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DEVELOPMENT OF AN APPROACH FOR OPERATIVE CONTROL OVER RAILWAY TRANSPORT TECHNOLOGICAL SAFETY BASED ON THE IDENTIFICATION OF RISKS IN THE INDICATORS OF ITS OPERATION

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Досліджується механізм забезпечення та управління безпекою руху на залізничному транспорті. Використовується реальна статистика порушень безпеки руху на залізницях України за останні роки. Для емпіричних досліджень і обґрунтування необхідності застосування системного підходу обрані три господарства, з вини яких відбувається понад 60 % транспортних подій на рік: локомотивне, шляхи, вантажних вагонів. Запропоновано системний підхід до управління технологічної безпеки. В якості вхідної інформації використовується статистика порушень безпеки. Кожна подія порушення безпеки систематизується по восьми параметрах, які характеризують місце, час вид події, його причину, винного, обставини, мотивацію, адресність шкоди. Формується відповідна база даних параметрів систематизації. Аналіз динаміки транспортних подій в одно-, дво- і трьохвимірному просторі параметрів систематизації дозволяє виявити приховані закономірності, які представляють собою загрозу погіршення стану безпеки та аварійної ситуації. Це трактується як вузьке місце, яке вимагає підвищеної уваги і розробки заходів запобігання переростання в аварійну ситуацію. Ризик визначено як найбільш значуща передумова транспортних подій. Передумови знаходяться в площині забезпечення перевізного процесу та мають системний характер.

Розроблено алгоритм оперативного управління технологічною безпекою і процедура підтримки прийняття оперативного управлінського рішення щодо зниження впливу ризиків. Алгоритм формалізований і готовий до автоматизації. Автоматизація передбачає використання цифрових технологій 4.0. Використання запропонованого підходу сприятиме зменшенню впливу людського фактора, підвищить оперативність і об'єктивність управлінських рішень по забезпеченню безпеки, зробить цілеспрямованим і ефективним фінансування безпеки. Запропонований підхід може застосовуватися для інших видів транспорту

Ключові слова: системний підхід, технологічна безпека, управлінське рішення, виявлення статистичної закономірності

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1. Introduction

Anyone, who worked in transport industry, would say that safety ensuring is the "holy of holies" for a transport company. Management and staff at all its levels consciously pay great attention to the problem of safety.

Let us clarify a subject of the study taking into account the fundamental nature of the "safety" term and a significant number of directions for its ensuring. This is technology safety management. Synonyms of the technological safety in transport systems are train operation safety, flight safety, road traffic safety. The beginning of the digitalization era leads to the transition from a competition to unification of different modes of transport. Concretization of a mode of transport is less and less used in passenger transportation by ground transport today. Freight logistics determines the optimal transportation of cargo regardless of the mode of transport. Such unification leads to the integration of transportation technologies and interconnection of technological safety issues in transfer, transshipment, passenger safety and cargo safety. This fact explains a need to take into account technological safety features of various modes of transport. Creation of a unified concept of transport safety management is likely in a short term. The first step is the practical unification of the classification of traffic accidents and it is already taken.

How is safety management executed? One of the five principles of the safety theory by Professor D. Petersen states: it is necessary to manage safety, like any other area of the transport system. But what is the management mechanism?

There are special regulatory documents, which regulate the content of the safety management system in railway transport in Ukraine and the European Union. The study of the documents gives reason to conclude that the "management system" term means a number of actions: ensuring, checking/control, recording and investigation of traffic accidents, licensing of staff. Of course, these are important safety functions, but not exhaustive ones.

There are no concepts of forecasting and operative management. This is not surprising, because there were no tools capable of implementation of the mentioned two management functions historically in formulation of principles of technological safety management in transport industry. Digitalization and implementation of 4.0 Industry project (and its analogues outside Europe) provided such a toolkit. Therefore, it is very important to formalize the process of forecasting and operative management of technological safety.

The regulatory documents on the system of railway traffic safety management states that subjects of management are staff, functional services, and structural units, which influence the management system to ensure its functioning. That is, making a management decision in the field of technological safety has a pronounced subjective nature.

There is no single understanding of the essence of a risk today. And there is no a standard procedure for application of the theory of risks to operative safety management. We understand risk as a threat of an emergency occurrence in a transportation process in the proposed study. One can justify the threat by systematization of real statistics of traffic safety violations and the subsequent detection of dangerous patterns.

The security problem is relevant in a civilized society by definition. However, the relevance of the proposed study has a feature. We know that traffic accidents occur randomly in time and localization. Therefore, the problem of forecasting and prevention of traffic accidents is extremely relevant.

2. Literature review and problem statement

As Wi-Fi systems and computer equipment are widespread nowadays, authors of papers [1, 2] consider capabilities of intelligent transport systems that provide for an exchange of information between vehicles, roadside infrastructure and a car using a Wi-Fi system. Such transport systems include traffic management functions and equipment safety, as shown in study [3]. Since 2015, European countries have introduced standards and additional industry specifications in the field of intelligent transport systems. However, integration of roadside infrastructure into intelligent transport systems involves a detailed study of systems and, of course, forecasting of failures in each segment of a road. In addition, there are unresolved issues of large volumes of preliminary studies. Thus, the approach requires a large amount of additional funds.

An option to overcome the indicated difficulties may be a different approach to the study of transport safety presented in [4, 5]. The approach supplements the study of intelligent transport systems. It simulates the behavior of a driver and a vehicle in a specific situation [4]. Authors of studies on modeling of accidents and their consequences use microsimulation packages [5]. It is possible to help a driver to prevent an accident in operative or offline mode using software and information on a type of a vehicle, a state of infrastructure and the environment. However, the widespread application of the approach is unlikely due to a need for constant changes in the model due to changes in the environment, infrastructure and in the state of a vehicle itself.

Work [6] introduces new methods for assessment of a level of traffic safety.

Many methods of studying of causes and consequences of accidents or critical situations use surrogate indicators in modern conditions. This type of indicator is useful usually for the study of critical accidents, which occur most often. Surrogate indicators make easier the analysis of such events. The problem of the application of surrogate indicators is that indicators assess this or that side of an accident. Authors of paper [7] propose to take into account the context for selection of an indicator. Accident analysis points to the problem of processing of data on causes of accidents and, as a consequence, preconceived conclusions, which leads to incorrect strategies for prevention of accidents in future, in work [8]. The development of various methodologies for investigation of accidents with vehicles, drivers and pedestrians continues [9]. This is an important aspect of technological safety management in a digitalized society. However, the works do not provide ways to apply them for prevention of accidents. So, there are no models for prevention of traffic accidents in [6–9].

It is impossible not to take into account social and environmental factors of the influence of vehicles on the environment and society in modern conditions. A harmonious interaction of the mentioned types of factors is important for stability of a transport system for European researchers. Authors of the approach use it in study [10]. However, such methods relate more to the philosophy of safety than to the technological sphere.

The traffic system provides for the interaction of various modes of transport among themselves. One of the main traditional directions of studies on technological traffic safety issues is safety of railway crossings [11–13], which are most significant in the statistics of accidents in railway transport.

The issues of technological safety, reliability and fail-safety are the most important in the development of technical standards and rules for functioning of railway and other modes of transport [14–17]. The reason is a multitude of internal and external factors of technical, technological, and anthropogenic nature. They lead to failures of railway transport systems [14].

It is necessary to note that rail transport carries significant volumes of dangerous cargo (including explosive cargo) [15, 16]. They cause the most severe emergency situations with negative consequences on the environment and the efficient operability of the railway industry [17].

Analysis of literature on the safety ensuring in air transport [18–21] shows also a lack of a complex approach and studies of this important issue. The main directions for solution of problems are:

a) concentration of attention on identification of mainly external risks [18];

b) definition of a systematic methodology and further creation of practical tools for decision makers to assist in determination of risks [19, 20].

Ensuring of safety in aviation has its own features. It is necessary to consider it in the context of the overall safety of the country [21].

Authors of paper [22] consider a safety culture in the port environment and issues of its assessment. Analysis of problems of technological safety in water transport does not present a complex approach.

Involvement of experts is usually necessary for making objective management decisions to ensure safety in transport under conditions of uncertain and innovative situations. However, involvement of experts often leads to subjectivity in terms of the belonging of an expert to a certain structure. There are various ways and methods for reduction of an impact of this negative aspect [23, 24]. The transportation process is continuous. Obtaining of expert opinions is not possible 24/7. Therefore, application of the principles of 4.0 Industry makes the proposed method impossible.

It is necessary to pay particular attention to international standards for harmonization of approaches to safety management and regulation of interstate contradictions in this area. In addition, the standards set objectives for scientific research.

There are all the necessary concepts of management in [25, 26]. There are an object and subject of management, management objectives, management principles and methods. There are management and safety control differentiated. However, they relate to the periodical support of making of management decisions in assessment and ensuring of traffic safety. The period is month/half year/year or occurrence of large-scale accidents. However, we know that implementation of risks is not periodical. The standards also do not include the concept of operative management of technological safety. They consider management in terms of ensuring, documenting, monitoring and control.

Authors of work [26] define the corresponding levels of risk of functional safety depending on a damage, which can be caused by anthropogenic objects to human life, human health or the environment. There are requirements for functions and safety completeness determined. However, there is no functional feedback (for equipment modification only) in the overall safety life cycle which makes it impossible to use it operative. Work [26] presents analysis and minimization of re-occurrence of all identified dangerous accidents during operation. Paper [27] presents general requirements to the analysis only. There are unresolved issues of formalization of the procedure. Authors recommend to develop them later. Similarly, there is no formalization of assessment of the level of functional safety. There is an additional documentation package described. All the above significantly complicates or makes it impossible application of the mentioned developments at this stage.

Researchers pay more attention to the concept of "life cycle costs" (LCC) due to increasing budgetary pressures, operational limitations and restructuring of European railways. Study [28] presents a revision of the strategy for tracks renovation, which is an essential component of train safety. A new maintenance strategy reduces projected budget requirements by at least 10 %. The LCC approach can lead to significant efficiencies in the "safety-safety costs" ratio. However, it does not apply to the operative management of traffic safety, but rather to capital investments in safety.

Authors present formalization of the technology for management of operative operation of a classification yard under conditions of transportation of dangerous cargo taking into account tasks of risk management in papers [29, 30]. There is a function of current risk and a criterion for the exposure of danger risk formed. It acts as an integral indicator of a level of danger. It is possible to determine it by modeling. The main objective of the development is to reduce processing time of carriages with dangerous cargo to avoid their large concentration at one station. However, it is necessary to apply the development in combination with changes in the technological process of operation of classification yards.

Thus, the main disadvantage of the existing studies in the field of technological safety management is a lack of a scientifically sound and formalized method for operative management, which leads to subjectivity and occurrence of emergency situations.

All the above suggests that it is advisable to perform a study on the approach to the operative management of traffic safety to prevent emergency situations.

3. The aim and objectives of the study

The aim of this study is theoretical justification and practical implementation of the operative management of technological safety in railway transport by identification and reduction of risks of an emergency occurrence.

We set the following tasks to achieve the objective:

– assessment of the level of systematicity in the existing structural-and-functional approach to analysis and management of traffic safety;

– justification of a systems approach for the operative management of technological safety;

– development of an algorithm for the operative management of traffic safety in railway traffic;

– proposing a procedure for supporting making an effective management decision.

4. Existing analysis of the state of railway traffic safety

It is known that stages of analysis and assessment of a state of processes precede the definition of control actions. The structural-and-functional approach is traditionally used in the field of traffic safety in railway transport. Let us consider the analysis of statistics of transport accidents in the railway transport of Ukraine for 2012–2017 to show its inconsistency and uncertainty.

Three departments have been selected, which account for more than 60 % of transport accidents per year. They are a locomotive department, tracks department and carriages department. Fig. 1 shows the ratio of a number of transport accidents due to each department to the total number of accidents over six years.

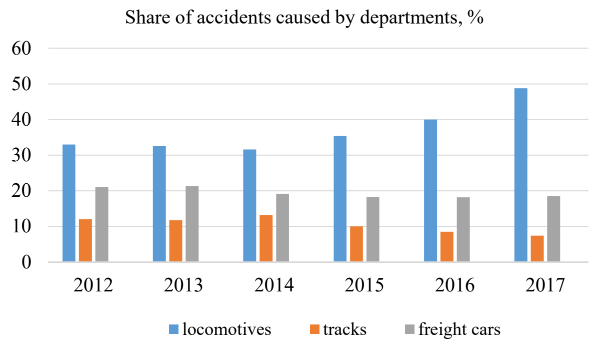

Fig. 1. Dynamics of transport accidents due to locomotive, tracks, and carriages departments of the main railway transport of Ukraine [31–36]

Visual analysis of Fig. 1 shows an increase in the share of guilt of a locomotive department, a decrease in the share of the tracks department and almost uniform distribution of the share of the carriages department. We can explain the negative dynamics in the locomotive department by a significant deterioration of locomotives (over 94 %) and a lack of natural renewal of the locomotive fleet.

However, should one look at the statistics from a different point of view, the conclusion on the negative dynamics of safety in the locomotive department is not entirely obvious.

Fig. 2 shows the dynamics of the absolute value of transport accidents in the locomotive department in recent years. It does not look so critical. The situation with ensuring of traffic safety generally improved until 2015. The number of traffic accidents caused by the locomotive department was approximately at the same level in 2012 and 2017.

Fig. 3 shows the average daily locomotive productivity for technological assessment of the locomotive department. The variational range of this parameter is about 5 % over five years. At first glance it does not seem disastrous from a safety point of view also.

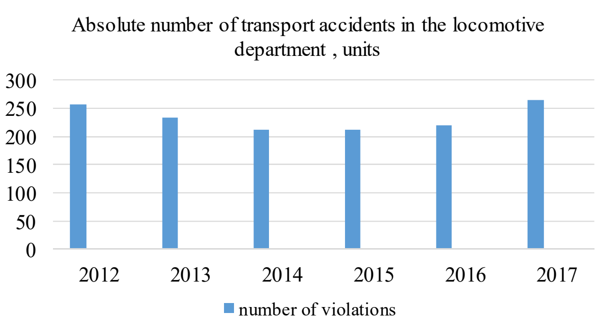

Fig. 2. Dynamics of traffic accidents due to the locomotive department of "Ukrzaliznytsya" joint-stock company [31–36]

Further, there are recommendations for elimination of causes of traffic accidents for individual departments in the analysis of the state of traffic safety. There is no systematic solution to determine the most important (dangerous) problem for railway transport as a whole and evaluation of directions for a comprehensive solution to the problem. It all comes down to the analysis of individual departments and their disadvantages in ensuring of traffic safety. However, it is unrealistic to solve the problems of all departments under conditions of a shortage of financial resources. We need to obtain priorities of a systematic nature, which are missing.

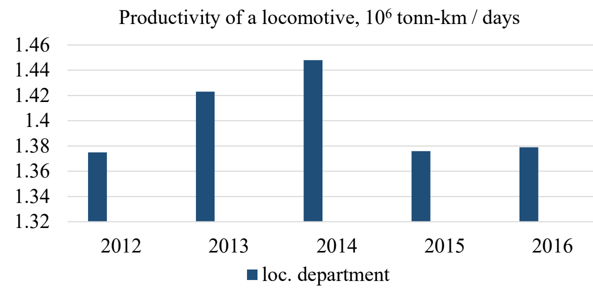

Fig. 3. Average locomotive productivity per day [37]

The reasons for this state of affairs in matters of traffic safety management are:

a) a traditional structural-and-functional analysis and approach to management in the railway transport of Ukraine and countries of Eastern and Central Europe. Such analysis is effective in terms of identification of disadvantages in activities of structural units, but it is ineffective in terms of assessment of traffic safety as a whole;

b) established traditions of analysis and assessment of the state of safety with a period of six months and a year. It is too large gap due to the loss of relevance of a situation;

c) necessity to form a systems approach in company management and management thinking.

5. Justification of the approach to the operative management of technological safety

The theoretical basis of the approach being developed is the method of statistical regularity (hereinafter MSR) developed in the scientific works of co-authors, for example, works [38, 39]. MSR is actually a systems approach based on the principles of self-organization, probability theory, mathematical statistics, and humanistic systems. Application of a probabilistic approach looks natural taking into account the principle of transport risk.

Researchers have increasingly applied the concept of "systems approach" in recent years when they want to emphasize complexity of a task or the composite nature of its solution. However, application of the systems approach basically comes down to rhetoric, terminology, a description of elements of a system and their connections, a declaration of the concept of "dimensionality", and mathematical models with simplified implementation conditions.

The base of MSR is a number of formalized procedures and measurable concepts. It is possible to apply incorporated principles, procedures, models and concepts for management of almost any structure or function of a complex production system [39].

The main provisions of MSR used in the operative safety management approach are:

– it uses data on traffic accidents, failures, faults, delays, i. e. violations of transportation process regulations, which exist in a transport company, as input information. The information refers often to security violation statistics. Such phenomena are investigated and various disadvantages of the transport process are revealed. One doesn't think about the disadvantages of the transportation process until registration of violations of rules. But the phenomena of violations, especially in traffic accidents (catastrophes, accidents, incidents) manifest the systemic nature of transport. Thus, the use of information on violations is a key point of the proposed systems approach;

– a statistical pattern is a trend or a clear tendency in dynamics of statistics of violations, which are indicators of a potential danger of an emergency occurrence;

– the final result of activity of a transport system is an indicator of the level of safety. It is an objective and a backbone factor. Its dynamics serves as a criterion for similarity of normality of the state of a transport system;

– a norm is a stereotyped (statistically generalized) behavior of a transport system. We consider the norm as a range of optimal interaction of a transportation process with the environment in terms of the approach. Construction of the norm occurs with application of methods of mathematical statistics;

– tolerance, as a violation of the transitivity law. Tolerance is considered physically as ambiguity and it is a justification for the norm as a range;

– introduction of the concept of a prerequisite in the analysis of cause-effect relationships of traffic accidents and violations of regulations. A prerequisite is a hidden or fundamental cause, which is located in the field of ensuring of a transportation process. The description of the formula of cause-effect relationships is as follows: prerequisite-cause-event-consequences;

– a bottleneck or risks are the most problematic aspects in ensuring of safety of transportation processes. In addition, bottlenecks are places of maximum expenditure of resources to maintain system stability and security.

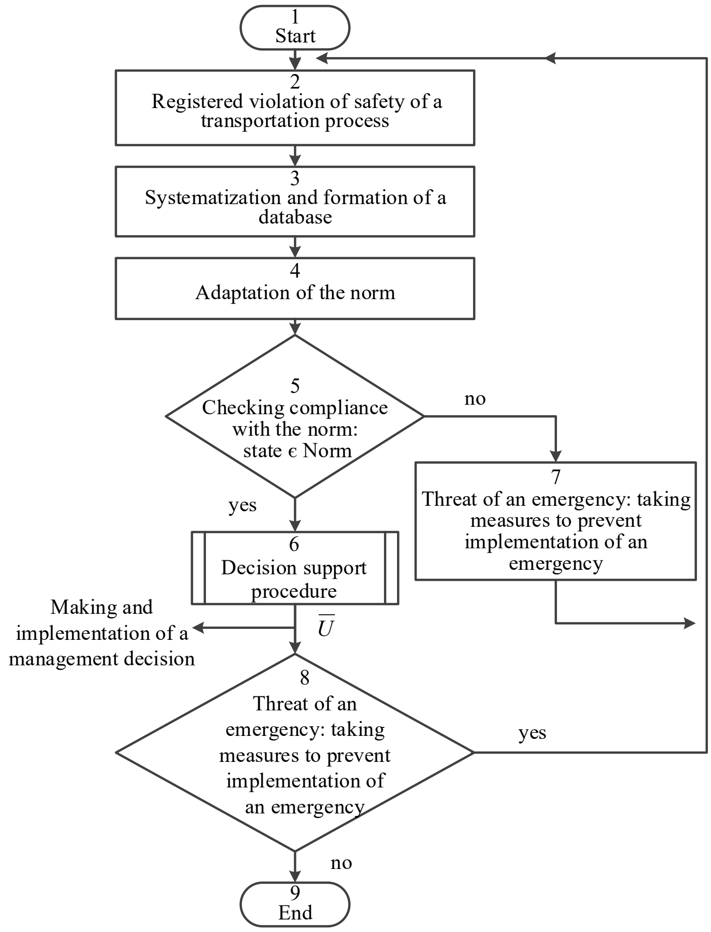

Fig. 4. Enlarged scheme of the algorithm of operative management of technological safety: *state* – a parameter, which characterizes the state of safety; *Norm* – a norm of safety of a transport system; $\overline{U}$ – an option of a management decision

6. Development of the algorithm for managing technological safety in railway transport

We interpret the algorithm in operation from the point of view of management theory as a finite set of precisely defined rules that describe an order of actions to solve a problem.

Fig. 4 shows a generalized (not detailed) scheme of the safety management algorithm. It looks quite traditional at first glance, but its innovation is in a content of the blocks. Let us describe functionality of the presented blocks successively.

Below is a brief description of the main blocks of the algorithm that require explanation.

Block 3. Systematization and formation of a database.

It is necessary to systematize each event of violation of traffic safety. Systematization is a description of each transport event in the form of answers to eight questions, which characterize it quite fully. The questions are: WHAT, WHERE, WHEN, WHY, HOW HAPPENED, WHO is responsible, WHO is damaged, INTENTIONAL/UNINTENTIONAL – motivation. It is possible to get registered answers to questions operative using the control computer.

There is a database formed for each of eight questions of systematization. It is updated after each accident. The deeper the history of a database in time, the more reliable the statistical results are.

There are the dynamics of changes in systematization parameters in time and dependence in a field of two or three parameters constructed, for example, (WHAT-WHERE), (WHO-WHY), (WHAT-WHERE-WHEN). The purpose of the construction is a search for patterns (trends/tendencies) that will help to identify risks of occurrence of emergency situations.

Block 4. Adaptation of the norm.

The term “norm” is key one in the approach. We understand the norm as a statistical stereotype of behavior or a functional optimum of system behavior (*FOpt*) here. One obtains the norm by processing of statistics of violations operative. That is why we speak about adaptation of the norm in real time.

Authors of some studies have earlier described the formation of the norm (for example, [38]).

Block 6. Decision Support Procedure (DS).

The proposed approach to the operative management of traffic safety justifies options of management decisions in the field of safety. Fig. 5 presents the decision-making procedure.

Block 6. 1. Identification of dangerous patterns – bottlenecks.

The bottleneck principle is one of the core principles of MSR. The analysis of the results obtained in 6. 3 block occurs in this block. There are two manifestations of the bottleneck: “maximum outshoot” (Fig. 5) and “negative trend” (Fig. 5) in Block 6. 1, respectively. There can be several bottlenecks.

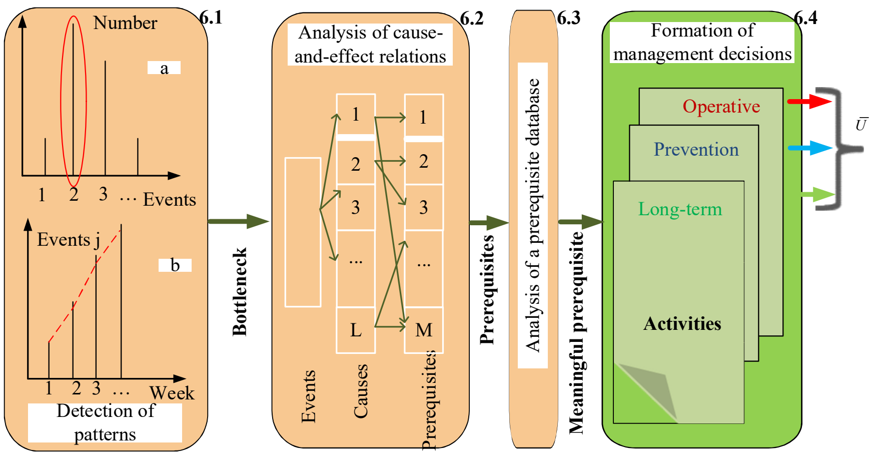

Fig. 5. Sequence of support for making management decision

Block 6. 2. Analysis of cause-and-effect relationships.

The final result of the block is determination of prerequisites of causes (fundamental causes), which lead to transport accidents.

The determination goes in two stages:

1) determination of possible causes of violation of transportation regulations from three component groups of the “man-equipment-environment” ergonomic interaction. These are technological causes, which arose during movement of a train – an unexpected failure of technical equipment of a rolling stock or infrastructure, an error of a driver or dispatcher, unforeseen environmental disasters;

2) determination of prerequisites of possible causes that led to technological causes. The prerequisites are not connected with the process of direct transportation. They consist of four groups: equipment, people, technology, and environment.

Block 6. 3. Analysis of prerequisites.

Detection of negative patterns in prerequisites of causes. They are determined by analogy with block 6.1. As a result, there are meaningful prerequisites of bottlenecks formed. These are risks of an emergency occurrence.

Block 6. 4. Reduction of an impact of risks.

This is formation of management decisions that can reduce or eliminate an impact of meaningful prerequisites. There are three types of management decisions: operational, preventive, and perspective. The specific content of the block is heavily dependent on a particular transportation company.

One should say a few words regarding the “prerequisite” term, which relates to 6. 2 and 6. 3 blocks. There is a similar term, “a prerequisite of an accident” (clause 2 of Appendix V) in a source [25]. It is used as a characteristic of a site where a transport accident occurred. Authors of the paper use the prerequisite term in the sense of a fundamental or underlying reason hidden in the initial investigation of a transport accident. The definition of a prerequisite requires a deeper analysis and the use of a special classifier of prerequisites.

Feedback on 6. 2 block Fig. 4, obviously, makes the proposed algorithm cyclical, and its action is launched in the on-line mode with another case of a violation of safety of a transportation process.

Authors performed the practical implementation of the algorithm of the proposed systematic approach in terms of identification of risks and development of management decisions for the Kyiv Directorate of Transportation of the regional branch of Pivdenno-Zakhidna Zaliznitsya of the “Ukrainian Zaliznitsya” Joint Stock Company in [38], as well as in [39] – for management of the process of acceptation of wheelsets for the railway transport of Ukraine at the Interpipe metallurgical plant.

The article justifies the need for a systems approach for ensuring of traffic safety practically.

It is the first formulation and development of the corresponding algorithm for operative safety management. Previously, there was not such a task, at least in Ukraine, due to its actual impracticability. The authors see their mission in justification of the approach and development of the main stages of actions (algorithm). This is a promising development.

The full implementation of the operative management algorithm will be possible with the implementation of basic 4.0 digital technologies, such as Big Data Analytics, Blockchain and cloud computations.

The development of digitalization in the civilized world shows that this is a matter for near future.

7. Results of the proposed approach to operative management of technological safety

There is an idea of operative technological safety management and forecasting of an emergency occurrence formulated for railway transport. The base of idea is a systems approach due to beginning of the digitalization era. We propose a specific order of actions that lead to formation of a management decision (management algorithm).

A distinctive feature of the proposed approach is a use of the theory of norms and its presentation as a zone of functional optimum in the “transport company – environment” interaction.

The base of the proposed systems approach is a use of information on violations in a transportation process (statistics of safety violations). A security level control parameter and a safety norm form as a functional optimum according to the statistics of violations. It is an interval of a change of control parameters with changing boundaries under condition of stable operation. This distinguishes it from established practice and other approaches, where norms are defined in the form of fixed or boundary indicators and focus on maintenance norms. The proposed approach uses the existing documentary and statistical base of a company. It does not imply introduction of new performance indicators for a transport company, which will make introduction of the safety management algorithm easier.

8. Discussion of results from the development of an approach to operative technological safety management

Transport is a set of interconnected structures, departments, divisions of a transport company itself, its partners and contractors. They are components and subsystems of an integral interconnected system. The operative management algorithm (Fig. 4) gives a possibility to identify systemic problem areas in ensuring of technological safety. Further ensuring of safety becomes transparent to management in terms of financing and staff actions. Such an approach should reduce an impact or eliminate bottlenecks – prerequisites for causes of transport accidents.

The management algorithm formalizes the process of support of management decision-making in the field of safety. The implementation of the algorithm presented in Section 6 with the use of 4.0 digital technologies (Big Data Analytics, Blockchain, cloud calculation, and possibly others) eliminates a need to form a large number of headquarters and working groups in the field of technological safety. That is, it will reduce an impact of the human factor.

It is important to use the established practice of document management and performance indicators maximally for the successful implementation of the developed approach, because these indicators are habitually used by most of the company's staff. It is very difficult to retrain everyone. This is critical for large organizations, which include rail transport.

Each organization and structural unit have its own activity features. Organizations, even similar ones, differ from each other in natural conditions, mentality of people, technical means, and other characteristics. Each organization has its own norm of behavior. Therefore, we should not compare one organization with another, even if they are similar functionally. It is important to summarize activities of each organization at different time intervals (to build trends) and set objectives differentially to ensure the required level of safety. This will make possible to use a norm as a functional optimum. It is possible to calculate an individual norm for the divisions of a transport company.

The article lacks specific digitalization technologies that will make enable the implementation of operative security management algorithm. This is the prospect for the future research.

9. Conclusions

1. The traditional analysis of the state of railway traffic safety is a classic structural-and-functional approach. The result is identification of causes of transport accidents in individual departments, but not in a transport company as a system. A decrease in the frequency of manifestation of the causes in future will lead to improved indicators in a department, but not necessarily in system indicators. As a result, funding for safety programs is proportional. Obviously, we need an approach to ensure and manage safety of transportations that considers transport as a system.

2. We propose a systems approach to the management of technological safety. It differs from existing approaches by the use of statistics on safety violations as input information, safety norms, and the principle of tolerance for perception of a transportation process. The maximum use of management features is characteristic in a transport company. Application of the approach makes possible to focus management's attention and material and financial resources on systemic problems, which will improve the system performance of transport.

3. There is the algorithm for the operative management of technological safety on the example of railway transport developed. Its feature is the use of information on violations of a transportation process in a transport company. The algorithm operates on-line and makes changes in a system of technological safety management after each registered case of technological safety violation. The algorithm will automate the process of investigation and analysis of transport accidents in the context of digitalization. It will reduce the human factor impact in all phases of safety management.

4. Application of the proposed approach for making management decisions will give possibility to assess failures in a transportation process systematically, to consider violations as a manifestation of a transport risk and to move from the concept of a search for a guilty party to the concept of identification and reduction of an impact of risks in a transportation process.

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IMPROVEMENT OF THE ANTI-COLLISION METHOD "VELOCITY OBSTACLE" BY TAKING INTO CONSIDERATION THE DYNAMICS OF AN OPERATING VESSEL

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Пропонується алгоритм урахування динаміки судна, що оперує, для методу попередження зіткнень «Velocity Obstacle». Цей алгоритм забезпечує основу для вибору спільних маневрів курсом і швидкістю із заданим початком для розходження з декількома «цілями» шляхом визначення методом перебору представницької множини допустимих варіантів маневру. Для застосування методу перебору виділяються діапазони зміни параметрів маневру (курсу і швидкості) і проводиться їх дискретизація з досить малим кроком. Для всіх пар дискретних значень зміни курсу і швидкості з урахуванням динаміки судна знаходиться траєкторія і тривалість маневру з визначенням на момент його закінчення місця судна і «цілей», а також встановлюється, чи буде він супроводжуватися перетином доменів небезпеки «цілей». Якщо немає пересічення жодного з таких доменів, то варіант маневру вважається допустимим. Отримана при переборі сукупність таких спільних змін курсу і швидкості утворює множину допустимих варіантів маневру. При знаходженні цієї множини динаміка судна враховується спрощено. Вважається, що повороти виконуються з постійною кутовою швидкістю, зміну лінійної швидкості при гальмуванні можна представити степеневим поліномом другого порядку, а зміни курсу і швидкості в спільному маневрі незалежні. У «цілей» використовуються кругові домени небезпеки, центр яких зміщений від центру маси «цілі» в бік носа на 1/3 частину радіуса домену. В цей радіус внесена поправка на розміри «цілі» і судна, що оперує.

Для перевірки отриманого алгоритму була складена програма на мові «Borland Delphi». Розрахунки по ній підтвердили працездатність алгоритму. Він дозволяє в реальному часі знаходити множину векторів швидкостей для розходження з урахуванням динаміки судна, що дозволяє підвищити точність прогнозу і безпеку маневрів. Використання у «цілей» зміщених, кругових доменів небезпеки дає можливість враховувати неоднакову ступінь ризику при пересіченні їх курсу по носі і по кормі

Ключові слова: попередження зіткнень, метод перебору, множина допустимих варіантів, алгоритм урахування динаміки

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1. Introduction

Among the components of scientific and technological progress at present is the development and introduction of unmanned vehicles, including autonomous marine vessels (ASV). To be operational on sea routes, such a vessel must be equipped with a collision avoidance system (CAS) responsible for divergence from other vessels in accordance with International Rules for Preventing Collisions at Sea-72. This task is complex, as the proper level of safety has not yet been achieved even for conventional, not autonomous, vessels. About 150 large ships collide in the world each year, about 3 of them sink. Technical losses from collisions are enormous. Among the measures taken to reduce the number of such accidents, the following are worth mentioning. The International Rules for Preventing Collisions at Sea (COLREG) have been introduced, which are mandatory for all ships of varying affiliation. In coastal areas of heavy navigation, they have been tightened by national requirements. Vessels are equipped with powerful integrated bridge systems that