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DEVISING A METHODOLOGY TO MANAGE THE PERFORMANCE OF TECHNICAL TOOLS OF RAIL TRANSPORT SIGNALING SYSTEMS BASED ON THE RISKS OF THEIR FUNCTIONING

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The object of this study is the process of ensuring the performance of technical means of alarm systems that perform the functions of control and safety of the movement of main railroad transport. On the railroads, there are regulations for monitoring and ensuring the necessary technical condition of the elements and devices of alarm system, but the number of failures does not decrease and, in addition, the process of their physical and moral obsolescence must be added. The most problematic areas in the technological process of service have been identified and an example of a management solution for their prevention has been proposed. The problem is determined in finding an effective way to control the process of keeping alarm systems in the required technical condition. The use of the method of finding hidden bottlenecks based on the analysis of failure statistics as risks and impact reduction is proposed. The research identified the lack of methodology in the form of the need to accumulate statistics of failures and constant monitoring of the implementation of the risk management program. In addition, the identified advantages of the methodology suggest that the proposed approach could solve the problem of justifying the most significant problem areas in the process of enabling the performance of railroad automation systems. To eliminate the identified lack of methodology, the development of appropriate software is proposed, with the help of which the statistical base would accumulate automatically. The solution to the problem is proposed in the form of planning for one year to monitor the most dangerous causes of failures. Thus, statistical methods are the most effective in managing organizational structures. It is proposed to adapt the results to the usual form for managers for widespread use in practice

Keywords: bottlenecks, hidden patterns, failures of technical means, statistics of violations

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1. Introduction

Transportation safety is the central backbone factor in the activities of rail and other modes of transport. Despite the banality of such a statement, it is necessary to emphasize the need to improve this problem. It is necessary to investigate this problem both in terms of equipment and technology for organizing and protecting users, cargo, the environment, infrastructure, and vehicles from the consequences of transport events and violations of traffic safety regulations.

Among the systems of railroad transport that secure transportation there is one for which this is the main task – the system of signaling and communication. This system enables the performance of railroad automation systems: rail circuits, traffic lights, electrical centralization, systems for regulating the movement of trains between stations, etc. Breakdowns or failures of the equipment of automation systems do not necessarily lead to accidents but they create risks of transport events at motion.

Over the past few decades, a set of regulatory documents on the technology of distance and railroad services has been developed. There are several paper and electronic sources where failures of technical means of signaling are recorded. But these statistics are mainly used to control the actions of the human factor, determine the reliability of technical means and inspections by the auditor's apparatus. That is, they have limited use. This is due, among other things, to the fact that information about failures is verbal in nature, therefore it is impossible to use it effectively in managing distances due to the impossibility of formalization.

Such valuable information that characterizes the real state of affairs should be effectively used in organizational management of distances. Namely, to determine the norm of activity, assess and predict the state of activity, determine the most problematic areas, dynamically review management decisions, implement in the form of computer software.

In the practical activities of distances and signaling and communication services, the method of controlling the performance of technical systems and the means they maintain will make it possible to solve several problems. Firstly, to identify and pay attention to the most problematic areas, secondly – to manage the risks of failures and, accordingly, transport events, and thirdly – to form a technological base for digitalization.

Therefore, research on the development and implementation of approaches to the management of structural units of organizations based on real information of their activities is relevant.

2. Literature review and problem statement

In the list of publications tackling the organizational management of railroad companies and their structural divisions, research on the identification and management of risks began to appear. But to this day there is no single interpretation of concepts, there are no common approaches, and the solution to the problem is at the initial stage.

Work [1] states that the existing methodology for assessing the level of safety in railroad transport does not reflect the real and adequate state of railroad safety. The solution to this problem, according to the authors, may be the development of a risk management system. The paper presents a posteriori and a priori risk values that allow them to characterize the actual safety – the real state of railroad traffic safety for the studied period, and the projected safety of railroad traffic. However, the risk system proposed in the work is of a generalizing nature, where the analyzed risks are combined into the following groups: general, local, technological, and technical risks, which makes it difficult to determine the causes of traffic safety violations.

The authors of [2, 3] note the need to reduce the existing levels of risk and further support risks not higher than the established level. This approach contributes to the adoption of decisions that take into account the uncertainty of conditions, the possibility of certain events or circumstances in the future (planned or not). In addition, the advantage of this approach is the ability to assess the impact of decisions made on the achievement of goals in the field of functional security of infrastructure and rolling stock. However, the papers do not consider the issue of collecting incoming information to ensure an effective risk management system.

In [4], the authors noted that through the analysis/assessment of risk, the safety management system provides hazard/risk identification and with an appropriate risk management system is able to ensure the safe and efficient organization of railroad transportation. However, the paper does not have a specific description of the information used to determine risks.

Work [5] identifies the risk of adverse events as one of the main problems of modern production and the main criterion for the implementation of danger. The use of risk management as a promising direction in the development of transport systems is proposed, which will make it possible to stabilize and increase the efficiency of their activities. The starting point of effective risk management in the control over transport processes at an enterprise is the construction of an effective risk management system. However, at present there is almost no information on risk management in railroad transport.

One example of the successful implementation of risk-oriented railroad management is the United Kingdom. The UK's Office of Rail Regulation (ORR) has developed an approach to the regulation of railroads that focuses on identified risk priorities, which are regularly reviewed. At the same time, the ability to process permits and other documentation and conduct reactive investigations of incidents is preserved. The success of the approach explains that the UK had the lowest death rate per billion train-km in Western Europe [6]. But the UK's rail management system has significant differences from other systems, making this idea quite exclusive.

According to [7, 8], risk management should be the basis of the EU railroad safety management system. In these sources there is very useful material. But the use of the results reported in [7] directly is impossible due to the fact that the risk management process and independent assessment has a standardized procedure that is absent from the national carrier. Using [8] is related to the use of a special EU directive, which is also impossible due to the fact that this directive is not in the regulatory sphere of railroads of other countries. Adopting a structured approach [9] in safety management allows one to identify hazards and constantly manage risks. This approach takes into account the common risks of all participants in the organization of railroad transportation: railroad companies, infrastructure managers and maintenance organizations, and other participants that could potentially affect the safe operation of the railroad system. Effective risk control is achieved through a process that combines three critical dimensions: technical, human, and organizational. The first (technical) component takes into account the use of tools and equipment. The human component is combined with the learning, skills, and motivation of people. The organizational component consists of procedures and methods that determine the relationship of tasks. However, the work under consideration is characterized by the scale of risk management at the level of management of a transport company, which has different tasks and indicators than the railroad services.

One example of the successful implementation of risk-oriented railroad management is Canada [10]. It provides a proactive approach to identifying risks and eliminating or mitigating (preventing) them. But the organization of rail transportation in Canada has its own specifics, which necessitates research taking into account the peculiarities of the work of other railroads.

The author of work [11] emphasizes that now risk management in the railroad industry is fragmentary and episodic, which determines the importance of applying a systematic approach to risk management, and, accordingly, the need to form a risk management system in railroad transport. This will provide an opportunity to satisfy the interests of all participants in business relations, improve the corporate governance system and ensure the adoption of more balanced management decisions. However, the paper presents only a theoretical part on the management of risks in railroad transport.

Polish railroad carriers use a comprehensive threat management system, which is carried out by separate modules.

Risk assessment in the system is carried out on the basis of analysis of the mode and consequences of failures and the probability matrix, while decision support is based on an analytical hierarchical process. Thus, the management and assessment of risks, according to [12], is defined as a recommendation on general safety methods as a tool to maintain railroad safety specifically for the conditions of Polish railroads.

In study [13], the authors emphasize that today there is no common understanding of the essence of risk, as well as the standard procedure for applying the theory of risks. A systematic approach to the management of technological safety on railroad transport, which uses the statistics of safety violations as incoming information, is proposed. Its use in making management decisions will make it possible to systematically assess failures in the transportation process, to perceive violations as a manifestation of transport risk. This approach will also allow moving from the concept of finding the culprit to the concept of identifying and reducing the impact of risks in the transportation process. However, the work does not have a specific idea of the management decision for railroad transport services.

Paper [14] states that through the analysis of railroad risk, it is possible to increase the level of safety, ensure the protection of its fixed assets, customers and employees, as well as reduce the maintenance costs of railroad assets and environmental impact. But the study does not take into account the peculiarities of risk analysis in structural units.

Work [15] considers the management of risks on the railroad under the conditions of operation and maintenance. The authors found that risk management by identifying it and implementing methods for its elimination will reduce the number of accidents, which, in turn, will increase the level of safety on railroad transport. However, the identification of risks in this study is carried out only on the basis of technical and non-technical characteristics.

In [16], the main components of effective railroad safety management are the identification and reduction of risks, the selection of competent specialists, regular monitoring of monitoring actions and change management. But practical recommendations for the implementation of risk management are not provided in the work.

The basic requirements for security in microprocessor control systems are set out in [16–19], specifications and demonstrations of reliability, availability, maintainability, and safety (RAMS) are considered. The works provide industry guidance on the overall RAMS process to minimize hazards and only provide assistance in matters of rail RAMS. Documents of this level also contain instructions for managing the general requirements for railroad RAMS, risk assessment, risk reduction strategies, specifications for requirements for railroad RAMS, elements of railroad RAMS. But the principles of RAMS in [17] are purely general methodological in nature and cannot be directly used at the level of the service or linear enterprise of the railroad. Paper [18] presents a safety justification for the overall process of ensuring reliability and safety for railroad transport and does not take into account the peculiarities of structural units. In addition, in [19], no practical recommendations have been provided for the implementation of RAMS in the software of alarm systems.

In [20], the control and safety of train traffic are considered, various principles of organization of train work and requirements for the functioning of railroad automation systems are presented, as well as relevant technical solutions on the railroads of the world. All materials are presented only in the review without specific technical features.

Work [21] considers the principles of ensuring the safety and reliability of the functioning of railroad automation and telemechanic systems, software, and structural methods for improving safety, the organization of a secure interface with the control object. Operational and technical requirements for microprocessor centralization systems, characteristics, and structure of a number of systems are given. However, in this paper there are no modern methods and technical solutions to ensure the operational state of alarm systems.

The principles of construction and safety of railroad automation systems are discussed in [22, 23]. These papers deal with the construction and functioning of elements and station control systems for the movement of trains. The principles of construction and ensuring the safety of floor equipment, in particular switch drives, traffic lights, rail circuits, and their circuit solutions are given. The most common electrical centralization systems are considered in detail. All materials are presented mainly on the example of outdated railroad automation systems, without paying enough attention to the approaches and methods of ensuring the performance of automation and signaling systems.

Thus, the real management of the activities of structural units revealed archaisms and traditionalism. Analysis of the above research showed that risk management is a necessary condition for the effective implementation of the safety management system on railroad transport. However, the lack of clear practical recommendations for the implementation of the risk management system necessitates the development of modern approaches that will take into account the peculiarities of the organization of railroad transportation and ensure an increase in the level of safety of railroad transport. The analysis of existing risk management systems on railroad transport in other countries [6–10, 12] showed that, first of all, these approaches should be based on digital technologies and use modern analytical and management methodology.

3. The aim and objectives of the study

The aim of this study is to develop a methodology for controlling the performance of technical means of railroad automation and its experimental confirmation. This will make it possible to effectively coordinate technological processes in the alarm and communication system.

To accomplish the aim, the following tasks have been set:

– to propose the principle of constructing a methodology for controlling the performance of elements of alarm systems based on the statistics of their failures;

– to implement the procedure of experimental verification to assess the reliability of the methodology for controlling the operational capacity of technical means.

4. The study materials and methods

The object of our study is the process of controlling the performance of railroad automation devices, represented by the real statistics of their failures for one and a half years [24] in the distances of signaling and communication of the railroad. The main hypothesis of the study assumes that the identification and application of hidden patterns in the statistics of failures of technical devices is informative and leads to effective management decisions. Assumptions about minimal distortion of failure data have been accepted. Simplifications that are accepted in the work is a list of reasons for failures that occur once a year, combined into a common group.

The theoretical basis of research was (a) the method of hidden statistical patterns (MSP) [13, 25, 26] and (b) the provisions of risk theory [27–30].

The method of hidden statistical patterns (MSP).

This method provides a search for hidden patterns – "bottlenecks" – in the statistics of the activity of the object of management (person, structural unit, organization). Bottlenecks are the most problematic places or places of maximum expenditure of resources to preserve the stability and safety of its transportation process. Below are four theoretical provisions of MSP, which are used in this paper:

1. Signs of defining "bottlenecks".

Sign 1 – "emission" (Fig. 1) of the parameters of statistics of violations for the period of analysis.

Red stroke in Fig. 1 indicates the "bottleneck" of the first sign, n – the number of elements of the statistics parameter.

Sign 2 — "negative trend" of dynamics (or time series) of changes in the parameter of statistics analyzed in neighboring periods of time.

Once, on the basis of the graphic image of the registered parameters, there is a uniform manifestation (that is, there is no pronounced "bottleneck"), then the sources of improvement of the situation should be sought in the plane of organization of the technological process as a whole.

There may be several "bottlenecks".

2. Systematization of cases of violations.

The problem of using statistical methods is the verbal way of representing them in the relevant sources of information. Therefore, to use statistical management methods, verbal information must be formalized or systematized.

MSP proposes to represent each failure of technical means of railroad automation in the form of answers to nine questions or in the space of nine parameters (Fig. 3).

The parameter "WHAT" characterizes the event according to the existing classifier of transport events. Evaluation of the geographical location of the event (station, site, run) is carried out by the parameter "WHERE". The WHEN parameter reveals the time of the event. Circumstances ("HOW") contains a qualitative description of the event: information about the train, locomotive, cars, weather conditions, the condition of the rolling stock, the state of the infrastructure, compliance with the schedule, the state of health of the locomotive crew, etc. The "WHY" parameter is a possible cause. "WHO" is a violator. The answer to the question "WHY" should explain the intentionality or randomness of the event. The "TO WHOM" parameter must contain information about the consequences of the loss. "FROM" – direction of movement.

3. Identification of patterns carried out by graphically constructing the following dependences:

a) variations of individual parameters of systematization WHAT, WHERE, WHEN, ... (Fig. 3) in time;

b) variations of the constituent nine parameters over time;

c) in the space of two and three parameters of systematization (for example, WHAT – WHERE, WHY – WHEN, WHAT – WHO – WHERE, ...).

4. The use of information about violations in the method of hidden statistical patterns.

In the railroad companies of the world, the state of safety is determined precisely by the statistics of violations of safe traffic regulations. There is a rational explanation for this: when everything is going well, the staff rarely thinks about the shortcomings and "bottlenecks". All transport events are investigated by special boards that comprehensively study the circumstances, causes, compliance with service technology, staff actions, etc.

Thus, safety violations provide valuable information about the shortcomings of the technological process of transportation, the main thing is to treat it objectively and use it correctly.

In addition, this procedure uses exactly the statistics that exist in the organization under study.

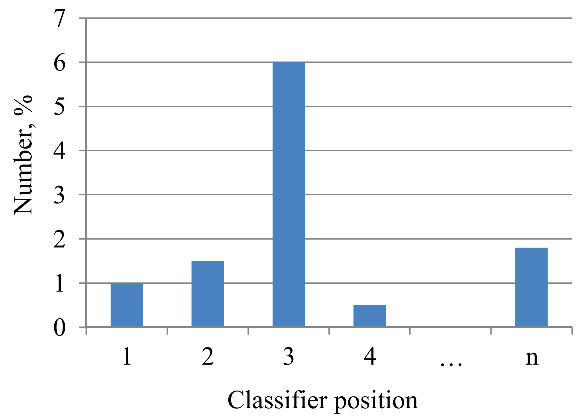

Fig. 1. The first sign of a "bottleneck" is "emission"

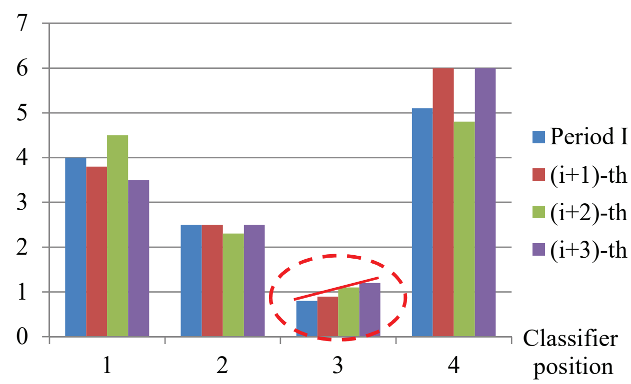

Fig. 2. The second manifestation of the "bottleneck" is the "negative trend" (marked with a red stroke) for four periods of control

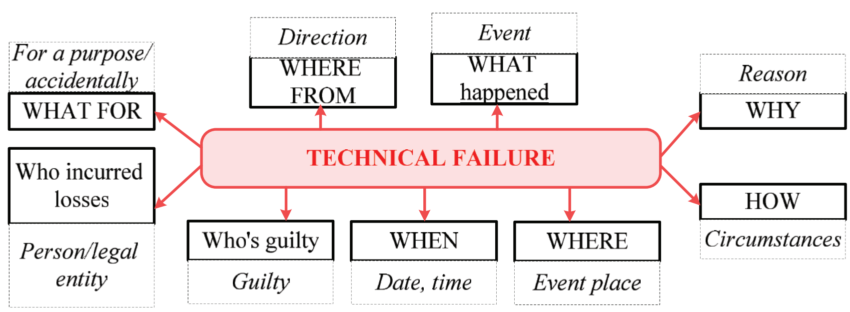

Fig. 3. Systematization of cases of statistics of failures of technical means of railroad automation

Provisions of risk theory.

The word “risk” has many different meanings: danger, probability, consequence, potential adverse factors, opportunities. The text of the ISO 31000:2009 standard provides a general definition of risk as “the impact of uncertainty on the achievement of goals” [29]. From this definition it follows that risk management is not a process superimposed on other management decision-making systems but is an extremely important component of all activities and processes. The implementation of risk management in the organization provides its management with the opportunity to make rational decisions based on the available information, no matter how complete it is.

For quality risk management, it is necessary to use the following criteria [27]:

– risks are identified in a timely manner;

– risks are carefully analyzed and assessed;

– the most important risks have a higher priority;

– action plans that are developed in the necessary situations are expedient, and there are necessary resources for their implementation.

Specific steps in the use of risk management are considered in accordance with [27] because the Regulation on the security management system must be used by all enterprises and organizations of Ukraine. And the staff, in accordance with this Regulation, must pass exams to obtain the appropriate certificate.

5. Results of the development of a methodology for controlling the performance of technical means of railroad automation

5. 1. Development of principles for controlling the performance of elements of alarm systems based on the statistics of their failures

The management methodology is based on the principle of a step-by-step representation of the process of making a management decision in the management of railroad signaling and communication on issues of ensuring the necessary level of condition of the technical means of distances (Fig. 4). Sequence is indicated by directed lines. Stages 2 and 3 are assigned by a dotted line to the provisions of the MSP “Identification of regularities” (p. 4 “Methods”).

Stage 1 is monitoring (continuous monitoring) of the state of technical means in accordance with existing regulations and identifying various kinds of deviations from the regulations (failures, errors, transport events). All these deviations are recorded in special journals on paper or electronic media. All this is a statistic of violations. It is desirable to integrate all statistics on the problem of security violations, that is, to reduce to one information base. However, this has not yet been implemented. Further, all statistics are systematized in accordance with Fig. 3 for all nine or fewer systematization parameters, as far as the available statistics allow. The result of stage 1 will be a database (DB) – a table that has the number of column sections equal to the number of systematization parameters. Thus, there may be 4–5 systematization parameters and, accordingly, database partitions. There is no need to add anything to the statistics because the principle of reliability will be violated, and there will be distrust of the staff. Everything must comply with the regulations for filling out the relevant journals. Nine parameters have well-thought-out regulations, for example, when investigating transport events on railroads (disasters, accidents, incidents).

Stage 2 – the database is analyzed according to the parameter “WHAT”. To do this, determine the total number for each position of the event classifier $p_i\left(i=\overline{1,N}\right)$, where N is the number of positions of the event classifier. The concept of a classifier in the paper is defined traditionally: a systematic list of named objects, each of which is provided with a unique code in accordance with it.

Further, bottlenecks are determined by the signs of Fig. 1, 2. The most frequent events will obviously constitute the greatest quantitative characteristic during the analysis period. There may be several such bottlenecks (denote them k, where $k<N$). Their number can be determined by the standard – 85 % of all events.

Stage 3 – for all k of the most frequent events, the causes are determined by the classifier of causes and the relationship between the classifiers, as shown in Fig. 5. The directional line indicates the relationship of the corresponding positions of the classifiers. The point is that the same event can have several causes.

If the interaction of the positions of the classifiers does not exist, then the determination takes place using, for example, expert assessment. However, in the distances and signaling service of the Southern Railroad, it does exist.

To further formalize the method, we represent the interaction of classifiers in the form of an incidence matrix INC=||inc$_{ij}$|| Fig. 6), where inc$_{ij}$=1 if there is a relationship between the i-th event and the j-th cause; inc$_{ij}$=0 if there is no connection between the i-th event and the j-th cause.

Further, for all the l reasons for which there is a connection with the most frequent events, the weightiest, respectively, to sign 1 are selected (Fig. 1). Let there be l_0 ($l_0 \leq l \leq M$) of them. These are the risks (bottlenecks-reasons). The definition of l_0 can also be determined from the condition of 85 % or more of the total amount of manifestations of l causes.

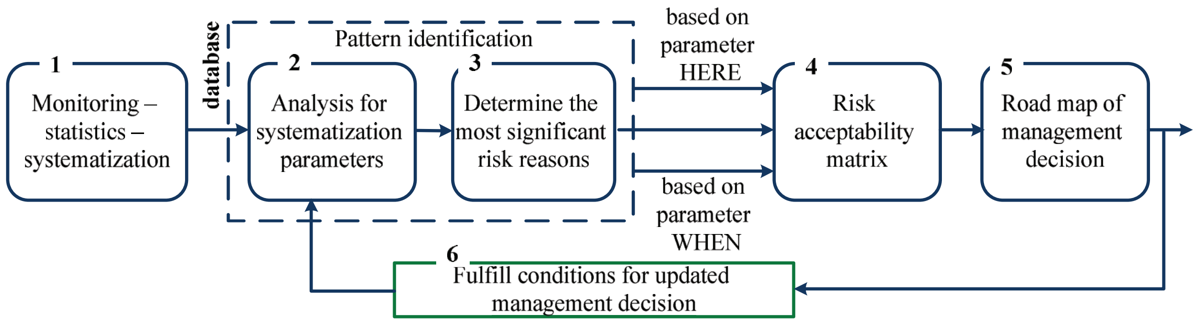

Fig. 4. The sequence of management decision-making

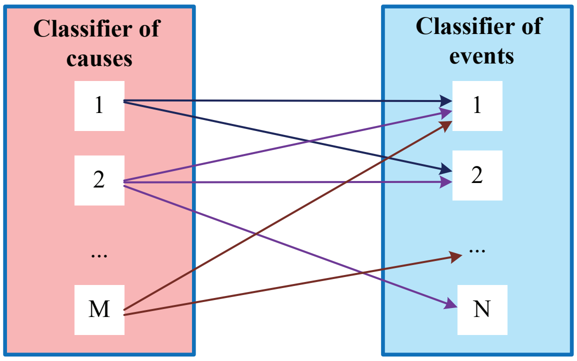

Fig. 5. The relationship between classifiers of events and causes

Event	Cause					
	1	2	…	*j*	…	*M*
1	inc_{11}	inc_{12}	…	inc_{1j}	…	inc_{1M}
2	inc_{21}	inc_{22}	…	inc_{2j}	…	inc_{2M}
…	…	…	…	…	…	
i	inc_{i1}	inc_{12}	…	inc_{ij}	…	inc_{iM}
…	…	…	…		…	…
N	inc_{N1}	inc_{N2}	…	inc_{Nj}	…	inc_{NM}

Fig. 6. Matrix of incidence of events and causes

The output of stage 3 is also a list of sections of the railroad track (parameter of systematization WHERE), which are tied to the reasons. When developing a management decision, one should also take into account the parameters of the failure time – WHEN, but it is used only in the analysis, and its use in the management decision, as well as the HOW parameter – the topic of further research.

Let's limit ourselves to three parameters out of nine. The choice of these parameters is explained by the fact that the WHO parameter in the alarm and communication system is obvious because the distances consist of areas attached to them, and the guilty specialist is usually also obvious. The WHY parameter is also obvious in practice, and the FROM WHERE parameter does not make sense in the operation of railroad automation. The WHO TO parameter is not recorded in the statistics of the alarm and communication system because these are statistics of transport events, although the consequences of the damage caused are recorded, say, in the form of violations of the schedule, train delays, damage to devices, or rolling stock, etc.

Stage 4 – The risk acceptability matrix is determined according to [27] as follows. First, the probability of each of the l_0 risks-causes from Table 1 is determined by expert means.

Each of the l_0 risk-causes receives the first identifier: from 1 to 5.

Then the severity of the risk is determined according to Table 2.

In Table 2, the concepts of accident and incident are used in accordance with the Regulations on the classification of transport events in railroad transport [31].

Accordingly, each of the l_0 risks-causes receives a second identifier: from A to E. Thus, each risk receives an index from 5A to 1E. And then, according to the ALARP model [27], each risk belongs to one of the three zones according to Table 3.

In Table 3, unacceptable risk areas are highlighted in red. Yellow indicates the permissible risk zones, taking into account the necessary measures. Potentially acceptable risk areas are marked in green.

Table 1

Determination of risk probability gradation

The likelihood of risk	Explanation	Gradation (degree) of risk	Almost reasonable frequency values: 1 time per ...
Frequently	It happens very often	5	Week
Periodically	It happens sometimes	4	Moon
Rarely	The probability of occurrence is small	3	Quarter
Unlikely	The probability of occurrence is very small	2	Year
Almost impossible	The probability of occurrence is almost impossible	1	Life cycle

Table 2

Determining the severity of risk

The seriousness of the consequences	Likely consequences	Risk gradation (level)
Catastrophic	– significant human casualties; – destruction of equipment, property	A
Dangerous	– serious bodily injury; – significant damage to equipment and/or property; – a serious decrease in the level of traffic safety, the onset of physical stress or such workload, when there is no confidence in the correct and complete performance of tasks by the personnel of the enterprise	B
Significant	– accident; – minor bodily injuries; – a significant decrease in the level of traffic safety, a decrease in the ability of the company's personnel to cope with adverse operating conditions due to an increase in workload or the emergence of conditions that reduce the efficiency of their work	C
Insignificant	– incident; – damage; – production restrictions	D
Not essential	insignificant consequences	E

Table 3

Risk acceptability matrix

Risk index	Risk zone
5A, 5B, 5C 4A, 4B, 3A	Unacceptable under these conditions
5D, 5E, 4C, 4D, 4E 3B, 3C, 3D, 2A, 2B, 2C	Acceptable with regard to reduction measures
3E, 2D, 2E, 1A, 1B, 1C, 1D, 1E	Acceptable

Stage 5 considers the development of a draft risk management guideline. These can be different forms: an action plan, a special order, expert assessments, and conclusions. But the most obvious, according to authors, is a guiding decision in the form of a roadmap.

Stage 6 – fulfillment of the conditions for updating the procedure for detecting dangerous factors or threats. This occurs in the following scenarios:

– there is an increase in the number of failures or transport events for unknown reasons;

– it is planned to replace the personnel of the enterprise, the main equipment, systems, technological process;

– during significant organizational changes, including in the structure of the enterprise;

– the conditions for the frequency of updating are met.

5. 2. Experimental verification of the reliability of the principles of operational management of technical means of railroad automation

The basis of experimental research was the database of statistics of technical failures in the signaling and communication distances of the Regional Branch “Southern Railroad” of JSC “Ukrainian Railroads” from 13.06.2018 to 29.12.2019 [24], that is, for 1.5 years. These are real data. The database is presented in the Excel environment. In total, the database contains 335 events of technical failures, which are represented in the form given in Table 4.

Experimental research will be carried out in accordance with the developed methodology for controlling the performance of elements of alarm systems based on failure statistics and sequence in Fig. 4.

Stage 1.

It was implemented by providing authors with a statistical database of failures [24].

Table 4

Failure database fragment

No.	Name of failure (WHAT)	When the failure happened (WHEN)		Failure localization (DE)		Reason for failure (WHY)	
		Date	Time	Station	Section	Name	Run
1	False operation of the rail circle---s.u.15---false operation I section of the distance of art. Rolling on the odd track of the Pokotilivka–Merefa run	13.06.2018	04:00	–	Lozova – Kharkiv\Pasazhyrskyi	Rail circles (track elements of rail circuits)\ False operation of rail circuits \W\Other---entrenchment of a long DT jumper on the rail of the feeding end of the r.k. and the distance section near s.u.15	Merefa – Pokotilivka
2	False operation of rail circuit---s.u.7---False operation of 1.2 sections of distance along the odd track of Lozova station	15.06.2018	03:11	Lozova	Lozova – Kharkiv\Pasazhyrskyi	Stands, relay cabinets, track, transformer, switch, cable boxes\Relay cabinets\Other---During a thunderstorm discharge, the failure of the arrester RVNSh-250 (No. 1535, checking the instrumentation – 27.07.17r, 1985) and the transformer SOBS-2 (No. 9196, checking the instrumentation unit – 28.11.12r, 1970) in the relay cabinet S/U No7	Track post 939 km – Lozova
3	False operation of the rail circle for 161 km 8 pc train No. 711 HRCS2 No. 9 of the URCM Kiraev TPS (UZSHK)---p.u.9---With the permitting display of SUN No. 9 and SUN No. 7 on the locomotive svshtlofor red fire, at a speed of 20 km/h	16.06.2018	18:28	–	Krasnograd – Lozova	Others---The reason was the failure of the terminal and ROM on the SSM board of the relay controller No. 3 in a modular room of 165 km	Orilka – Grazhdansky (RZD)
...	...	...	...	...	...	...	...

Stage 2.

Table 5 give the results of the manifestation of failure statistics events in accordance with the existing event classifier in the alarm and communication service. The paper proposes a grouped classifier of events by technological type (Table 6). The principles of forming a grouped classifier are shown in background colors. The lack of color refers to the position "Other" in Table 6.

For availability and awareness, Fig. 7 provides a diagram of the manifestations of events of failures of the equipment of the alarm systems of the grouped classifier (Table 6). From Fig. 7 it follows that more than 80 % are three types of failures: rail circles, traffic lights, and switches. This confirms the existing problem of maintenance of technical means in the alarm system.

Fig. 8 shows a diagram of the manifestation of events of technical failures for the period 13.06.2018–29.12.2019.

Analysis of the dynamics of failures in Fig. 8 indicates the absence of pronounced patterns.

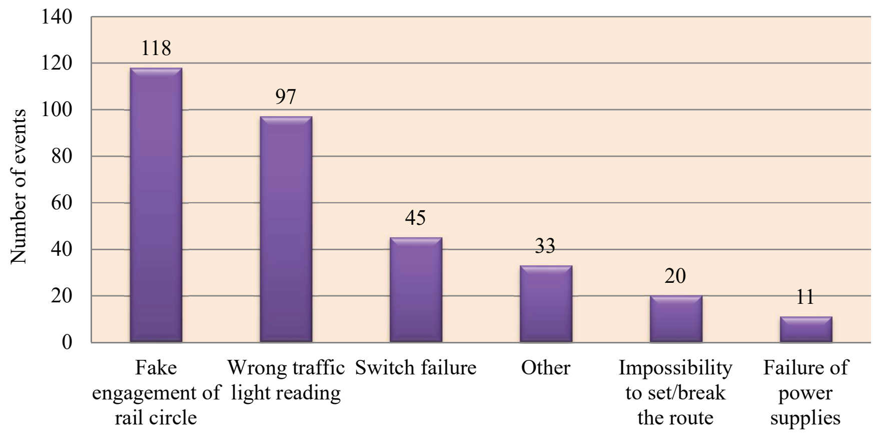

Fig. 7. The frequency of manifestation of events of technical failures in the alarm and communication system of the Southern Railroad for the period 13.06.2018—29.12.2019

Table 5

Existing event classifier

Event name	Number of cases in failure statistics
Fake rail wheel operation	118
Overlapping the traffic light from the permitting reading to the prohibiting	36
Other	33
The inability to open or close the traffic light	29
Inability to transfer the switch	25
The absence of any reading at the traffic light (extinct)	20
Loss of control of switch position	20
Impossibility of changing the direction of movement in the run	13
Power failure	11
Inconsistency between the traffic light readings and the state of the rail circle it encloses	8
Unable to set a route	5
Failure of management and control bodies	4
Failure of ALS codes	3
Inconsistency in the readings of the traffic light/road sign	3
Impossibility of management/control of a subordinate separate point (district) using remote control devices	3
Malfunction of devices on the run according to the information of the station control devices (according to the indication on the control device)	2
Impossibility of setting a route, opening a traffic light	1
Impossibility of opening a route (automatic, artificial)	1
Malfunction of the crossing traffic light	1

Table 6

Grouped event classifier

Name of the event	Designation	Number of cases in statistics	Relative frequency, %
False operation of the rail circle	RC.	118	36
Incorrect traffic light indicators	TrL.	97	30
Switch malfunction	RSw.	45	14
Other	Oth.	33	10
Impossibility of installing/unlocking marching route	Impossibility of installing/unlocking marching route	20	6
Failure of power supply devices	Failure of power supply devices	11	4
In total		324	100

For further search for patterns, we will analyze the statistics in the plane "WHAT-WHEN" of manifestations of events by month and by period of the day, given in Tables 7, 8.

Table 7

The results of the analysis of the number of manifestations of events by month

Event	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
1. Rail circle (RC.)	–	–	–	–	–	+	+	+	+	+	–	+
2. Traffic lights (TrL.)	–	–	–	–	–	–	–	+	+	+	+	+
3. Rail switches (RSw)	+	+	+	+	–	–	+	–	–	–	–	+
4. Routes (Rt.)	–	–	–	–	+	–	+	–	–	–	+	–
5. Power devices (Pdv.)	–	+	–	–	–	+	–	–	–	–	–	–
6. Other (Oth.)	+	+	–	–	–	+	+	–	–	–	–	–
Total	30 %		13 %			30 %			27 %			

Note: "+" means the presence of this event in a given month; "–" means the absence of this event in a given month

The color background in Table 7 marked months in which certain events occurred. Such information will help management plan measures to control the operation of technical means and predict the occurrence of certain failures.

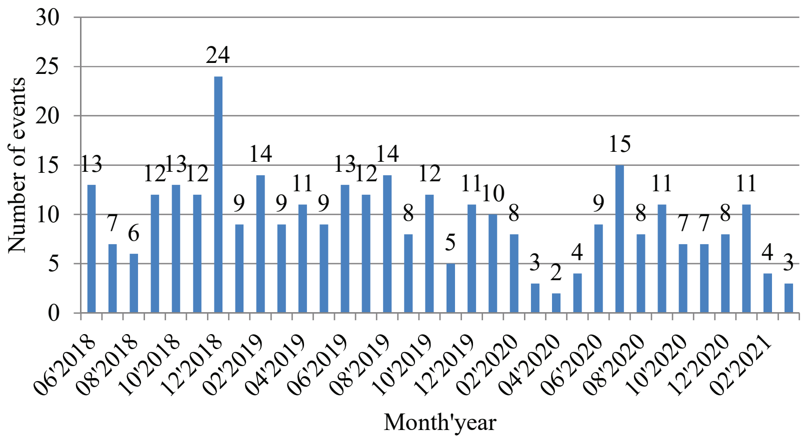

Fig. 8. Time series of technical failures by month

Table 8

The results of the analysis of the number of manifestations of events by the hour of the day

Event	Time of day, hours		
	0–8	8–17	17–24
1. Rail circle (RC.)	34	34	32
2. Traffic lights (TrL.)	29	50	21
3. Rail switches (RSw)	47	42	11
4. Routes (Rt.)	30	60	10
5. Power supply devices (Pdv.)	27	46	27
6. Other (Oth.)	28	36	36
On average:	32	45	23

For example, in March and April, it is necessary to pay attention primarily to the switches, in May – to the impossibility of establishing/opening the route. Analysis Table 7 indicates different periods of failures. The most stressful months are February, June, July, and December. This can be explained by seasonal environmental conditions (high and low temperatures, snow drifts, ice, etc.).

Analysis of the frequency of technical failures by time of day (Table 8) indicates that the most dangerous for the operation of traffic lights and power devices is the period from 8 to 17 hours, and for the rail switch – the period from 0 to 8 hours. The relatively higher average number of failures during working hours is due to purely technological reasons and is not a clear first sign of a "bottleneck" (Fig. 1).

Stage 3.

Let's analyze the statistics of technical failures in the plane of "WHAT-WHY", that is, events and reasons. First of all, a classifier of causes should be developed. It is provided in Table 9.

"10. Others" included causes that occurred 1–2 times a year, that is, the probability of their occurrence is very small.

Table 10 shows the matrix of cause-event relationships in statistics [24].

Stage 4.

We define as threats 85 % of all failures, which from the point of view of the normal law of probability distribution is sufficient. These are the first four events of the event classifier (Table 6) and, accordingly, the first four columns of Table 11.

Table 9

Classifier of causes

Name of the reason in the statistics of failures	Position of the classifier of causes
Malfunction of auto-locking elements	1. ALE
Power supply	2. PwS
Burnout of the lamp	3. Burn.L
Malfunction of relay elements of electrical centralization	4. EC
Cable failure	5. Cable
Failure of elements of the arrow electric drive and control circuit	6. EAD
Service personnel error, incorrect adjustment	7. PE
Lightning discharge	8. Thunderstorm
Unknown reasons	9. Unknown
Loss of contact in soldering (cold soldering), failure of semiconductor elements, failure of the work algorithm, malfunction of the microprocessor component, other	10. Other

Table 10

Frequency of detected causes in events

Cause	Event						Total manifestations of causes
	1. Rail circle	2. Traffic lights	3. Rail switches	4. Routes	5. Power supply devices	6. Other	
1. ALE	63	17	–	–	–	10	90
2. PwS	14	11	3	4	10	4	46
3. Burn.L	1	34	–	–	–	2	37
4. EC	2	14	5	10	–	1	32
5. Cable	14	4	5	1	–	3	27
6. EAD	–	–	19	–	–	–	19
7. PE	4	3	8	2	–	1	18
8. Thunderstorm	11	–	–	–	–	2	13
9. Unknown	3	5	3	2	–	5	18
10. Other	6	9	2	1	1	5	24

Note: "–" means no indicator

For risks, we will determine the causes of failures of technical means of railroad automation.

Table 11 gives the matrix of risk assessment according to the rules defined in Tables 1, 2.

Table illustrates 11 that the three reasons (1. ALE, 3. Burn.L and 4. EC) belong to the zone of unacceptable risks (high probability of occurrence) and others – acceptable ones taking into account measures to reduce (low probability of occurrence). That is, all these risks require constant attention and control by the management of the service and the distance of signaling and communication.

The dynamics of the manifestation of unacceptable risks are shown in Fig. 9.

Stage 5.

The following risk management solution is proposed:

– for acceptable risks, taking into account measures to reduce (yellow background), the existing staff control procedure works;

– for unacceptable risks, a procedure for additional measures is proposed, the regulations of which are represented in the form of a roadmap (Table 12). Such events can be special meetings, involvement of experts, analysis of the dynamics of statistics of failures and causes, others. The criterion for determining the time of a special event is no later than one month from the moment of the onset of a negative increase in risk statistics (Fig. 9).

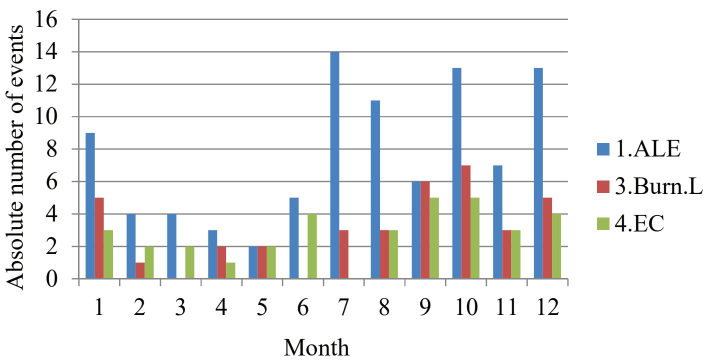

Fig. 9. The absolute number of unacceptable risks per month

Table illustrates 12 that the most critical for the malfunction of autoblock elements are the months of May and November. For the burnout of the lamp – June and November, and for the malfunction of the relay elements of electrical centralization – April and July. That is, November is the most sensitive month to the risks of failure of technical devices.

6. Discussion of results of the study of the performance of technical means of railroad automation

The results of our study:

– development of the principle of constructing a methodology for controlling the performance of elements of alarm systems based on the statistics of their failures – shown in Fig. 1–6 and given in Tables 1–3;

– implementation of the experimental verification procedure to assess the reliability of the methodology for controlling the performance of technical means – given in Tables 5–12 and shown in Fig. 7–9.

Real statistics of failures are used ([24], Table 2), which reflects not only the facts of activity but also indirectly the physical wear of technical means.

The development will be clear and obvious to the staff because it uses the statistics of this particular organization.

In addition, statistical methods are most effective in managing complex human-machine systems, which is a system for signaling and communication of railroad transport.

The identification of hidden "bottlenecks" was used (Fig. 1, 2, Table 11), which are the most problematic places in the technological process of service. "Bottlenecks" as the most significant and dangerous causes of failures were used as risks of disruption of the functioning of automation and alarm systems. To prevent them, an example of a management decision was developed (Table 12). This document is adapted to the usual realities of the functioning of railroads.

Table 11

Matrix of risk assessment and acceptability

The likelihood of risk	Severity of risk				
	Catastrophic A	Dangerous B	Significant C	Insignificant D	Minor E
Often 5	–	3. Burn.L	1. ALE	–	–
Periodically 4	–	4. EC	2. PwS 6. EAD 7. PE	–	–
Rarely 3	–	–	5. Cable	8. Thunderstorm	
Unlikely 2	–	–	10. Other	–	–
Almost impossible 1	–	–	–	–	–

Note: "–" means no risk

Table 12

Critical risk management roadmap

Risk	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
1. ALE	–	–	–	–	+	–	–	–	–	–	+	–
3. Burn.L	–	–	–	–	–	+	–	–	–	–	+	–
4. EC	–	–	–	+	–	–	+	–	–	–	–	–

Note: «+» means the presence of a cause in a given month; «–» means no cause in a given month

The application of risk management (Tables 1–3, 11, 12) was carried out on the basis of a regulatory document [26], which is mandatory for all enterprises in the field of railroad transport.

The advantages of the developed methodology compared to [5–9] are explained by the fact that the risks were obtained not on the principle of "as it should be" but "as it is", that is, they are real. In contrast to [10–12, 15], our studies use the peculiarities of railroad transport in Ukraine. In contrast to [16–19], the current work provides practical recommendations for the implementation of the principles of RAMS. In contrast to [21–23], a modern approach to the management of structural organizations is provided. This approach solves the problem of substantiating the most significant problem areas of the process of ensuring the performance of railroad automation systems, which means targeted control, which is important in the face of staff reductions and limited funding.

The provided example of practical application of the developed methodology is actually an algorithm for risk management in distances and signaling and communication services of railroads, that is, the basis of digital technologies [32]. For unlimited application of the developed methodology in practice, it is necessary to develop a computer program. But even under a "manual" mode, its application takes one to two days. The main thing in using it in practice is the desire and interest of both management and engineering and technical workers within the system.

As a relative drawback of the methodology, one can note the need to accumulate failure statistics (that is, an increase in the volume of the database) and constantly monitor the implementation of the risk management program and the management decisions. But when developing the appropriate software, these statistical savings will occur automatically, and this deficiency will be eliminated.

The limitation of the developed methodology may be the amount of statistical data and the level of reliability.

The development of this procedure will be the application of the prerequisites for events of technical failures as risks – these are the basic reasons for failures that are in the field of organization and maintenance of technological processes [13]. In addition, another option for the development of the methodology will be the development of the concept of risks and crises in the transport company [25].

The application scope of the results is the structural units of railroad transport, which ensure the safety of the movement of trains. The procedure can also be used in other modes of transport, it should only be adapted it to the relevant failure statistics.

Conditions of use of our technological advancement involve the presence of a computer database of failures and the desire of the management of structural and production units to obtain an effective mechanism for influencing forecasting and risk management in ensuring traffic safety.

Expected effects from the use of the technological advancement are controllability of the process of ensuring the performance of technical means in the face of staff reduction and financial conditions.

7. Conclusions

1. A procedure of managing the performance of technical means is a set of stages: the analysis of statistical data on failures, determining "bottlenecks" as hidden patterns, as well as the possibility of highlighting and managing risks.

2. An experimental study of the developed methodology revealed three causes of technical failures (auto-blocking, lamp burnout, and electrical centralization failure), which belong to the zone of unacceptable risks. Thus, the number of reasons for technical failures that require constant monitoring and control of management is 20 % of the total number of reasons.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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The study was conducted without financial support.

Data availability

All data are available in the main text of the manuscript.

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