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Reliability and Safety Management of the Transportation Process Using Systems for Continuous Monitoring of Railway Infrastructure Facilities

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ABSTRACT

While analysing the problem of increasing reliability and safety of the rail transportation process, it is shown that modern train traffic control systems do not automatically consider the events of decrease in reliability of railway infrastructure facilities; however, such a linkage is quite possible. The proposed architecture of a promising train traffic control system can be based on railway automation and remote-control (telemechanics) systems, which have a safe information interface with the means of continuous monitoring of railway infrastructure facilities.

The objective of the article is to present theoretical principles of managing reliability and safety of the transportation process using «new generation» automation systems, closely integrated with technical monitoring tools. A demonstrated simplified structure of the train traffic control system has an information interface with the means of continuous monitoring of railway infrastructure facilities. The developed reliability models of the train traffic control system consider the state of railway infrastructure facilities.

It is shown that it is necessary to consider the safe state of the infrastructure system in the train traffic control system. Possibilities of managing the risks of reduced reliability and safety of the transportation process are shown using stationary monitoring tools for railway infrastructure facilities.

The improvement of monitoring technology and the effective use of stationary monitoring systems makes it practically possible to implement the function of managing reliability and safety of the transportation process and the entire railway complex.

Keywords: railways, management of the transportation process, train traffic safety, railway automation and remote control systems, monitoring systems for engineering structures and facilities, train traffic control system reliability model, transportation process reliability and safety management.

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INTRODUCTION

Devices and systems controlling critical technological processes are implemented in accordance with the specified requirements for reliability and safety of operation. This fully applies to the railway complex. However, during operation of such a complex system as a railway transport system, where a huge number of participants are involved in the transportation process, including technical facilities and operational employees (train dispatchers, station duty officers, drivers, operating personnel of service departments, etc.), failures and persistent failures cannot be ruled out. They can result in violations in the train schedule, and some of them may even pose a threat to train traffic safety.

The final links in the complex chain of ensuring the transportation process from the point of view of train traffic safety are the technical means of railway automation and remote control (RARC) [1]. They allow remotely controlling objects at stations and sections, transmitting data on the speed regime along sections of the track to drivers through colour lights. RARC technical means are implemented in accordance with certain safety concepts, for example, for microelectronic systems, safety methods and principles are established in [2].

However, the RARC technical means, although implemented as safe, do not consider, during operation, the changing conditions of railway infrastructure facilities that do not directly affect them [3]. That is why the situations are not excluded during operation of the railway transport system, when the presence of a dangerous defect in an engineering structure (for example, a violation of clearance values at the approach of buildings [4; 5]) does not initiate switch-on of prohibiting indication of the colour light signal enclosing the corresponding section. Moreover, in this case, it is impossible to initiate a prohibiting indication in RARC system even manually (except for the barrage signalling equipment).

To increase fault tolerance, railway infrastructure facilities undergo diagnostic procedures at predetermined intervals using both manual and automated tools.

These include wearable diagnostic tools as well as stationary monitoring tools. Not many facilities are currently equipped with the latter. The choice of an object for monitoring is determined by the presence of an unacceptable risk to train traffic safety. For example, in [6], a case is described when a bridge collapsed in front of a moving train on the railways in Russia (a bridge across the Kola River in Murmansk region at 1436,1 km of Oktyabrskaya Railway). Subsequently, a new bridge was erected on this site equipped with a monitoring system for engineering structures and facilities [1, 2].

From a safety point of view, it is important to technically ensure the linkage of train traffic control systems with monitoring systems for railway infrastructure facilities, which are being developed and gradually put into operation [7–14]. Features of building RARC systems in the presence of linkage with monitoring tools are described in [3].

The *objective* of this work is to present theoretical principles of managing reliability and safety of the transportation process using automation systems of the «new generation», closely integrated with the technical means of monitoring.

RESULTS

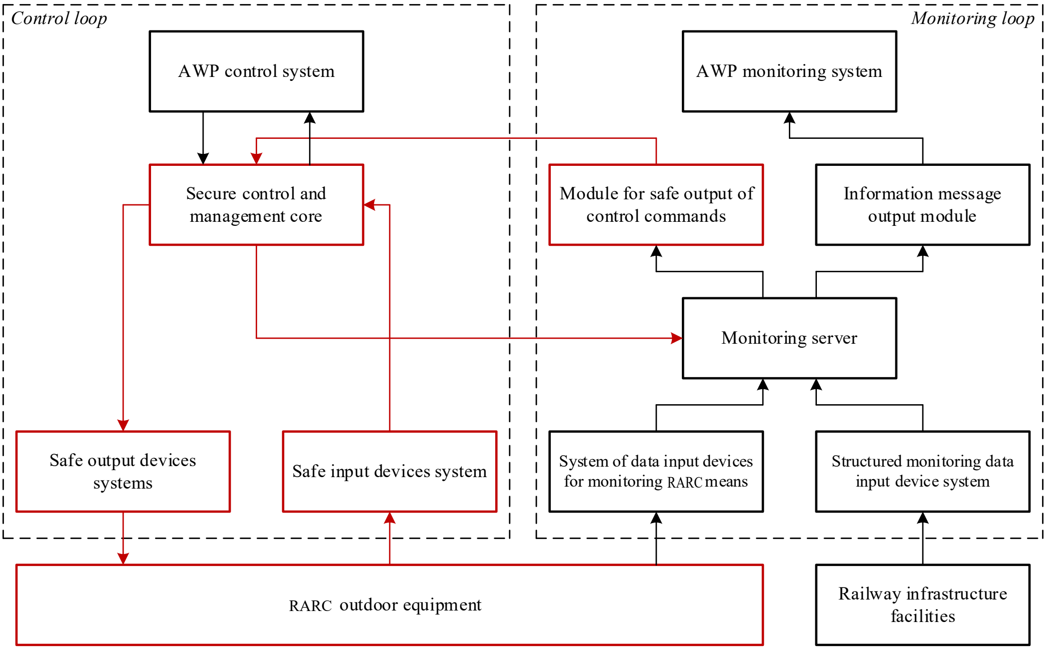
Architecture of a Safe Train Control System

Pic.1 shows the architecture of a safe train traffic control system, in which a control circuit and a monitoring circuit are differentiated. The concept of the system is described in [3]. Moreover, the monitoring circuit has a separate subsystem for monitoring RARC devices and a subsystem for monitoring railway infrastructure facilities (the blocks are highlighted in red (lighter colour) comprise devices that are subject to functional safety requirements).

Currently, monitoring systems are not implemented in this way: monitoring tools for RARC devices [7–9] and tools for monitoring infrastructure objects are implemented separately by corporate divisions (in both cases there is mainly data from portable (mobile) monitoring tools, while stationary monitoring systems can also be used) [10–14]. However, it is clear that a reliable diagnosis and, as a result, genesis and prognosis, is impossible without taking into account the historical operational data on

[1] Russian Railways: bridge with the first innovative system of continuous monitoring and connection to the control of the barrage signal [RZD: most s pervoi innovatsionnoi sistemoi nepreryvnogo monitoringa i podklyucheniem k upravleniyu zagraditelnym signalom]. Mostovie sooruzheniya. XXI vek, 2021, Iss. 4 (51), pp. 18–19.

[2] Trend of the 21st century: the bridge over the Kola in Murmansk region found its digital twin [Trend XXI veka: u mosta cherez Kolu v Murmanskoi oblasti poyavilsya tsifrovoi dvoinik]. [Electronic resource]: https://gudok.ru/news/infrastructure/? ID=1624944&ysclid=ldbk3kmtol843556271. Last accessed 25.01.2023.



Pic. 1. Architecture of a safe train traffic control system [developed by the authors].

monitoring objects (physical characteristics, ongoing maintenance and repair procedures, operating conditions, etc.), as well as the full set of monitoring data collected regarding the technical condition of all infrastructure facilities, and not just individual ones (for example, data only from monitoring systems for RARC devices). Moreover, at present, monitoring systems are not connected in any way with RARC systems themselves: neither directly by a feedback circuit, nor as a means of indication; such linkage is not provided for in description of the nearest developments of train traffic control systems [15–18].

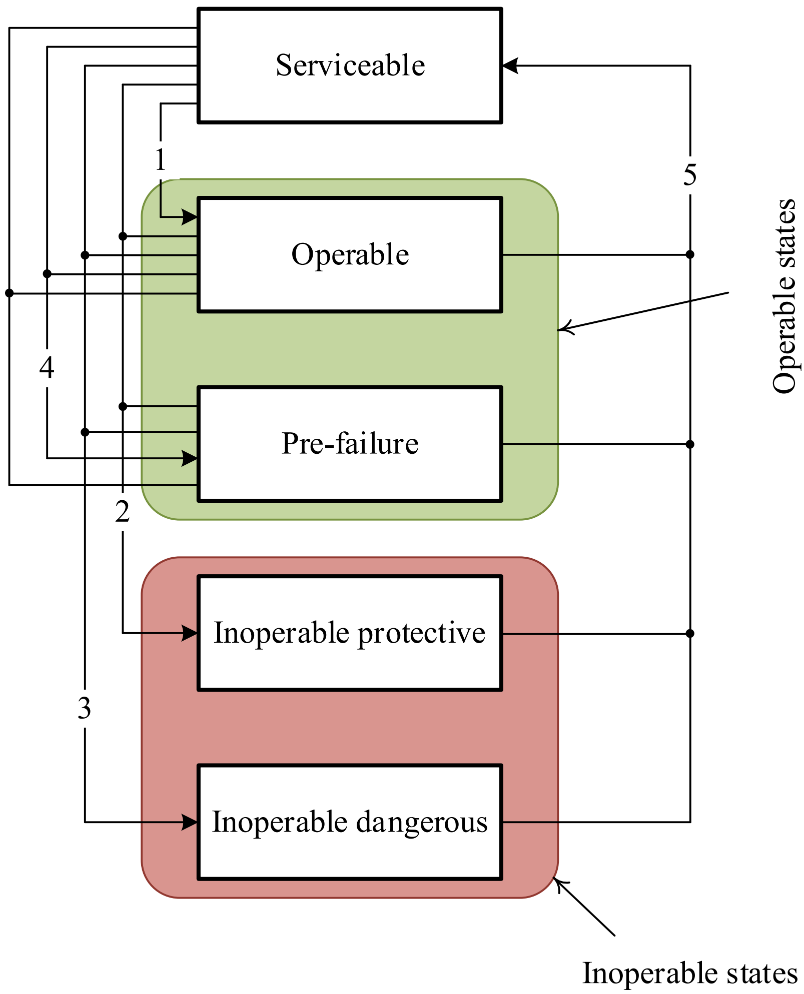
It should be noted that, historically, RARC systems were not endowed with built-in tools for measuring and automatically analysing diagnostic data [19].

It can be said that Pic. 1 shows the architecture of a promising RARC system, in which, according to monitoring data, it is possible to calculate the conditions for the transition to certain protective states, both for RARC facilities themselves and for infrastructure complex objects. At the same time, of course, the regulatory framework for implementation of such a system should be determined, because RARC systems are subject to severe restrictions on implementation from the standpoint of functional safety [20; 21]. Therefore, existing/known stationary monitoring systems and tools for intelligent processing of monitoring results should be subject to similar constraints (when linking systems), and the principles for implementing safe monitoring systems should be specified and regulated.

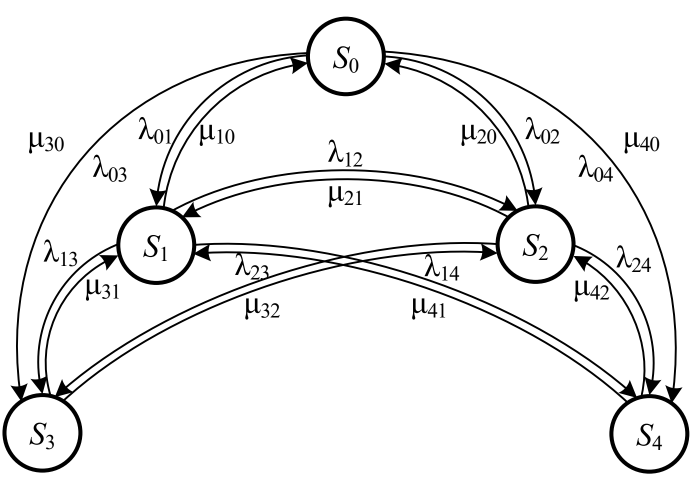
Graph of the State of Train Traffic Control System

In [22], it is determined that RARC devices and systems can be in several states: serviceable, operable, operable pre-failure, inoperable protective, inoperable dangerous and limit states (strictly speaking, the limit state is the extreme degree of inoperability of an object, it can also be protective, and dangerous). We emphasise that this applies only to the RARC devices and systems, as a sort of «closed systems» that do not take into account the influence of destabilising factors on the infrastructure complex of railways [3].

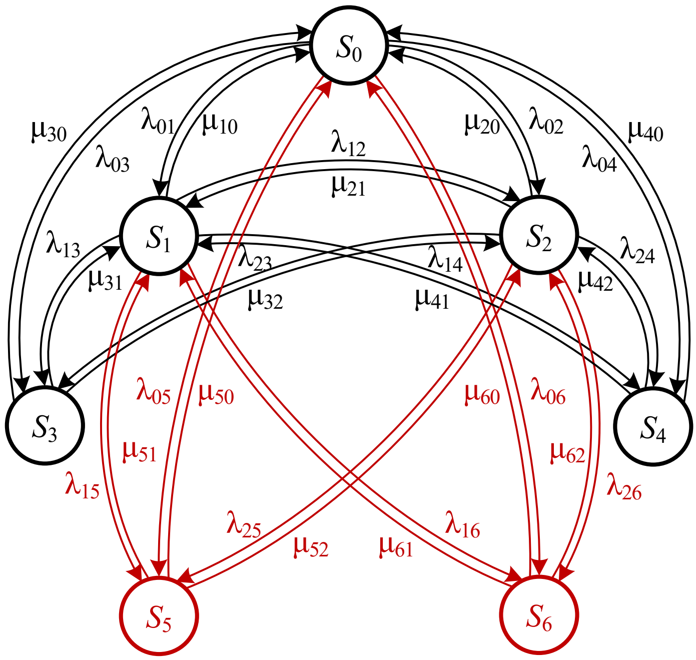
Pic. 2 shows a diagram of the states of RARC devices or systems and transitions between them (the limit state is not shown, since it actually coincides with one of the inoperative states). State-to-state transitions occur when performance deteriorates or improves and is associated with occurrence of a series of events. In Pic. 2 the numbers 1, 2, 3, and 4 show the transitions that occur when events of deterioration in the state of devices or systems occur: 1 – damage, 2 – protective failure, 3 – dangerous failure, 4 – pre-failure. The number 5 shows the transition that occurs



Pic. 2. Diagram of states of RARC device or system and transitions between them [developed by the authors].



Pic. 3. The state graph of RARC device or system [developed by the authors].



Pic. 4. Modified state graph of the train traffic control system [developed by the authors].

during the restore and repair event. Inoperable states include both protective and dangerous states. Operable states include both serviceable and pre-failure [22].

Transitions between device or system states occur under the influence of failure and recovery flows. The transition graph can thus be represented as shown in Pic. 3.

In Pic. 3 states are indicated as follows:

• S_0 – serviceable state of RARC device or system;

• S_1 – operable state of RARC device or system;

• S_2 – operable pre-failure state of RARC device or system;

• S_3 – inoperable protective state of RARC device or system;

• S_4 – inoperable dangerous state of RARC device or system.

On the arcs in the graph in Pic. 3 there are the values of intensities of transitions of the train traffic control system from state S_i to state S_j and vice versa. Intensities associated with deterioration in performance of a device or system are denoted by λ_{ij}, and those associated with improvement by μ_{ji}.

However, we emphasise that the states S_0–S_4 refer directly to the actual state of RARC device or system.

Let us further consider the train traffic control system, which includes not only RARC devices and systems, but also the means of the infrastructure complex and the systems intended to monitor them. Let us expand the number of states into which the train traffic control system can pass. We will further assume that the states S_0–S_4 already refer to the considered extended train traffic control system. Let us assume that the systems of stationary monitoring of railway infrastructure facilities are connected to the RARC systems through a secure interface platform. Thus, the monitoring system is able to produce two additional states for the control system:

• S_5 – protective state of the train traffic control system, corresponding to the defect of the infrastructure object;

• S_6 – dangerous state of the train traffic control system, corresponding to the defect of the infrastructure object.

The modified state graph of the train traffic control system is shown in Pic. 4. It introduces two new states and transitions that transfer the train traffic control system to them. States S_5 and S_6 refer to two states of the traffic control system being in a state of inoperability (or partial operability) of railway infrastructure facilities. In well-known studies, for example, [23; 24], the states S_5 and S_6 do not appear in any way.

The graph shown in Pic. 4 is not complete (some transitions are excluded). In addition, we note that for the monitored objects of the

$$
\begin{cases}
\frac{\partial P_0(t)}{\partial t} = \mu_{10}P_1(t)+\mu_{20}P_2(t)+\mu_{30}P_3(t)+\mu_{40}P_4(t)+\mu_{50}P_5(t)+\mu_{60}P_6(t)- \\
-(\lambda_{01}+\lambda_{02}+\lambda_{03}+\lambda_{04}+\lambda_{05}+\lambda_{06})P_0(t); \\
\frac{\partial P_1(t)}{\partial t} = \lambda_{01}P_0(t)+\mu_{31}P_3(t)+\mu_{41}P_4(t)+\mu_{21}P_2(t)+\mu_{51}P_5(t)+\mu_{61}P_6(t)- \\
-(\mu_{10}+\lambda_{13}+\lambda_{12}+\lambda_{14}+\lambda_{15}+\lambda_{16})P_1(t); \\
\frac{\partial P_2(t)}{\partial t} = \lambda_{02}P_0(t)+\lambda_{12}P_1(t)+\mu_{42}P_4(t)+\mu_{32}P_3(t)+\mu_{52}P_5(t)+\mu_{62}P_6(t)- \\
-(\mu_{20}+\mu_{21}+\lambda_{23}+\lambda_{24}+\lambda_{25}+\lambda_{26})P_2(t); \\
\frac{\partial P_3(t)}{\partial t} = \lambda_{03}P_0(t)+\lambda_{13}P_1(t)+\lambda_{23}P_2(t)-(\mu_{30}+\mu_{31}+\mu_{32})P_3(t); \\
\frac{\partial P_4(t)}{\partial t} = \lambda_{04}P_0(t)+\lambda_{14}P_1(t)+\lambda_{24}P_2(t)-(\mu_{40}+\mu_{41}+\mu_{42})P_4(t); \\
\frac{\partial P_5(t)}{\partial t} = \lambda_{05}P_0(t)+\lambda_{15}P_1(t)+\lambda_{25}P_2(t)-(\mu_{50}+\mu_{51}+\mu_{52})P_5(t); \\
\frac{\partial P_6(t)}{\partial t} = \lambda_{06}P_0(t)+\lambda_{16}P_1(t)+\lambda_{26}P_2(t)-(\mu_{60}+\mu_{61}+\mu_{62})P_6(t).
\end{cases} \quad (1)
$$

railway infrastructure, the states preceding the failure can be introduced into consideration. For artificial structures, these are the so-called limit states (by load). In the graph shown in Pic. 4, the limit states recorded by the monitoring system are not highlighted, although their introduction into consideration is also possible. In practice, the transition to such a state may be associated with the introduction of special regimes for moving through the sections of the track with railway infrastructure facilities, for which deviations from permissible norms have been recorded [3].

Reliability Models for the Train Traffic Control System

Let us assume that the processes occurring in the system are Markov random processes, and the corresponding conditions are satisfied. This allows, according to the graph in Pic. 4, obtaining the system of equations of A. N. Kolmogorov, the principles of formation of which are described in [22] (1).

System (1) is supplemented by the normalisation equation:

$$\sum_{i=1}^{6} \frac{\partial P_i(t)}{\partial t} = 1. \quad (2)$$

As $t \to \infty$, the following limit theorem of A. A. Markov [22] holds: if all intensities of event flows are constant, and the state graph is such that one can go from each state to each other in a finite number of steps, then the limit probabilities of states exist and do not depend on the initial state of the system.

Analysis of the graph shown in Pic. 2 allows us to conclude that the Markov theorem is applicable to the system under consideration. According to this theorem, we get:

$$\lim_{t\to\infty} \frac{\partial P_i(t)}{\partial t} = 0, i = \overline{0,6}. \quad (3)$$

Using (3) and (2), we rewrite the system (1) as (4).

The system (4) is solved by any of the known methods [22].

Having discarded one of the equations of system (4) (except for the normalisation one), we pass to the matrix form (5).

Let us denote by A_i the matrices in which the i-th column is replaced by the column of free terms, $i = \overline{0,6}$, and by Δ and Δ_i the determinant of the matrix A and A_i. Then Cramer's method can be used to obtain the values:

$$P_i(t) = \frac{\Delta_i}{\Delta}, i = \overline{0,6}. \quad (6)$$

In practice, it is quite laborious to obtain the values of intensities of transitions between the states of the train traffic control system, especially regarding transitions to dangerous states. Therefore, simulation modelling is required. Statistical data can be obtained just using monitoring tools during operation over a sufficiently large time lapse.

For the graph shown in Pic. 4, the probabilities of transitions from the state S_i to the state S_j can be given, and vice versa. Then the reliability model can be specified using the matrix of transition probabilities and the vector of initial probabilities. For the graph shown in Pic. 4, it looks like:

$$\begin{cases}\mu_{10}P_1(t)+\mu_{20}P_2(t)+\mu_{30}P_3(t)+\mu_{40}P_4(t)+\mu_{50}P_5(t)+\mu_{60}P_6(t)-\\ -(\lambda_{01}+\lambda_{02}+\lambda_{03}+\lambda_{04}+\lambda_{05}+\lambda_{06})P_0(t)=0;\\ \lambda_{01}P_0(t)+\mu_{31}P_3(t)+\mu_{41}P_4(t)+\mu_{21}P_2(t)+\mu_{51}P_5(t)+\mu_{61}P_6(t)-\\ -(\mu_{10}+\lambda_{13}+\lambda_{12}+\lambda_{14}+\lambda_{15}+\lambda_{16})P_1(t)=0;\\ \lambda_{02}P_0(t)+\lambda_{12}P_1(t)+\mu_{42}P_4(t)+\mu_{32}P_3(t)+\mu_{52}P_5(t)+\mu_{62}P_6(t)-\\ -(\mu_{20}+\mu_{21}+\lambda_{23}+\lambda_{24}+\lambda_{25}+\lambda_{26})P_2=0;\\ \lambda_{03}P_0(t)+\lambda_{13}P_1(t)+\lambda_{23}P_2(t)-(\mu_{30}+\mu_{31}+\mu_{32})P_3(t)=0;\\ \lambda_{04}P_0(t)+\lambda_{14}P_1(t)+\lambda_{24}P_2(t)-(\mu_{40}+\mu_{41}+\mu_{42})P_4(t)=0;\\ \lambda_{05}P_0(t)+\lambda_{15}P_1(t)+\lambda_{25}P_2(t)-(\mu_{50}+\mu_{51}+\mu_{52})P_5(t)=0;\\ \lambda_{06}P_0(t)+\lambda_{16}P_1(t)+\lambda_{26}P_2(t)-(\mu_{60}+\mu_{61}+\mu_{62})P_6(t)=0;\\ P_0(t)+P_1(t)+P_2(t)+P_3(t)+P_4(t)+P_5(t)+P_6(t)=1.\end{cases} \quad (4)$$

$$P_{ij}(t)=\begin{vmatrix} p_{00} & p_{01} & p_{02} & p_{03} & p_{04} & p_{05} & p_{06}\\ p_{10} & p_{11} & p_{12} & p_{13} & p_{14} & p_{15} & p_{16}\\ p_{20} & p_{21} & p_{22} & p_{23} & p_{24} & p_{25} & p_{26}\\ p_{30} & p_{31} & p_{32} & p_{33} & 0 & 0 & 0\\ p_{40} & p_{41} & p_{42} & 0 & p_{44} & 0 & 0\\ p_{50} & p_{51} & p_{52} & 0 & 0 & p_{55} & 0\\ p_{60} & p_{61} & p_{62} & 0 & 0 & 0 & p_{66}\end{vmatrix}. \quad (7)$$

The vector of initial probabilities has the form:

$$P_i(0)=\begin{pmatrix}P_0(0),P_1(0),P_2(0),\\ P_3(0),P_4(0),P_5(0),P_6(0)\end{pmatrix}. \quad (8)$$

For example, in [24], the author uses numerical data obtained from the results of operation of a railway track on one of the sections of Kazakhstan to solve a similar problem for assessing the state of the track superstructure (without taking into account data from stationary monitoring systems, but only according to failure accounting systems).

In practice, the use of the above reliability models requires availability of statistical data on operation of infrastructure facilities on the considered section of the railway – this can be either an assessment within the station and adjacent sections, or an assessment within a certain section of the railway line. Naturally, the data will be very different for stations and sections with different technical equipment, exhausted resource and workload.

An Example of Determining the Probabilities of a System Being in Various States

In the experiment, there was no binding to a specific section of the railway, and the transition matrix and the initial state vector were set arbitrarily:

$$P_{ij}(t)=\begin{vmatrix} 0,3 & 0,3 & 0,2 & 0,1 & 0,01 & 0,08 & 0,01\\ 0,2 & 0,48 & 0,05 & 0,1 & 0,01 & 0,15 & 0,01\\ 0,2 & 0,38 & 0,05 & 0,2 & 0,01 & 0,15 & 0,01\\ 0,2 & 0,69 & 0,01 & 0,1 & 0 & 0 & 0\\ 0,2 & 0,74 & 0,01 & 0 & 0,05 & 0 & 0\\ 0,2 & 0,69 & 0,01 & 0 & 0 & 0,1 & 0\\ 0,2 & 0,74 & 0,01 & 0 & 0 & 0 & 0,05\end{vmatrix},$$

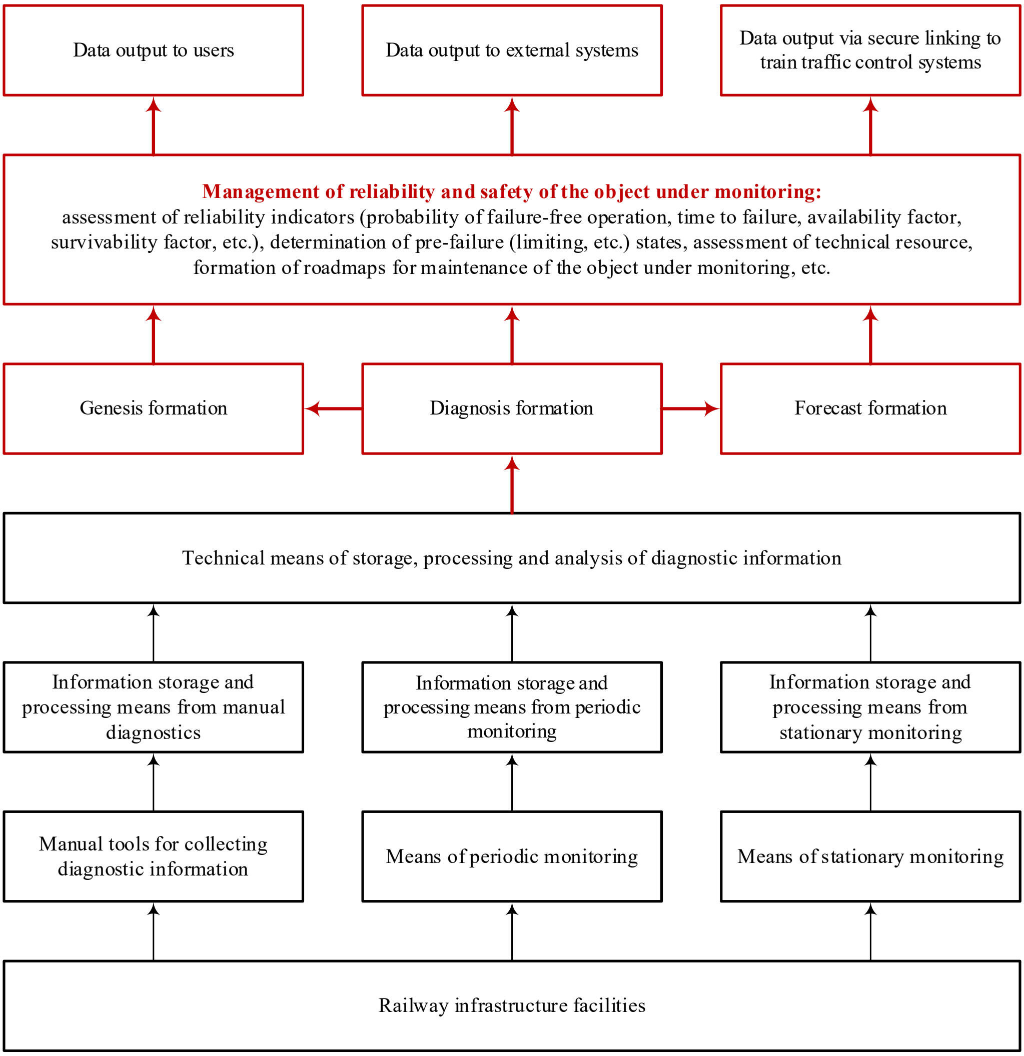
$$P_i(0)=(1,0,0,0,0,0,0).$$

Using the Markov chain calculator [25], we simulated operation of the system described by the graph in Pic. 4, with the selected initial data. The steady state vector obtained at the third simulation step has the following form:

$$P_i(0)=\begin{pmatrix}0,22,\ 0,48,\ 0,07,\\ 0,1,\ 0,01,\ 0,11,\ 0,01\end{pmatrix}.$$

For real examples, other values will be obtained, since in practice the probabilities of transitions to dangerous states are extremely small. For example, for elements of devices and train control systems, the dangerous failure RARC es, according to [2], lie in the range $\lambda=10^{-8}...10^{-14}\ {}^{1}\!/\!{}_{h}$.

$$A=\begin{pmatrix} \lambda_{01} & -\mu_{10}-\lambda_{13}-\lambda_{12}-\lambda_{14}-\lambda_{15}-\lambda_{16} & \mu_{21} & \mu_{31} & \mu_{41} & \mu_{51} & \mu_{61} & \vline & 0\\ \lambda_{02} & \lambda_{12} & -\mu_{20}-\mu_{21}-\lambda_{23}-\lambda_{24}-\lambda_{25}-\lambda_{26} & \mu_{32} & \mu_{42} & \mu_{52} & \mu_{62} & \vline & 0\\ \lambda_{03} & \lambda_{13} & \lambda_{23} & -\mu_{30}-\mu_{31}-\mu_{32} & 0 & 0 & 0 & \vline & 0\\ \lambda_{04} & \lambda_{14} & \lambda_{24} & 0 & -\mu_{40}-\mu_{41}-\mu_{42} & 0 & 0 & \vline & 0\\ \lambda_{05} & \lambda_{15} & \lambda_{25} & 0 & 0 & -\mu_{50}-\mu_{51}-\mu_{52} & 0 & \vline & 0\\ \lambda_{06} & \lambda_{16} & \lambda_{26} & 0 & 0 & 0 & -\mu_{60}-\mu_{61}-\mu_{62} & \vline & 0\\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & \vline & 1\end{pmatrix}. \quad (5)$$



Pic. 5. Reliability and safety management structure using monitoring systems for railway infrastructure facilities [developed by the authors].

Modelling data can be refined using existing stationary and portable monitoring and technical diagnostic tools, and the operation process itself will be described by constantly changing data on the technical condition of infrastructure facilities.

Management of Reliability and Safety of the Transportation Process Using the Stationary Monitoring Tools

The technical linkage of train traffic control systems with systems monitoring railway infrastructure facilities makes it possible in practice to solve the problem of reliability management and reduce the risks of violations of train traffic safety.

Reliability reduction risks can be managed by influencing the failure RARC es, both those that occur in the system itself during its operation, and those failures that can develop due to improper maintenance and repair (remember the example already mentioned earlier, when incorrect maintenance of supports of the bridge over the Kola River led to the collapse of the bridge [6]).

Let us denote by λ_F and λ_M the failure RARC es during operation of the system and during its maintenance, respectively, and the amount of losses from the failure of the infrastructure object – through P. Then the risk can be determined by the formula:

$$R = P\lambda_{FM}, \quad (9)$$

where $\lambda_{FM} = \lambda_F + \lambda_M$.

In formula (9), it is possible to reduce the value of λ_{FM} due to the use of monitoring tools:

$$R\left(\vec{\lambda}_{FM}\right) \rightarrow \min_{\vec{\lambda}_{FM} \in \lambda_{FM}}. \quad (10)$$

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A decrease in λ_{FM} is achieved both by decreasing λ_F and by decreasing λ_M. A decrease in the value of λ_F is possible due to the fixation of a set of states preceding failure (pre-failure, limit, etc., synonyms used in various fields of technology). Reducing the value of λ_M is possible due to formation of roadmaps for maintenance of monitoring objects (predicted maintenance times of the device) and increasing their service life. This, of course, is possible only with improvement of technologies for monitoring the technical condition, standardisation, and introduction of standards for assessing reliability of monitoring results.

Risk reduction (10) also contributes to reduction of dangerous failures in operation of infrastructure facilities of the railway complex and the train traffic control system (when they are linked) as a whole.

Reducing the risk of violation of train traffic safety is possible thanks to introduction of additional protective states of the train traffic control system (Pic. 4). Events that bring the system into states S_4 and S_6 must be excluded by design. For RARC systems, this is currently being implemented at the development stage (but, by the way, the occurrence of transitions to dangerous states is possible with improper commissioning and subsequent maintenance of RARC devices and systems, for which there are enough examples from operating practice). For objects of the infrastructure complex, a hazardous impact is excluded by maintenance and periodic monitoring by mobile diagnostic tools. In the presence of a stationary monitoring system, the train traffic control system itself will also consider defects in the railway infrastructure. This means that such events that could potentially lead to an accident or catastrophe will be prevented by influencing the transportation process itself.

The presence of a stationary monitoring system makes it possible to reduce the risk of dangerous failures of the railway infrastructure that occur with intensity λ^D_F:

$$R_D = P_D \lambda_F^D, \quad (11)$$

where P_D – dangerous failure loss.

Thus, the presence of a stationary monitoring system linked to the train traffic control system makes it possible to reduce the value of λ^D_F and minimise the risk of violation of train traffic safety:

$$R\left(\vec{\lambda}_F^D\right) \to \min_{\vec{\lambda}_F^D \in \lambda_F^D}. \quad (12)$$

Linking the monitoring system of railway infrastructure facilities with the train traffic control system makes it possible to increase reliability and safety of the transportation process (Pic. 5). Blocks corresponding to information processes in the monitoring system are highlighted in red (lighter colour).

With improvement of approaches to the synthesis of train traffic control systems with information linkage to monitoring systems, it becomes possible to manage reliability and safety of the entire railway complex. In addition, subsequent information linkage with the systems of organisation and operational control of train traffic is also possible, and failures of railway infrastructure facilities can be automatically taken into account when managing traffic on railway lines in case of the influence of external destabilising factors. This, in turn, contributes to development of the principles of dispatching the transportation process. For example, by linking the monitoring system with the train traffic control system, the innovative intelligent dispatching system described in [26] can be modified. In addition to the well-known functions of the dispatching system, it already proposes to use information about the predicted times of the start and end of technological operations at stations and automatic construction of fragments of the train schedule on this basis, and after their approval by the train dispatcher, to transmit recommended train driving modes to the driver via radio channel. However, the description of conceptual foundations of such linkage is beyond the scope of this article.

CONCLUSION

Management of reliability and safety of the transportation process on the railways is possible due to improvement of monitoring technologies and the effective use of stationary monitoring systems. This allows not only optimising the procedures for operation and maintenance of railway infrastructure facilities, but also opens opportunities for creating a train traffic control system that automatically takes into account the state of the railway infrastructure in the process of implementing the transportation process.

Technical coordination of train traffic control systems and stationary monitoring systems with development of control actions for traffic control means can significantly increase the level of safety of the railway transport system. But at the same time, certain restrictions are imposed on the monitoring system itself, related to reliability of the generation of one or another information message based on the results of monitoring data analysis. As noted earlier [3], in practice, this value should be normalised, and the monitoring systems themselves should be certified for compliance with safety integrity levels. Introduction at the synthesis stage of RARC system of additional states associated with the transition of critical railway infrastructure facilities to protective and dangerous states (directly affecting safety of the transportation process) makes it possible to foresee in the control system possible reactions to a decrease in safety indicators and development of a protective impact.

The reliability models of safe train traffic control systems presented in the article make it possible to evaluate the probability of transition to one state or another at each stage of operation. Their use as part of digital models of railway stations, sections and entire lines could be especially effective if properly equipped with technical monitoring tools.

Further research is important from theoretical and practical point of view. It should refer to analysis of the models shown in the article with the help of real statistics for railway sections, development of requirements for safe implementation of the «monitoring function» and the monitoring systems themselves, determining the criteria of transition of train traffic control system into different states if defects of rail infrastructure objects occur, development of concepts for integrating such a control system into a single intelligent dispatching system, as well as with simulation modelling of railway transport systems with an assessment of the impact of the application of the monitoring results on the transportation process for automatic influencing traffic participants.

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