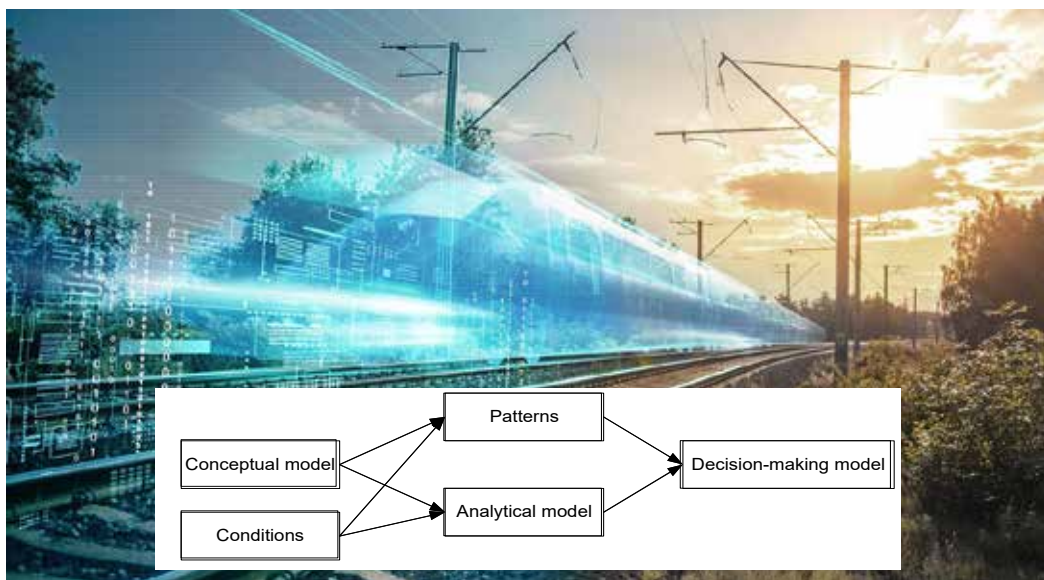
DISCUSSION OF THE RESULTS

As a strategic direction for digitalisation and social cybernation, planning of the workforce for maintenance of railway infrastructure is an addition to the existing methodology for setting planned targets for performance of work (dependence 1) by determining the number of performers to complete the task.

The basic regulation documents for calculating the standardised number of employees and the standardised duration of work are, for example, TNK⁴ or TNV⁵.

The algorithm for digitalisation and social cybernation of staff planning is that after establishment of planned targets for performance of work (dependence 1), the duration of work in working hours or working days is determined, as a quotient from dividing the planned volume of work by duration of the working day.





Pic. 2. Model building scheme [13].

Further, the planning process is carried out with the set number of workers, for example, according to TNK⁴ or TNV⁵.

When developing the «Schedule of execution of planned works» it is necessary to adhere to the following principle. At the beginning, the most labour-intensive work with the largest number of workers is distributed per working days. In case of incomplete workload of working days until the end of the month, the performers of this work are transferred to another job the next day (the «ladder» principle).

If the next work does not require involvement of all performers, those who performed the first job are transferred to the next jobs in parts. It should be borne in mind that the following works according to their technological features may require a certain stipulated number of workers, which is indicated in TNK⁴ or TNV⁵ for this work.

After completing formation of distribution of workers who have performed the first work for other works until the end of the month, it is possible to start distributing the remaining unallocated works. The distribution principle remains the same.

When forming list of workers intended for individually performed works, it is possible to attract several performers to speed up the performance. The situation of supplementing or reducing the number of teams, which are indicated in TNK⁴ or TNV⁵ for this work, is unacceptable.

To control the correct distribution of work and performers, it is recommended to keep records of performers regarding each working day.

When carrying out the operation of distributing working days for cases of incomplete working hours, several solutions may be considered [14; 15]. For example, redistribution of part-time working hours for travelling to the job location and back, for passage of trains and other losses of a production and technological nature. In this case, it is necessary to recalculate duration of working hours for the entire period of this work. This will lead to a decrease in duration of working days and a decrease in production, which must be considered when calculating the volume of work.

Another distribution option can be redistribution of excess time in the form of additional time to each working day as a factor in increasing labour productivity. This option is possible when the part-time job received by calculation is distributed within 30–40 % of the full working day.

After distribution of works and performers in accordance with the specified volumes and duration, a statement of the actual number of performers is drawn up.

The actual number of employees is one of the indicators that is used in the accounting system for the number of performers at a particular enterprise. In addition, such a calculation will help to analyse the work of the enterprise,

identify shortcomings in the work of the team and provide opportunities for optimisation at a particular enterprise.

After drawing up a list of the actual number of performers, a list of the payroll of performers is drawn up.

The list number of performers of current maintenance of the track within the whole track division, which are based on materials of, for example TNK⁴ or TNV⁵, is determined by summing up the number of performers of each work, which is provided for by technology.

CONCLUSIONS

The research presented in the article is aimed at developing a mechanism for planning labour resources, their optimisation, rational distribution and control.

The algorithm for digitalisation and social cybernation of workforce planning allows keeping an operational record of each performer in accordance with the results of the work performed and occupation of performers according to the attendance number. Further development of the developed algorithm considers the process of automated operational accounting and control of staff planning, as well as of their performance in implementation of the assigned production tasks.

The stage of preliminary assessment of application of the proposed algorithm for digitalisation and social cybernation of staff planning supposes an increase in labour productivity, approximately by 20–25 %, an increase in quality of work and a more effective assessment of activities of each worker.

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ICAO: Runway Safety Training

EXPRESS INFORMATION

ICAO will partner with ACI, IATA and CANSO on new runway safety training initiative.

The new online course has been specifically designed for air traffic controllers and aeronautical information service staff. It will

be available for enrolment in April of this year on the ICAO Global Aviation Training website. The course complements existing courses developed in cooperation with Airports Council International (ACI) for airport operations staff, and with IATA for flight crews.

Keywords: ICAO, training, air safety control, runway, online course.



With the coming into effect this November of its new Global Reporting Format for Runway Surface Conditions (GRF), ICAO has agreed to partner with the International Air Transport Association (IATA) and the Civil Air Navigation Services Organisation (CANSO) on a new joint GRF training programme.

The new online course has been specifically designed for air traffic controllers and aeronautical information service staff, and will be available for enrolment in April of this year on the ICAO Global Aviation Training website. It complements existing courses developed in cooperation with Airports Council International (ACI) for airport operations staff, and with IATA for flight crews.

«Runway safety continues to remain aviation's biggest safety challenge, representing more than half of all accidents reported to ICAO for

commercial operations», emphasized ICAO Secretary General Dr. Fang Liu. «We have been collaborating in recent years on numerous initiatives to reduce runway safety related accidents and incidents worldwide, and the hard work undertaken to forge international consensus on the new GRF, in addition to this new collaborative training course supporting it, should help to deliver substantial runway safety performance improvements».

The ICAO GRF will be effective as of 4 November 2021, and establishes a new methodology for assessing and reporting runway surface conditions to improve take-off and landing performance.

The new agreement is the first of its kind between the three international organisations, and sets the stage for future collaboration on global safety enhancement initiatives. ●

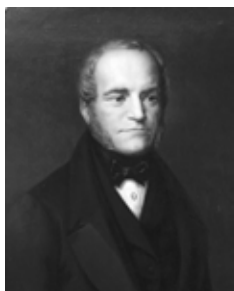
Compiled based on the ICAO news release of March 5, 2021: <https://www.icao.int/Newsroom/Pages/ICAO-to-partner-with-IATA-and-CANSO-on-new-runway-safety-training-initiative.aspx>.

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The railway is still the first one, currently it is at the top regarding the speed.



HISTORY WHEEL



**PRESS
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*What impressed the readers of the Rail Business Journal most 111 years ago?
The speed of giant passenger steam locomotives...*





REVIEW ARTICLE

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The First Main Line in Russia



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ABSTRACT

The article is dedicated to the 170th anniversary of the first Russian railway main line St. Petersburg–Moscow. The country's railway transport, as the main type of transportation, has a rich history and remarkable patriotic, labour, scientific, and technical traditions. We must remember them. The emergence of railways in Russia, as in other countries of the world, was accompanied by many problems that needed to be solved: financing methods, types of ownership, track gauge, types of traction and signalling, traffic management and

control, competition with other modes of transport, etc. The stage of emergence of railways in Russia is very instructive. What extreme points of view were expressed, and how long did it take to start building main lines? After the society realised the need for construction of railways, it became obvious that the costs required are not affordable neither for the state, nor for creditors, nor for private entrepreneurs.

To better understand how construction of the first railway in Russia was conducted, the article offers many illustrations.

Keywords: main line, formation and construction, survey and design, construction sites, bridges, stations, signalling, steam locomotives, coaches.

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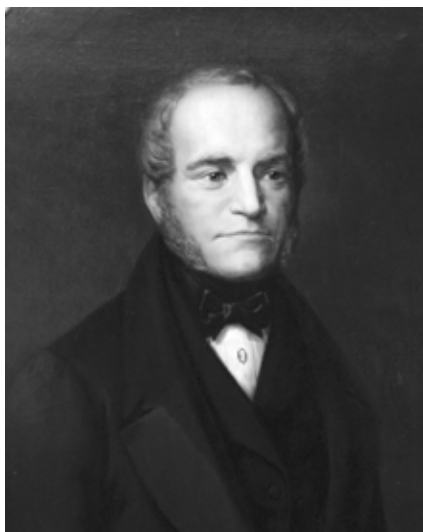
*The text of the article originally written in Russian is published in the first part of the issue.
Текст статьи на русском языке публикуется в первой части данного выпуска.*

On July 8, 1826, the Ministry of Railways discussed for the first time a number of proposals for construction of railways in Russia and rejected them, noting that such roads are economically unprofitable, and that they are difficult to be maintained in our climate, especially in winter. And in the future, there were many opponents of railways in Russia comprising the Chief manager of transportation routes K. F. Tol, the Minister of state property Count Kiselyov, the Minister of finance E. F. Kankrin, the Minister for war Count Chernyshev, the Minister of the imperial court Prince Volkonsky, the Chairman of the State Council prince Vasilchikov, the Minister of the interior L. A. Perovsky, the head of the Commission of projects and estimates of the Department of transportation routes M. G. Destrem and a number of other government officials.

The arguments of opponents of construction of railways were expressed by Minister of finance E. F. Kankrin: *«Not only should the idea of covering Russia with a whole network of railways be considered as exceeding any real possibility, but a sole construction of a railway from St. Petersburg to Kazan should be recognised as several centuries premature. The government can draw its subjects into the greatest losses. Steam traction can in no case be allowed on railways, because due to the lack of coal in Russia, it will entail destruction of forests. For transportation of troops, railways are also unsatisfactory, since they should have a huge number of carts (cars) for this item, which are not needed at all in ordinary times. Duty-free import of cast iron and rails will entail the exit from the state of capital and, finally, alienation of land for the roadbed and various buildings will require enormous costs»*. There were especially many critics among the owners of canals and stagecoaches, who were afraid of losing their monopoly on transportation of goods and passengers.

While such discussions were going on, in England and the United States, massive construction of railways began. And yet, in Russia there were many people who believed that it was in a country with vast areas that railways were needed, since they were a reliable means of communication that allowed to regularly move large masses of goods with minimal expenditure of manpower and resources.

In August 1834, following the invitation of the Mining department, a famous Austrian engineer, professor at the Vienna Polytechnic Institute Franz



Pic. 1. Franz Anton Gerstner.



Pic. 2. Emperor Nicholas I.

Anton Gerstner came to St. Petersburg to organise construction of railways in Russia (Pic. 1). In September Gerstner left St. Petersburg via Moscow and Kazan for the Urals to get acquainted with the real conditions and possibilities of railway construction.

Upon his return to St. Petersburg, he submitted to Emperor Nicholas I (Pic. 2) a detailed note in which he outlined his views on construction of railways. He noted that *«... there is no country in the world where railways would be more profitable and even necessary than in Russia since they make it possible to shorten long distances by increasing speed of movement»*.





Pic. 3. Nicholas I discusses railway projects.

Gerstner proposed to build a road between St. Petersburg and Moscow, then to connect Moscow with the main waterway of the country – the Volga with the line Moscow–Kazan or Moscow–Nizhny Novgorod (Pic. 3). Then he intended to connect the line between St. Petersburg and Kazan with Odessa or Taganrog, pointing out that with assistance of the shipping company along the Volga and the Caspian Sea, the Asian trade of Russia would be ensured, and the competition of England would be eliminated. But for a start, he considered it expedient to build some kind of small line in order to dispel doubts about the possibility of operating the railways in winter conditions. Only then, relying on the experience gained, he did plan to start building a main line from St. Petersburg to Moscow.

Somewhat later, this proposal included only construction of St. Petersburg–Moscow line, and then it all came down to construction of an experimental St. Petersburg–Pavlovsk railway on an equity basis (Pic. 4).

On March 9, 1835, Gerstner submitted a petition *«for permission to establish a company with a capital of 3 million roubles for construction of a railway from St. Petersburg to Tsarskoe Selo, Pavlovsk and Kolpino in the form of the first experience in construction of this kind of track, to prove usefulness of the railway for the public, shareholders and the state with this construction»*.

On June 8 or 19, 1835, Emperor Nicholas I wrote a resolution with his own hand on Gerstner's note. There is no date on the resolution, but it might become the date of founding of railways in Russia. The content of the resolution is literally the following: *«I read it with great attention and was convinced, as before, in favour*

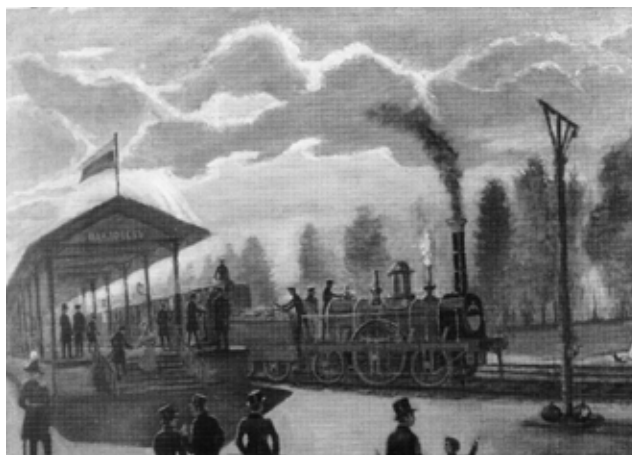
of this cause: but I am not convinced that Gerstner would find enough capital to start such a huge enterprise. On this subject I wish written explanations from him; then, if necessary, I will call him to myself. I will allow the road to Tsarskoe Selo, if he will present plans to me».

Thus, despite all doubts on the part of the government officials closest to the Emperor about the expediency of railways, their fate was decided by the will and conviction of usefulness and necessity for the country by Emperor Nicholas I. The Tsarskoye Selo railway was built in 1837. The experience of the Tsarskoye Selo railway showed that in the harsh climatic conditions of Russia, railways can operate steadily and generate income for their owners.

The next issue was construction of new lines in Russia. All proposals from both domestic and foreign entrepreneurs and financiers were based on the joint-stock form of ownership. For construction of a railway between St. Petersburg and Moscow, many different proposals and applications were received, but they were all rejected.

The most solid proposal with the assistance of P. P. Melnikov and Count A. A. Bobrinsky, who was very close to the sovereign, came from German bankers Dufour and Harkart. They were famous for being the first bankers of the sprawling commercial city of Leipzig and establishing Dresden railway, one of the best in Europe in technical terms, and bringing in a good income.

The proposal was as follows (as described by P. P. Melnikov): St. Petersburg–Moscow railway is being built by the joint-stock company being formed. The calculations assumed transportation



Pic. 4. Tsarskoye Selo railway.

of 200000 passengers and 24 million poods of cargo per year.

«From the environment of a company consisting of foreign, mainly German capitalists and based in Leipzig, the Board of Directors is formed, which is located in St. Petersburg. The Government Commission will oversee the actions of the chief director, and the government can be the closest participant in the case, leaving behind a part of the shares. The main advantage that bankers ask for is the government's guarantee for a 4 % income on shares, which guarantee will not lead to any additional payment from the treasury, if the income of the road is more than 4 %, and meanwhile, an important and useful business will be performed without a donation from the state and an unforgettable monument to the present reign will be erected». In the future, such a guarantee of the government for the receipt by shareholders of a certain income has found widespread use.

This proposal and the justifications attached to it were received by Nicholas I, who ordered formation of a special committee to study them and develop proposals.

Throughout 1841, there was a fierce struggle between the supporters of construction of St. Petersburg–Moscow railway and its opponents. The final decision was made on January 13, 1842, at a special meeting in the presence of the Emperor.

Concluding the debate of the meeting, the Tsar said that he had come to a conclusion about the usefulness of St. Petersburg–Moscow railway in terms of its influence on industry and trade, and that the road should be arranged with government funds and remain within its hands.

At the beginning of 1842, a corresponding decree was issued. This is how the first state (state-owned) railway in Russia was born.

Since all the ministers were against the construction of St. Petersburg–Moscow railway, Nicholas I (Pic. 2) established a Special Committee to carry out this enterprise and appointed the heir to the throne, Tsarevich Alexander Nikolaevich, the future Emperor Alexander II, as chairman.

Already on January 29, 1842, the first meeting of this committee was held under the chairmanship of the heir to the crown. At this meeting, a draft Decree of Nicholas I was prepared for the Governing Senate, a Construction Commission was formed, and the Minister of finance was instructed to allocate funds necessary for construction of a railway between the capitals.

On January 30, 1842, the Construction Commission under the chairmanship of Count Benckendorff began its work; it was entrusted to carry out surveys and draw up an estimate for Colonels P. P. Melnikov (Pic. 5) and N. O. Kraft (Pic. 6). The decision of the Committee was approved on February 1, 1842, by Nicholas I.

On August 11, 1842, after the appointment of Count P. A. Kleinmichel as Chief Governor (Pic. 7), changes were made in the higher bodies in charge of the railways.

By the decree of Nicholas I to the Governing Senate of August 11, 1842, the Construction Commission was abolished, and the Department of Railways was established, whose duties included management of all railways. Under it, a temporary technical commission was formed during construction of St. Petersburg–Moscow railway.





Pic. 5. Engineer Lieutenant General P. P. Melnikov.



Pic. 6. Engineer Major General N. O. Kraft.



Pic. 7. Count P. A. Kleinmichel.



Pic. 8. Monument to Nicholas I in St. Petersburg.

When designing the railway, there were two proposals, one – to lead the road directly to Moscow, the other – with a call to Novgorod. Nicholas I (Pic. 8) imposed the following resolution: *«To arrange the road in a direct direction, because I do not find any good reason to lead it to Novgorod, which will not lose the benefits that it uses».*

The projected line was divided into two construction sections: St. Petersburg–Bologoye (Northern Directorate), headed by P. P. Melnikov, and Bologoye – Moscow (Southern Directorate), headed by N. O. Kraft (Pic. 9).

To carry out exploration work, seven special parties were formed, staffed by graduates and students at the Institute of the Corps of Railway Engineers, which were headed by N. I. Lipin (Pic. 10), I. G. Verigo, P. P. Zuev, V. I. Kirchner, A. I. Shtukenberg (Pic. 11) and others. In one of the groups a railway engineer D. I. Zhuravsky (Pic. 12) worked, who later became the country's largest scientist in the field of bridge construction.

The main field work was completed in the spring of 1843. The total length of the explored variants of the route was 6000 km, or about 10 km per 1 km of track.

There was no experience in design and construction of railways in the 1840s. Therefore, in 1842, Major of the American service J. Whistler was invited to consult on construction of the St. Petersburg–Moscow road (Pic. 13). His advice was highly professional and very helpful



Pic. 9. Scheme of St. Petersburg–Moscow railway.

to the builders. In 1847 he was awarded the Order of St. Anne, II degree.

P. P. Melnikov was responsible for development of technical conditions and standards for design and construction of St. Petersburg–Moscow main line. He suggested a 5 ft (1524 mm) track, which is 89 mm wider than Stephenson's. The choice of a track wider than 4 feet 8.5 inches provided a more convenient placement of the locomotive mechanism, an increase in the volume of the boiler, the weight of the cargo in cars, and better stability of rolling stock. The gauge proposed by P. P. Melnikov was adopted throughout the Russian railway network.

P. P. Melnikov invented and introduced many technical and railway terms that are still used today. For example, stations of I, II, III and IV classes, which were located on the main line, respectively, at a distance of about 160, 80, 40 and 20 km.

The issues of organising construction of railways in the 1840s presented significant difficulties due to the lack of experience in design and construction of such large lines as St. Petersburg–Moscow railway. The more respect is given to the optimal solutions found by the pioneers.

The construction of the road began in the summer of 1843. To bring the administrations as close as possible to the objects under construction, the Northern Administration was located at Chudovo station (111 versts from St. Petersburg) (Pic. 14), the Southern – first in Vyshny Volochek



Pic. 10. N. I. Lipin.



Pic. 11. A. I. Shtukenberg.



Pic. 12. D. I. Zhuravsky.





Pic. 13. J. Whistler (1800–1849).

(an important centre of the systems of channels connecting the Volga with the Neva) (Pic. 15), and then in Tver (it was supposed to tranship cargo from the Volga River) (Pic. 16).

On St. Petersburg–Moscow railway, pointless switches with double movable rails were used. They were much more stable in the horizontal plane and provided a smoother entrance to the branch compared to switches with single movable rail. However, the presence of a rupture in the track at the beginning of the turnout could lead to derailment of rolling stock going in trailing direction. Soon, switches appeared with two movable straight blades from ordinary rails, which were the prototype of modern switches.

Wooden beams were used as an under-switch base. They had required elasticity, significant strength, were simple in shape, easy to operate and manufacture.

The organisational and technological construction plan provided for:

- Selection of support bases in the zones of adjoining the route to the waterways of communication, along which the supply of materials and equipment was carried out.
- Multi-beam method of construction work, when they are carried out from one point in several directions at the same time.
- Stage-by-stage commissioning of road sections, which speeds up and reduces the cost of construction.

The acceleration of construction was facilitated by introduction of elements of mechanisation of work. For example, during development of a huge excavation between Valdai and Berezaika stations, earth-moving machines similar in design to excavators were used. When driving the piles of the bridge crossings, steam piles were used. For transportation of soil, specially designed earth-carrying cars and a track for them were used.

Difficult problems arose during construction of 19 overpasses, 69 pipes and 184 bridges, including across large rivers as the Volga, Volkhov, Tvertsa, Msta. D. I. Zhuravsky supervised the design of bridges. One of the features of bridge crossings was the significant height of supports, which made it necessary to use large spans instead of small ones to avoid the rise in construction costs. In addition, the



Pic. 14. Railway bridge at Chudovo station.



Pic. 15. Vyshny Volochek.



Pic. 16. Tver Station.

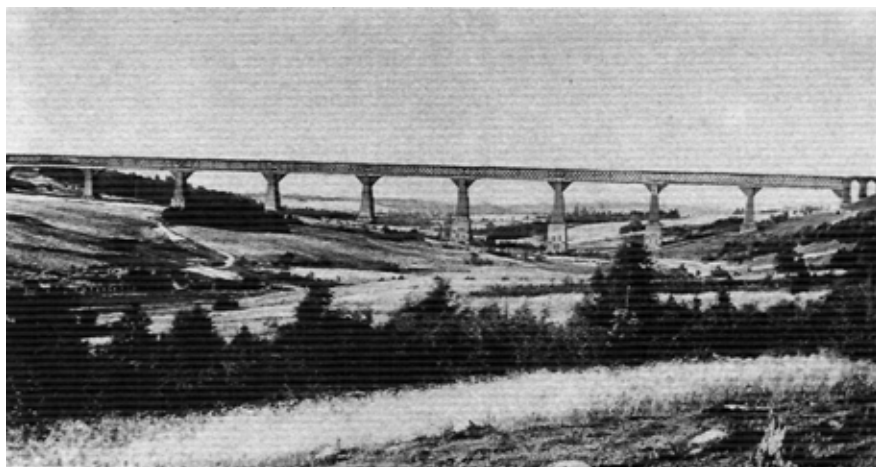
frequently placed supports at small spans impeded navigation and made it difficult for ice to pass through.

D. I. Zhuravsky refused to blindly copy large-span structures of wooden bridges known at that time. Rightly believing that the arch system at high bridges heights would require construction of massive and expensive supports, he turned his attention to lighter beam spans with wooden trusses, proposed by the American engineer W. Howe. However, there was no theory for calculating such structures, which raised serious doubts about correctness of the approach to

assigning dimensions of the sections of individual elements.

In 1845, D. I. Zhuravsky created a theory for calculating lattice trusses, giving a method for determining the forces in individual elements. In particular, he found that the cross-sections of vertical metal strands were assigned in the Howe trusses unreasonably: the strands at the supports are heavier loaded and should be more powerful. For design reasons, a constant cross-section of the truss chords was provided along the entire length, while in single-span structures, the chord cross-section could





Pic. 17. Verebyinsky viaduct.

be fully used only in the middle of the span. For bridges of large spans, the scientist proposed a continuous beam system that ensures the rational use of the belt material.

Based on the research, D. I. Zhuravsky gave recommendations on the calculation of the Howe trusses and developed projects for wooden bridges across all major watercourses on St. Petersburg–Moscow railway line. Five groups of span structures with lengths from 16,4 to 60,8 m were developed. The design of structures was accompanied by comprehensive studies of their work under load and the properties of the building materials used.

The span structures of all bridges had wooden multi-lattice continuous trusses formed by the superposition of several simple triangular lattices on top of each other, which significantly improved the work of compressed elements.

The Verebyinsky viaduct became a unique bridge crossing (Pic. 17). According to contemporaries, this viaduct was considered one of the best structures of this type, not only in Russia, but in Europe and America.

The Msta bridge had nine spans of 61 m each. Its supports were pyramidal wooden tower structures on a stone foundation, sheathed with iron.

A feature of the bridge over the Volkhov, which had five spans of 51 m each, was a ten-meter adjustable navigable span of the opening system. The author of the project, engineer V. I. Grave, to ensure the balance of the system at any opening angle, proposed a counterweight to the original design.

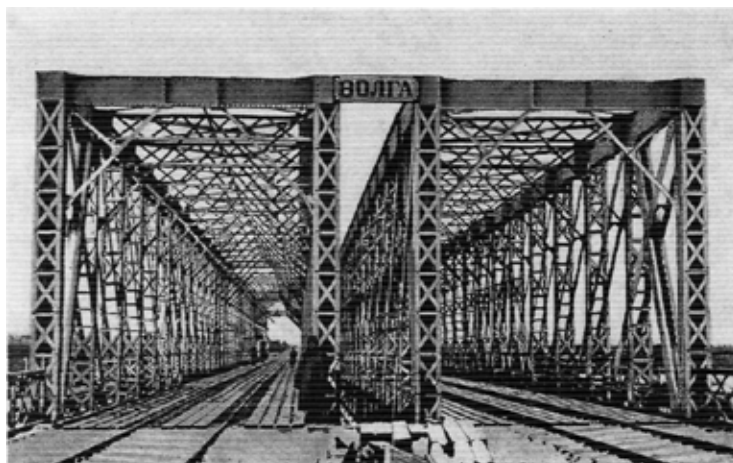
The bridges across the Volga (Pic. 18) and Tvertsa each had three spans 59,6 m long. The bridges across the Obvodny Canal and the river Slavyanka were significantly different from the

others. The stretched belts of the Howe trusses used in the span structures of these bridges were metal (iron).

The Aleksandrovsky Mechanical Plant of St. Petersburg–Moscow Railway became the firstborn of railway engineering. Passenger locomotives of 2-2-0 type produced by the plant were later designated «B». An internal eccentric steam distribution mechanism set in motion double (expansion) spools, which made it possible to reverse the machine and change the degree of filling the cylinders with steam. In a tubular boiler, a cone draft was used, which made it possible to regulate the process of fuel combustion, depending on intensity of operation of the steam engine. The pressure in the boiler increased up to 8 atm, the power of the steam locomotive – up to 130 hp. It drove trains of six cars at a speed of 40 km/h. In addition, steam locomotives of 1-2-0 and 1-2-1 types were built.

Commercial steam locomotives of 0-3-0 type produced by the Aleksandrovsky plant (Pic. 19), which received the designation «D», were similar in many design solutions to passenger locomotives. They had a power of about 140 hp and drove 22-coach trains at a speed of 15 km/h.

The first domestic freight wagons (Pic. 20) appeared on St. Petersburg–Moscow railway. They began to be built at Alexandrovsky plant in 1846. The cars were four-axle, with wooden bodies, a central hitch, without side buffers, and with a hand-operated braking device. The carrying capacity of the covered car with a container of 7,8 tons was 8,2 t. For bulk and long cargo, four-axle platforms with a tare weight of 6 tons and a carrying capacity of 10 tons were



Pic. 18. Entrance to the railway bridge across the Volga.

also built. Their axial load was 4 tons instead of 10 tons, for which the rail track was designed.

In 1845, Academician B. S. Jakobi (Pic. 21) received a task to set up telegraph communication along St. Petersburg–Moscow railway, which was under construction. Before the completion of this project, the German company Siemens, invited to participate in organisation of such a connection, laid a cable line, which consisted of two copper wires, insulated with gutta-percha and placed in a wooden gutter, filled with an insulating mass. The line was laid along the side of the track at the ends of the sleepers. It began to be exploited in 1852 with the use of Siemens telegraphs, and then Morse, since the latter provided more reliable communication.

However, the design of the laid cable turned out to be unreliable, therefore, in 1854, at the suggestion of B. S. Jakobi, it was decided to replace it with an overhead line, which had three steel wires with a diameter of 5 mm, suspended on poles by means of iron hooks with insulators. 16 pillars were installed per verst. In the future, overhead communication lines were also used on all railways under construction.

All projects of the buildings of St. Petersburg–Moscow railway are permeated with the ideas of the Tsar's favourite, the architect K. A. Ton (Pic. 22). Ton designed the entire area of 644 km road as a single ensemble in the form of a gigantic square. Nikolaevsky railway station (Pic. 23) was built in 1844–1851 according to the project of Konstantin Ton, with the participation of Rudolf Zhelyazevich. The building combines the forms of the Italian Renaissance and ancient Russian motives. A novelty at the time was a solution with a metal covering over the end sections of railway

tracks and adjacent passenger platforms. If the passenger station building itself was designed by Ton in traditional forms and structures, then the landing stage had no analogues in the architecture of the past. The triangular trusses of the apron cover created a completely new image of the transport interior.

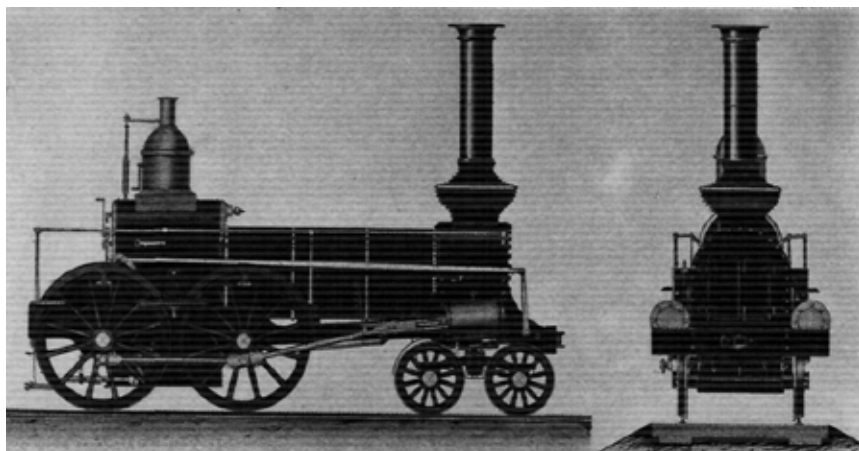
The station building is round in plan, located along the length of the entire adjacent square. Konstantin Andreevich used the motives of the town halls of Western European cities, the clock tower indicates the direction of the main entrance. The Emperor himself took an active part in the design of the new station (Znamenskaya) square.

N. I. Miklukha was appointed the first head of the passenger station and the station of St. Petersburg–Moscow railway (Pic. 24). His apartment was located in the very building of the station, in addition, the offices of employees, the railway administration, and the imperial premises were located here.

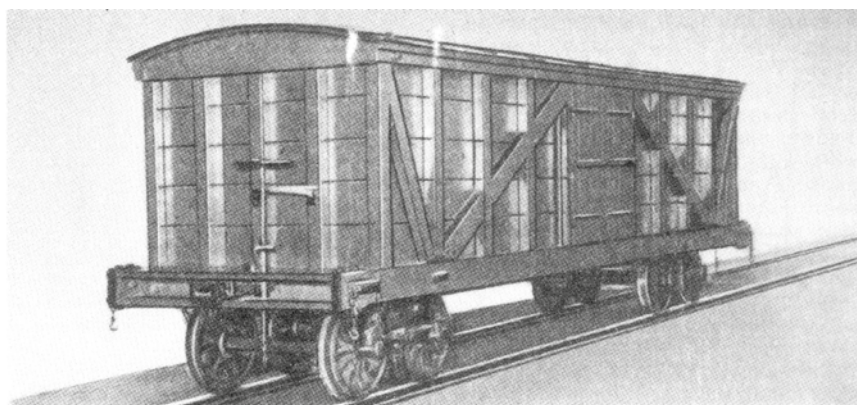
Leningradsky railway station (until 1855 – Petersburgsky, in 1855–1923 – Nikolaevsky, in 1923–1937 – Oktyabrsky) (Pic. 25) is the oldest of the nine stations in Moscow. The station building was built in 1844–1851 according to the project of Konstantin Ton by the architect Zhelyazevich. For the station, the construction commission chose the Kalanchevsky wasteland on the northeastern outskirts of Moscow.

The construction of Petersburgsky railway station in Moscow began in 1844 under the direction of the managing head of transportation routes, Peter Kleinmichel, who had disagreements with Ton. So, Kleinmichel demanded the use of brickwork with thin seams, which seemed to him





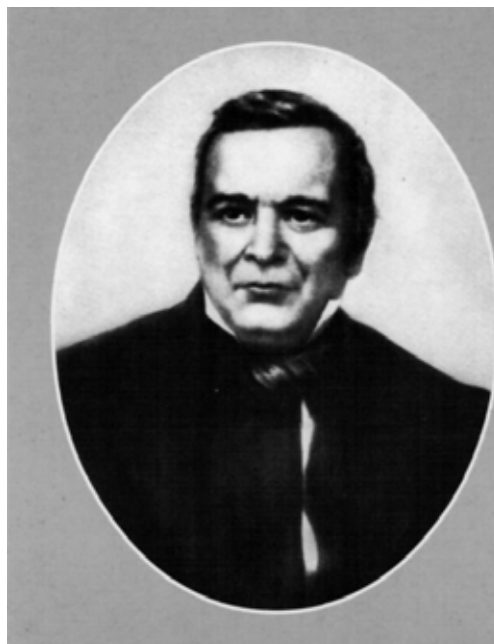
Pic. 19. The first domestic commercial steam locomotive.



Pic. 20. The first covered car of St. Petersburg-Moscow railway.



Pic. 21. B. S. Jacobi.



Pic. 22. Architect K. A. Ton.



Pic. 23. Nikolaevsky railway station in St. Petersburg.

more aesthetic. The architect refused to comply with this instruction, fearing a violation of the solidity of walls and the occurrence of cracks. As a result of conflicts in 1847, the work was entrusted to Rudolf Zhelyazevich, who was more flexible.

The construction was completed in 1851. The building was a stylistic pair of the station in St. Petersburg, but it was smaller in size. The central part of the building was occupied by a spacious two-story lobby. The premises of the station were decorated with oak parquet and marble Swedish stoves. The imperial halls had massive oak doors and mirrored wardrobes. The second floor of the main building of the station was allocated for the apartments of employees.

As the work progressed, the road opened section by section. In 1847, a permanent traffic was opened between St. Petersburg and Kolpino. In 1848 service traffic was carried out to Chudovo station and between Tver and Vyshny Volochk. The opening of the entire road to Moscow took place on November 1, 1851.

Once construction was completed, the initial period of its operation is also of interest. In the absence of sufficient experience in operating railway transport, it was believed that only people accustomed to a clear army order could ensure safety and regularity of movement in the best way.

Therefore, by order of the Main Directorate of Railways and Public Buildings dated September 23, 1851, No. 180, 14 separate military workers, 2 conductor and 1 telegraph companies were formed for operation of the railway. They were recruited by the military department from among the non-commissioned officers and privates of active military service.



Pic. 24. I. N. Miklukha.





Pic. 25. Nikolaevsky railway station in Moscow.

There were 3500 people in the military workers' companies. One of the conductor companies included steam locomotive drivers, their assistants, and firemen.

In total, during construction of St. Petersburg–Moscow main line, about 46 million cubic meters of earthworks were carried out, two large stations were built in both capitals, as well as other 34 stations, and 190 bridges. The construction of this railway cost 67 million roubles (one third of the annual budget of the Russian Empire in 1842). In the middle of 19th century, this railway was the most technically advanced and the longest (644 km) double-track railway in the world.

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The Greatest Passenger Steam Locomotive in the World



News from the archives

The publication in Rail Business [Zheleznodorozhnoye delo] Journal of 1910 introduced the most powerful steam locomotive of the time to the readers. It was intended for passenger traffic in the United States.

Keywords: railway, steam locomotive, passenger traffic, history.

In No. 24 of Rail Business [«Zheleznodorozhnoye Delo»], 1909, I described the greatest commercial steam locomotives built by Baldwin's plant in Philadelphia for Southern Pacific R. R.; now I will add that in practice they turned out to be extremely efficient and expedient, that at the present time there are already up to a dozen of them working, and that it was decided to supply them exclusively to the entire mountain division of this road.

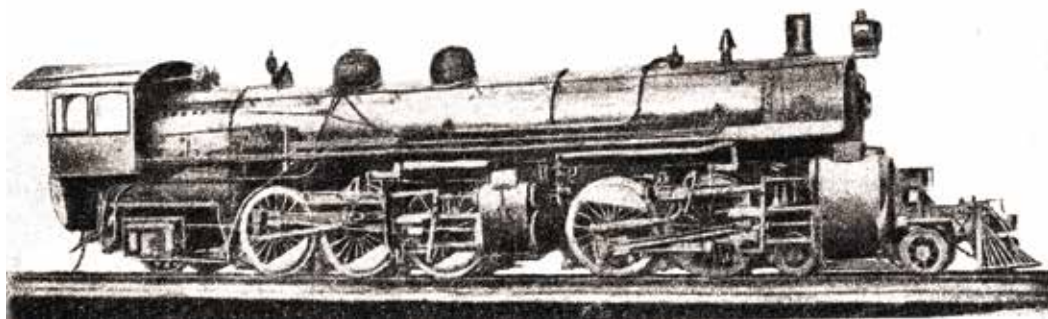
It goes without saying that mountain passes affect both freight and passenger traffic in the

same way, and this is especially noticeable in cases where different lines compete with each other during long journeys by shortening time they need. Over the past year, it is precisely this kind of competition that has resumed with great energy between a whole half-dozen transcontinental lines of the North America, operating between the Atlantic and Pacific oceans; time between New York and Chicago has been shortened from 18 to 15 hours, time between Chicago and Los Angeles or San Francisco from 72 to 60 hours, and all roads are striving to reduce travel times to three days,

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Acknowledgements. The editorial board expresses its gratitude to the staff of the library of Russian University of Transport for their assistance in preparing the publication.

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



i.e., 3250 miles or 4875 versts to be travelled in 72 hours, including all stops and connections in Chicago. Atchison, Topeka & Santa Fe RR Co., which has over 10000 miles of track and its own continuous line from Chicago to Los Angeles and San Francisco, is closest as compared to all its other competitors to achieve this. Although it has built 400 miles of new track, bypassing the highest of its mountain passes in the main ridge of the Rocky Mountains in Colorado, it was still hampered by three other passes – in New Mexico, Arizona, and California, especially in this last one, through the Sierra Madre ridge. To overcome it and win 2–3 hours, this company built at the same Baldwin plant a new passenger steam locomotive-monster that has just arrived here, weighing with a tender the same three hundred tons as the aforementioned commercial steam locomotives of Southern Pacific R. R. Co. The locomotive itself weighs 376450 English pounds; the rest comes from a tender raising 12000 gallons of water and 4000 gallons of oil, so a steam locomotive can do with a heavy train 100 English miles without stopping. Locomotive and tender length is of 105 feet; traction force is of 53000 tons. It is of a composite Mallet type, with five pairs of propelling wheels 73 inches in diameter, connected in 3 and 2 pair seats, with the rear three pair seat powered by high pressure cylinders and the front two pair by low pressure cylinders. This locomotive is designed for high speed and at relatively steep climbs, with a traction force 50 % higher than the strongest passenger locomotives currently in use anywhere. Otherwise, the essence of its design is the same as that of the commercial steam locomotives I described in No. 24.

In the case of the modern American design of rolling stock, both steam locomotives and passenger and freight cars, a decisive transition

to larger and heavier types should be stated. All the main lines have completely left the wood and went over to steel. The prejudice against steel passenger cars because of the noise they supposedly produce in motion was completely dispelled by improvements in their design, and their comparative safety, even in the most severe crashes, was never in doubt. The intensification of commodity traffic, which again began with rapid leaps after a hitch in industry and trade caused by the stock exchange panic in the autumn of 1907, promises again, and very soon, to reach the limit of modern railway performance, and an increase in the load capacity of freight cars is one of the main means to raising it. Steel freight cars lift 100000 English pounds, almost double the largest wooden ones, and although they cost twice as much, they are much more durable and safer in crashes and fires.

The remarkably rapid spread of gasoline and electric motors on steam railways should also be noted. The rapid development of electric trams in all densely populated areas and between major cities – such as between Boston and New York and between Chicago and St. Louis – affected passenger traffic on steam trains so badly that they found themselves forced to establish motor traffic on all of their suburban lines. There is still a fierce struggle between numerous types of motors for these roads, but even now two or three of them have established their superiority over others and are entering general use. I hope in the near future to give the readers of «Zheleznodorozhnoe Delo» a detailed description of them, if I am able to cope with the Russian nomenclature of the issue.

P. A. Tverskoy
Los Angeles, California
(Zheleznodorozhnoe delo [Rail Business],
1910, No. 17–18, pp. 104–105) ●



A REVIEW ARTICLE 282

Technical diagnostics: synthesis of self-checking circuits of embedded.



BIBLIO-DIRECTIONS

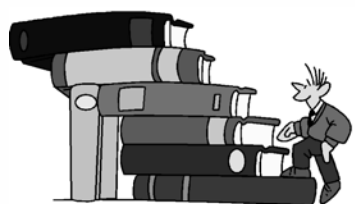


SELECTED ABSTRACTS OF D.SC. AND PH.D. THESES SUBMITTED AT RUSSIAN TRANSPORT UNIVERSITIES 286

- Improvement of methods for diagnosing asynchronous traction electric motors of locomotives on the railways of the Republic of Uzbekistan.
- Evaluation of economic efficiency of development of transport infrastructure, considering the volume and unevenness of traffic.
- Development of the method of calculation of rigid airfield pavements. Application of predictive regulators to control distributed generation installations in railway power supply systems.
- Management of resource supply of the innovative development of a transport company.
- Development of methods and means of RFID-navigation for control of movement of metro trains.

NEW BOOKS ON TRANSPORT AND TRANSPORTATION 291

List of selected books recently published in Russia and other countries.





Review of the book «Proceedings on the Self-Checking Embedded Control Circuits Synthesis Theory Based on Binary Redundant Codes»



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Anzhela Yu. MATROSOVA

Proceedings on the Self-Checking Embedded Control Circuits Synthesis Theory Based on Binary Redundant Codes. Vol. 1. Moscow, Nauka publ., 2020, 611 p. ISBN 978-5-02-040758-9.

Proceedings on the Self-Checking Embedded Control Circuits Synthesis Theory Based on Binary Redundant Codes. Vol. 2. Moscow, Nauka publ., 2021, 527 p. ISBN 978-5-02-040757-2.

The first volume of the book includes papers devoted to three main areas of research in the field of synthesis of self-checking discrete systems: study of features of classical sum codes (Berger codes), modular sum codes, as well as their modifications proposed by the authors of the articles; study of features of codes for which check bits are obtained using convolutions modulo $M = 2$ of a part of data bits (polynomial codes and classical Hamming codes); research of the Boolean Complement method for organisation of self-checking discrete systems based on redundant binary codes. Materials are provided on detailed characteristics of error detection in data bits of redundant binary codes under the condition of error-free check bits, descriptions of methods for constructing previously unknown modified sum codes and features of methods for

synthesizing self-checking discrete systems based on binary redundant codes.

The second volume of the book includes papers in the field of constructing binary sum codes weighted bits and transitions between bits occupying adjacent positions in data vectors of code words, as well as the results of studying their characteristics and methods of synthesising coding equipment. The issues of application of features of codes in organisation of self-checking discrete systems are considered. The reader will find on the pages of this volume materials on detailed characteristics of error detection in data bits of weight-based sum codes provided that the check bits are error-free, descriptions of methods for constructing previously unknown weight-based sum codes and features of methods for synthesising self-checking discrete systems based on them.

The book can be useful for developers, researchers and engineers working in the field of technical diagnostics of discrete systems and synthesis of systems with fault detection, as well as students studying computer science, computer technology and automation.

Keywords: automation hardware, synthesis of self-checking circuits, embedded control, binary redundant codes, self-checking discrete system.

For citation: Matrosova, A. Yu. Review of the book «Proceedings on the Self-Checking Embedded Control Circuits Synthesis Theory Based on Binary Redundant Codes». World of Transport and Transportation, 2021, Vol. 19, Iss. 2 (93), pp. 282–285. DOI: <https://doi.org/10.30932/1992-3252-2021-19-2-20>.

The text of the review 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.

In 2021, the Nauka Editions published a two-volume edition of «Proceedings on the self-checking embedded control circuits synthesis theory based on binary redundant codes», which included the main papers of the team of St. Petersburg scientific school on technical diagnostics under the guidance of professors Valery Vladimirovich and Vladimir Vladimirovich Sapozhnikovs, published in the period from 2009 to 2020. In our opinion, the published work deserves special attention of the scientific community due to the fact that it actually determines the main stages in the development of code methods for synthesising means of detecting errors caused by faults of various physical nature in technical systems.

First, it is necessary to remind the reader that in development and design of technical means of automation, both in industry and in transport, special attention is paid to the issues of not only ensuring correct execution of laid down algorithms, but also to protection against failure, malfunction, and their manifestations in the form of errors in calculation results. This requires the developer to lay down the properties of checkability, self-testing, self-checking, fault-tolerance, safety behaviour in case of failures and other malfunctions at the stage of creating the very prototype of the future device. It is on these properties that the reliability characteristics of the device and the nuances of its operation depend in the future. As a result, all the features of the life cycle of technical means of automation are determined even at the stage of its development, when it is possible to foresee the most rational architecture of the device, the composition, and the need for technical means of diagnostics, to assess the risks of failures and persistent failures.

In the transport industry, information and control systems for critical purposes are often used, the failure of which should not lead to a hazardous event (potentially affecting development of conditions for the occurrence of accidents and disasters or leading to them). It is for this purpose that special requirements have been developed for critical information management systems, which are somewhat similar, but somewhat different in various branches of transport. For example, in the railway sector, in development of microelectronic and microprocessor-based train control systems, the following concept is adhered to [1]: *single defects in hardware and software should not lead to*

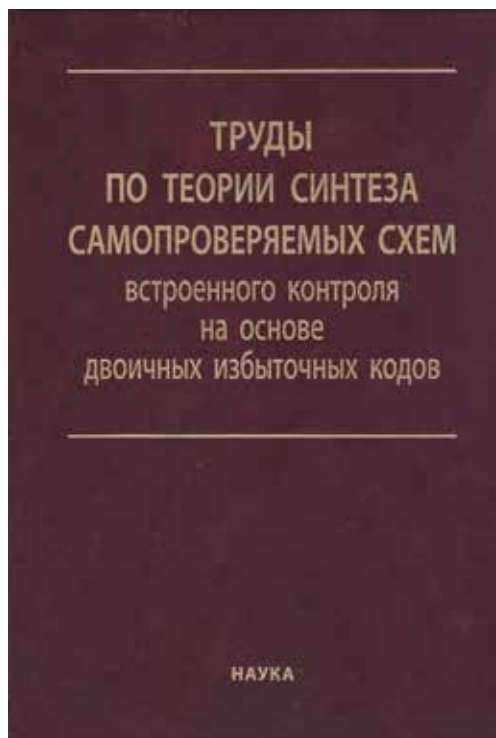
dangerous system failures and should be detected during operating or test influences no later than the second defect arises in the system. Hence it follows that the most important in construction of modern control systems are not only the principles of synthesis of systems with controllable structures, but also the principles of implementing diagnostic support.

Diagnostic support of technical systems allows solving problems of test and working (functional) diagnostics [2; 3]. Test diagnostics implies disconnecting an object from performing its main functions in order to apply special testing influences to its inputs. Working diagnostics is connected with the fact that working combinations are at the same time test ones for the object being diagnosed. The diagnostic procedure itself does not require disconnecting the diagnosed object from the controlled devices. In systems of critical application, both of these types of diagnostics are used on an equal footing. This, of course, requires the introduction of both hardware and software redundancy (redundancy and diversity), the use of information and time redundancy. One of the most important approaches to implementation of operational diagnostics procedures is the use of self-checking embedded control circuits (ECC). It is the issues of the synthesis of ECC for devices of automation and computer technology that the published edition is devoted to.

The book «Proceedings on the self-checking embedded control circuits synthesis theory based on binary redundant codes», presented in the form of two multi-page volumes, contains the main scientific works in the field of the theory of synthesis of ECC based on noise-immune redundant codes. The book includes four main sections. The first three form the first volume of the monograph and the fourth constitutes the second volume. A feature of the book and the research of the authors is that they consider not just ECC structures implemented on a specific element base, but the general features of the use of redundant coding for solving technical diagnostics problems. This makes the described results universal and applicable not only to the modern element base, but also to the developed one, which is important under the conditions of constant improvement of computer and information technologies [4].

The first section is devoted to the synthesis of ECC based on codes with summation of single digits and a description of their properties. The





features of classical sum codes (Berger codes) and their modifications obtained by calculating the weight of the data vector in the residue ring according to a predetermined modulus, dividing data bits into subsets with control of the weight of each of them, calculating special correction factors when constructing codes are covered. Separate materials are devoted to the application of the properties of sum codes in the synthesis of ECC.

The second section is devoted to the study of the characteristics of the well-known polynomial codes and Hamming codes in ECC. With regard to the set diagnostic tasks, the detecting abilities of these codes in data bits are considered. The main features of the class of systematic codes are shown, related to the fact that the resulting codes due to the use of modulo two convolutions in the synthesis of their encoders have non-unidirectional functions of the digits, and therefore their use in the synthesis of ECC should consider these circumstances.

The third section covers the results of the authors in the field of development of the Boolean Complement method for the synthesis of ECC. Here, all methods consider the use of constant-weight codes when organizing ECC with transformation of the last values of working functions of the objects to be diagnosed (and not

with concatenation (addition), as in the case of using separable codes). The Boolean Complement method allows synthesising completely self-checking ECC even in the case when this cannot be achieved by classical methods (including duplication with subsequent control of the outputs of the same name of various devices).

The fourth, the largest, section covers the features of the use of weight-based sum codes in the synthesis of ECC. The authors consider various methods of constructing sum codes, between the data bits of which inequality is established. It is achieved by assigning weight coefficients to the digits (or a group of digits) from a natural series of numbers. Such codes are divided by the authors into two classes – codes with summation of weight coefficients of the digits and transitions between the digits (in fact, the weight coefficients of the groups of digits). The monograph «Proceedings on the self-checking embedded control circuits synthesis theory based on binary redundant codes» describes codes with arbitrary weight coefficients, as well as codes, in the construction of which weighting of one and several digits is used, special sequences of weight coefficients are applied. Methods for synthesising ECC using the properties of weight-based sum codes are presented.

The authors show that it is possible to effectively use the properties of detecting errors of various multiplicity and types in the synthesis of ECC. Errors are classified according to the number of distortions of zero and one digits in data vectors into unidirectional and multidirectional, and the latter, in turn, into symmetrical (with the same number of distorted zero and one digits) and asymmetrical (with unequal). It is widely known that modern means of computer-aided design of automation circuits and computer technology consider only the possibility of detecting unidirectional errors by a number of codes. This is also used when choosing controllable structures and methods of error control in ECC at the device outputs. However, the authors have shown that many redundant codes have not only the ability to detect unidirectional errors, but also other types of errors, including up to a certain fixed multiplicity, which can also be applied in practice. In separate articles in the book, algorithms for the synthesis of completely self-checking ECC are given, taking into account such features of redundant codes. The established features should be taken into account in development of automated design tools for devices, which will reduce their structural (and when implemented at the software level – software) redundancy.

It should be noted that the authors are developing code methods for synthesizing ECC, described in the well-known publications of the Soviet and post-Soviet period of development of technical diagnostics [5–7], as well as in foreign publications [8–10]. At the same time, the results presented in this two-volume book are associated with a fairly deep level of research, and not superficial, as it was before, before the publication of the works of the co-authors of the book. Accordingly, the presented theory allows the designer to have a wide field of choice of the coding option when synthesizing ECC.

Unfortunately, in the post-Soviet space, there are not so many scientists who are engaged in the synthesis of completely self-verified ECC, and insufficient attention has been paid to their works.

However, the use of the results and their development allows in practice to more reasonably choose the method of implementing ECC, taking into account the specifics of the diagnostic object itself, which, ultimately, allows not only to reduce the complexity indicators of technical implementation of diagnostic tools, but also to improve economic indicators.

The book covers the results without reference to specific devices and systems, without highlighting any industries and transport, and will be of interest to a wide range of specialists in the field of automation and computer technology, who are engaged in development and improvement of computer and information systems.

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SELECTED 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.

Тексты авторефератов на русском языке публикуются в первой части данного выпуска.

DOI: <https://doi.org/10.30932/1992-3252-2021-19-2-21>

Khamidov, O. R. Scientific fundamentals for improving methods for diagnosing asynchronous traction electric motors of locomotives on the railways of the Republic of Uzbekistan. Abstract of D.Sc. (Eng) thesis [Nauchnie osnovy sovershenstvovaniya metodov diagnostirovaniya asinkhronnykh tyagovykh elektrodvigatelyei lokomotivov na zheleznnykh dorogakh Respubliki Uzbekistan. Avtoref. dis... doc. tekhn. nauk]. St. Petersburg, PGUPS publ., 2021, 32 p.

The thesis stated and solved an important scientific and technical problem of developing scientifically based methods for diagnosing and predicting the technical state of asynchronous traction electric motors (ATED) of locomotives to increase their operational reliability and ensure the safety of train traffic on the railways of the Republic of Uzbekistan. At the same time, the results of bench tests and processing of measuring information of ATED diagnostic tools of locomotives in operation were used with the help of data mining, and specifically with the use of artificial neural networks (ANN) technology and expert systems.

It has been established that the existing systems for monitoring, diagnostics and management of locomotive operation require significant improvements. The process of monitoring and diagnostics of locomotives can no longer be standardised within the framework of «normal» maintenance and repair programs; software and technical maintenance poorly adapts to rapidly changing operating conditions and there is no support system, either decision-making system, or specialised software for parametric identification of forward and reverse neural network models of locomotive ATED.

The concept of construction of modern intelligent control systems, diagnostics and forecasting of the technical state of ATED equipment of locomotives based on the use of quantitative and qualitative models using neural

network technologies and methods of decision theory using expert systems is proposed.

It was found that a condition for effective use of bench tests and built-in diagnostic tools for ATED of locomotives is associated with the need to develop additional measures at the design stage of a modern locomotive, when it is necessary to provide for identification of critical groups of equipment subject to in-depth control, diagnostics, as well as for development of a list of controlled parameters and the choice of scientifically based methods for processing the received information on the basis of the performed analysis of methods of domestic and foreign stationary and built-in tools of technical diagnostics.

A complex of models of the process of control, diagnostics of the technical state of ATED of locomotives has been developed on the basis of SADT-methodology and IDEF-technologies, which makes it possible to identify the main series of functional diagnostic problems and substantiate the requirements for the choice of methods, algorithms and decision-making in the process of monitoring, diagnostics and forecasting of the technical condition of locomotives, which provides an increase in reliability of the classification of the actual state of locomotives in monitoring and diagnostic systems.

It has been established that a feature of the tasks of obtaining and processing information in control systems, diagnostics, in addition to the data structure, is the presence of expert diagnostics experience, the use of which makes it possible to increase the efficiency of classifying the actual state of ATED of locomotives with a limited volume of the training sample, as well as of predicting its technical state.

Formalised methods and techniques have been developed for monitoring and diagnosing the technical state of ATED of locomotives using neural network technologies, expert systems, based on the use of the mathematical model of ATED in the diagnostic process, which allows to increase productivity and reliability of the processes of diagnosing the technical state of locomotive equipment based on the results of bench tests and analysis of measurement information of built-in diagnostic tools for operating locomotives, which allow to reduce costs for monitoring and diagnostics of the technical condition of locomotives during its bench tests and during operation by 2–3 times due to the more complete use of a priori and a posteriori information about ATED operation modes, automation of data processing, application of

modern methods of data mining at all stages of ATED diagnosis and decision making.

Simulation models of ATED of locomotives and its components were developed, with the help of which a training set for ANN was created.

A technique based on modern neural network technologies has been developed, which makes it possible to quickly and efficiently investigate asymmetric modes during operation of ATED of locomotives, allowing to solve a wide range of practical problems of monitoring the technical condition of locomotive ATED.

An improved method of deep learning (combining functions) for monitoring, diagnosing and predicting the technical condition of windings and bearing assemblies of ATED of locomotives is substantiated and proposed, which provides an opportunity to improve the learning ability using a deep auto-encoder of faults and ATED features to further increase the diagnostic efficiency. Deep linking functions are introduced into softmax environment to train an intelligent locomotive ATED winding and bearing fault diagnosis model. The results obtained confirm that the proposed method is more effective and reliable for studying the features and diagnostics of faults in windings and bearings of ATED of a locomotive than traditional methods. In comparison with the standard neural network, the proposed method shows slightly better performance.

The versatility of the developed methods and methods for detecting malfunctions, processing measurement information to improve quality of diagnosing ATED of a locomotive was confirmed in the process of implementing an improved deep learning method for detecting a malfunction, diagnosing and predicting the technical condition of the rotor and bearing assemblies of ATED of locomotives.

It is theoretically substantiated that the use of up-to-date intelligent methods and software of systems for monitoring parameters, diagnostics and forecasting the technical state of ATED with the use of ANN and expert systems gives a significant economic effect by preventing sudden failures and accidents, identifying incipient defects and taking timely measures to prevent their development, denial of routine maintenance on a serviceable ATED, correct planning of repairs, accurate planning of consumables for repairs and, as a result, a decrease in spare parts stocks, as well as by extending the service life of the objects of diagnostics.

Reliability and adequacy of neural network diagnostic models is confirmed by the stable convergence of simulation results and data obtained from the results of ATED bench tests of modern locomotives. The root-mean-square error of the response of the models is less than the random error of changing the monitored diagnostic parameters of locomotives.

It has been established that it is highly desirable to use an improved method of deep learning of neural networks to create diagnostic devices and software and hardware systems, since it is a powerful means of recognising and predicting signals, and its learning ability makes it possible to develop adaptive systems for protecting and diagnosing locomotive equipment. The use of neural network technologies for operational control, correction of the volumes of planned types of repairs, as well as assessment of the technical condition of locomotive equipment has good prospects, allowing the maximum use of the entire amount of diagnostic information stored on the onboard computer to improve efficiency of the maintenance and repair system.

The work had theoretically substantiated and experimentally confirmed the effectiveness of the proposed methodology, which diagnoses faults for balanced and unbalanced ATED data sets of locomotives using modern deep learning methods. First, the received signals are integrated into the constructed NS algorithm for layer-by-layer feature extraction, after which the extracted deeply sensitive features are transferred to the classifier for monitoring, diagnosing and predicting the technical state of ATED of locomotives.

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.

Ledney, A. Yu. Development of methodological approaches to assessing the economic efficiency of development of transport infrastructure, considering the volume and unevenness of traffic. Abstract of Ph.D. (Economics) thesis [Razrabotka metodicheskikh podkhodov k otsenke ekonomicheskoi effektivnosti razvitiya transportnoi infrastruktury s uchetom ob'emov neravnomernosti perevozk. Avtoref. dis... kand. ekonom. nauk]. Moscow, RUT publ., 2020, 24 p.

The objective of the dissertation research is to develop an improved methodological toolkit for assessing effectiveness of development of transport



infrastructure, considering unevenness of transportation volumes.

The economic analysis of the use and development of the Russian transport infrastructure is carried out, the main problematic issues that need to be addressed to ensure sustainable development of the country's economy are highlighted.

The evolution of methods for assessing the economic efficiency of development of transport infrastructure has been analysed, considering domestic and international experience, and the directions for their improvement have been substantiated.

The problem of uneven transportation and its impact on the economic efficiency of projects and programs for development of transport infrastructure has been studied, the methodological tools for determining seasonal unevenness of the load of the transport infrastructure have been improved.

The influence of seasonal unevenness of transportation on economic indicators of the use and development of transport infrastructure (using the example of railways) is revealed.

An improved methodology for assessing effectiveness of capital investments in development of transport infrastructure, considering seasonal unevenness of transportation and the load of infrastructure, is proposed.

In the course of the completed dissertation research, the scientific task of improving the methodological tools for assessing the effectiveness of development of transport infrastructure, taking into account unevenness of transportation volumes, was stated and solved.

Using the improved methodological tools, the working hypothesis of the study was confirmed that when assessing the economic efficiency of transport infrastructure development projects, one should consider the factor of uneven traffic, which significantly affects the economic indicators of transport activity.

Based on the research carried out, in the future, it is planned to develop a comprehensive methodology for assessing the economic efficiency of development of transport infrastructure, considering the volume and unevenness of traffic, including an assessment of increase in the value of transport infrastructure by reducing unevenness of loading.

08.00.05 – Economics and management of the national economy (economics, organisation and management of enterprises, industries and complexes – transport).

The work was performed and defended at Russian University of Transport.

Makarova, E. A. Development of the method of strength calculation of rigid airfield pavements. Abstract of Ph.D. (Eng) thesis [Razvitie metoda prochnostnogo rascheta zhestkikh aerodromnykh pokrytii. Avtoref. dis... kand. tekhn. nauk]. Moscow, MADI publ., 2020, 24 p.

The purpose of the dissertation research was to improve the method for calculating rigid coatings using optimisation methods.

The results of the research carried out made it possible to draw the main conclusions on the topic under study.

The limiting states of calculating rigid airfield pavements, presented in the form of inequalities without restraints, make the problem indefinite and lead to the appearance of non-optimal options for pavements.

Based on the study, it was found that replacing the distributed load with a concentrated force when determining the deflections is possible without restrictions, and for bending moments it is permissible only for aircraft with a track and a chassis bogie base exceeding 0,6 m.

The drawback of the method for calculating rigid airfield pavements is revealed, which consists in the existence of a false solution in the range of admissible pavement thicknesses. The false decision is typical for six-wheel aircraft supports with a track that exceeds the base. No false solutions were found for two- and four-wheel supports.

The estimation of the number of possible optimal solutions of the problem of strength calculation of airfield pavements is carried out.

It has been established that the structures of rigid airfield pavements studied at civil airports in Russia and foreign countries have a safety margin with a percentage of understressing reaching 34 %.

The introduction into the design practice of the proposed method for calculating rigid airfield pavements will reduce the required value of the pavement layer thickness on average for a single-layer option to 4 cm, and for a two-layer option – up to 7 cm. At the same time, a reduction in the cost of paving construction can reach 20 %.

The research carried out indicates that special attention should be paid to the following priority tasks: improving the methodology for calculating asphalt concrete airfield pavements; improvement of the methodology for calculating mixed airfield pavements; improvement of the methodology for calculating reinforced concrete

airfield pavements, considering new building materials.

05.23.11 – Design and construction of roads, metro, airfields, bridges and transport tunnels.

The work was performed and defended at Moscow Automobile and Road Construction State Technical University (MADI).

Nguyen Van Huang. Application of predictive regulators to control distributed generation installations in railway power supply systems. Abstract of Ph.D. (Eng) thesis [Primeneniye prognosticheskikh regulyatorov dlya upravleniya ustanovkami raspredelennoi generatsii v sistemakh elektrosnabzheniya zheleznikh dorog. Avtoref. dis... kand. tekhn. nauk]. Irkutsk, IrGUPS publ., 2020, 18 p.

Decentralised power generation technologies based on distributed generation (DG) installations are fully applicable to railway transport. The purpose of the research presented in the thesis was to develop methods and means to improve quality of control processes in power supply systems of railways (PSSR) equipped with distributed generation installations.

A structural-parametric synthesis of control systems for installations of distributed (own) generation of railway transport, implemented based on automatic excitation regulators (AER) and rotation speed (ASR), using predictive algorithms, has been performed.

A method for controlling the frequency of DG installations has been developed, based on the use of auto-predictive (self-adjusting) speed controllers and applicable in implementation of intelligent electrical networks (Smart Grid).

A method is proposed for determining time constants of predictive links for automatic controllers of excitation and speed of synchronous generators.

A technique has been developed for tuning digital automatic regulators of DG using predictive control of distributed generation installations with energy storage devices, which ensures a decrease in voltage dips; on the basis of computer studies, it is shown that the combined use of predictive algorithms and coordination of regulator settings makes it possible to obtain an additional effect when controlling the rotor speed and voltage of synchronous generators of DG in transient operating modes.

A method for eliminating flicker in low voltage networks based on controlled distributed generation

units has been developed; prognostic algorithms are proposed for controlling the modes of gas turbine plants.

Digital models and results of modelling dynamic processes in the areas of non-traction consumers' power supply and practical recommendations on the use of predictive controllers for DG installations were used in the scientific and technical developments of the «Parametr» centre. Practical suggestions for the use of predictive algorithms are implemented in the recommendations for tuning automatic regulators of a turbine generator set with a capacity of 3,125 MW•A of the central production site of Khiagdinskoye field. The thesis materials are used in the educational process at the departments of educational institutions of Irkutsk and the Phu Tho province of the Socialist Republic of Vietnam.

The prospect of further development of the topic may consist in conducting research aimed at using nonlinear predictive models in the excitation and speed controllers of DG generators, as well as multi-agent technologies for coordinated adjustment of AER and ASR.

05.13.06 – Automation and control of technological processes and production (transport).

The work was performed at Irkutsk National Research Technical University and Irkutsk State Transport University, defended at Irkutsk State Transport University.

Rasskazova, E. E. Management of resource supply of the innovative development of a transport company. Abstract of Ph.D. (Economics) thesis [Upravlenie resurso-obespecheniem urovnya innovatsionnogo razvitiya transportnoi kompanii. Avtoref. dis... kand. ekonom. nauk]. Moscow, RUT publ., 2020, 24 p.

The purpose of the dissertation research is to develop an economic toolkit for comprehensive assessment and management of the innovative development of a transport company in a highly dynamic environment.

As a result of the study, the hypothesis was confirmed that the structure of innovative potential and its resource supply determine the degree and rate of innovative development of a transport company, and also significantly affect other components of the potential.

A set of indicators characterising the components of potential, which determine the level of innovative development of the company, is revealed. They are associated with the



resources used, their structure, applied technologies. Based on this analysis, the components of the company's innovative potential were formed.

Models and an algorithm for determining the degree of innovative development of a transport company have been developed, which make it possible to assess its impact on all components of its potential, to increase the objectivity of assessing the actual level of innovative development of a transport company.

A methodological approach to assessing the impact of the components of the innovative potential on economic indicators of a company is proposed, and an algorithm for assessing the necessary change in the components of the potential for the given requirements for changing economic indicators is formed. The algorithm can be used as the basis for a system for monitoring the economic activity of a transport company.

As prospects for further research on this topic, it seems necessary to elaborate on the level of innovative development of a transport company, as well as to analyse the relationship between the structure of resources and the level of innovativeness of technology, the nature and phases of the life cycle of the project being implemented.

08.00.05 – Economics and management of the national economy (economics, organization and management of enterprises, industries, complexes – transport).

The work was performed and defended at Russian University of Transport.

Tyulyandin, O. N. Development of methods and means of RFID-navigation for control of movement of metro trains. Abstract of Ph.D. (Eng) thesis [Razrabotka metodov i sredstv RFID-navigatsii dlya upravleniya dvizheniem poezdov metropolitena. Avtoref. dis... kand. tekhn. nauk]. St. Petersburg, PGUPS publ., 2020, 18 p.

The purpose of the study was to increase efficiency of functioning of automatic control systems for movement of metro trains using RFID navigation, where navigation accuracy and reliability are the main indicators.

In the course of the research carried out in the thesis work, an analytical review of existing methods and means of binding metro trains to the coordinates of the track in Russia and abroad

was carried out. Based on the results of the review, it was proposed to create RFID navigation, in which navigation accuracy and reliability are the main indicators.

The functions of RFID navigation are determined, including continuous positioning of trains in operation on the route with sufficient accuracy to solve problems of automatic control of movement of metro trains. The main difference between RFID navigation and existing methods is the automatic input of initial coordinates of trains without participation of the driver. A compensation method has been developed that made it possible to ensure the continuity of the binding when zeroing the accumulated errors.

Probabilistic methods, mathematical models, and programs for assessing the probability of gaps in reading radio frequency tags for readers with external triggering and with continuous scanning have been developed, which made it possible to investigate their causes and give recommendations for reducing the number of gaps by two orders of magnitude, which consists in increasing the scanning time to the maximum value. For new developments, a transition to continuous scanning readers is proposed.

Methods, mathematical models, and programs have been developed for assessing the navigation accuracy of positioning trains using radio frequency tags. In this work, accuracy characteristics of RFID-binding have been obtained for the first time. For readers with an external trigger, the binding accuracy in the low-speed zone is ± 25 cm, for readers with continuous scanning ± 10 cm. The results confirmed the possibility of using RFID navigation to control movement of trains at closed-type stations.

Original methods and algorithms for technical diagnostics of RFID-means have been developed, allowing to monitor and predict the technical condition of the radio-frequency path of SBPP equipment. The proposed solutions make it possible to timely detect an increase in the contact resistance in detachable connections in order to prevent gaps in the reading of radio frequency tags due to signal attenuation.

05.22.08 – Management of transportation processes.

The work was performed and defended at Emperor Alexander I St. Petersburg State Transport University.

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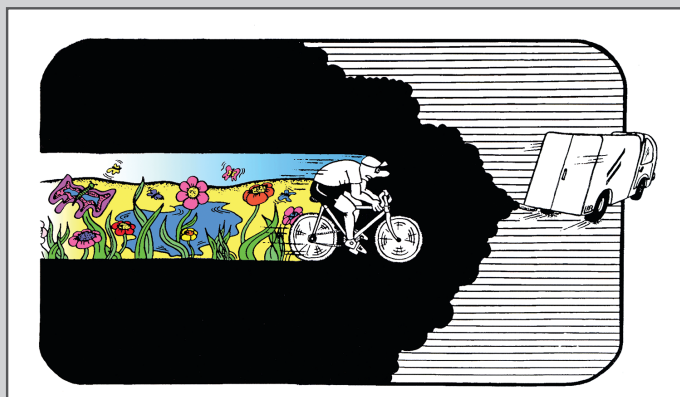


Рис. Вячеслава Шилова / Pic. Viacheslav Shilov

Весна... / The spring...

АНЕКДОТ

НА ОБОЧИНЕ

● Конец юности – когда в транспорте начинают спрашивать студенческий билет.

– Начало старости – когда перестают спрашивать пенсионный.

● Гонщики на автомобилях – автогонщики.

Гонщики на велосипедах – велогонщики.

Гонщики на мотоциклах – мотогонщики.

Гонщики на самокатах... – самогонщики?

● Надпись у железнодорожного переезда: «Поезд здесь проходит за 20 секунд независимо от того, находится ли ваш автомобиль на рельсах или остановился за шлагбаумом».

Афоризмы Quotes

● Железнодорожная станция – это нечто, что может породить город.

Сантьяго Калатрава, испанский архитектор, инженер, скульптор

● A railway station is something that can generate a city.

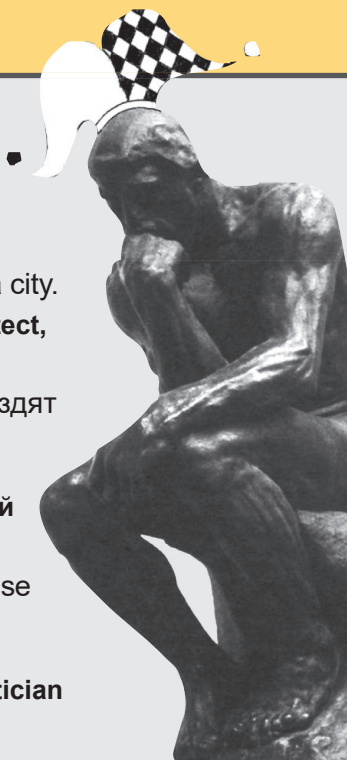
Santiago Calatrava, Spanish architect, engineer, sculptor.

● Продвинутый город – это не тот, где бедные ездят на автомобилях, а скорее тот, где даже богатые пользуются общественным транспортом.

Энрике Пеньялоса, колумбийский политик и урбанист

● An advanced city is not one where even the poor use cars, but rather one where even the rich use public transport.

Enrique Peñalosa, Columbian politician and urbanist





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