https://doi.org/10.33271/nvngu/2024-5/099

Z. Matsuk[*1],
orcid.org/0000-0001-6114-9536,
A. Belikov[1],
orcid.org/0000-0001-5822-9682,
V. Protsiv[2],
orcid.org/0000-0002-2269-4993,
V. Severyn[1],
orcid.org/0009-0002-4387-6494,
V. Kharchenko[1],
orcid.org/0000-0002-7653-3001

1 – Ukrainian State University of Science and Technologies, SEI "Pridneprovsk State Academy of Civil Engineering and Architecture", Dnipro, Ukraine
2 – TAFE NSW (Technical and Further Education New South Wales) Liverpool College, Sydney, Australia
[*] Corresponding author e-mail: matsuk.z.n@gmail.com

ADEQUACY OF MEASURES TO THREATS AS ONE OF THE FUNDAMENTAL PRINCIPLES OF SAFETY RISKOLOGY

Purpose. To justify the need to apply the "principle of adequacy of probabilities" as a measure to improve the risk management methodology, to prevent (counteract) existing and emerging risks (threats) to the security of complex systems.

Methodology. The well-known methodological principle called "Ockam's Razor" was used. In the course of the research, a complex method was used, which included formal and logical analysis of normative and scientific and technical literature, analysis of statistical data, synthesis, abstraction, experiment, observation, generalization of data, description.

Findings. In the course of the research, one of the threats (danger, risk) was identified, which simultaneously affects the existence of such a system due to traffic safety of rolling stock of rail transport enterprises, and the full implementation of the system's capabilities due to axle loads, mass and speed movement of rolling stock, level of operating costs, passenger flow, regularity of transportation, etc. Experimental application of the lubricant "Mariol NT" in SPP 12-5, GS-3 lubrication systems showed a decrease in wear intensity by 240 %. Due to the use of a new lubricating material applied to the friction surface of wheel rims as part of the paint coating, the wear intensity of flanges of twin-wheel rims is reduced by 2.2 times, and that of locomotives by 2.4 times.

Originality. It was determined that the "principle of adequacy of probabilities" as a measure of improvement of the risk management methodology, prevention (counteraction) of existing and prospective risks (threats, dangers) during the safety assessment of complex systems is currently not applied, but its consideration helps to prevent (countermeasures) to existing and emerging risks (threats) to the safety of complex systems.

Practical value. The use of the "principle of adequacy of probabilities" allows for the theoretical and experimental determination of the numerical value of the ratio between the probability of an event occurring, caused by the action of an identified threat that negatively affects the state (level) of safety and operability of system elements at all stages of its existence, and the probability of a positively compensatory effect of the developed countermeasure to the identified threat.

Keywords: *rolling stock, lubricant, safety, risk, threat, probability*

Introduction. The first attempts of risk management were mentioned in scientific literature in the early twenties of the twentieth century. It was in economics. Thus, a risk theory started to form. Afterwards, in the system of international standardization, the concept of "risk" was introduced as an ambiguity of achieving a goal [1, 2].

By the beginning of the twenty-first century, the term "probability" appeared in the international terminology of risk management. This term means the possibility of something occurring in a specified period of time, regardless of whether this possibility is measured or defined and described. At the same time, the concept of "probability" is revealed in the theory of risk as a measure of the possibility of an event occurring, given by a number.

On the basis thereof, in 2001, the concept of "risk" as the probability of the occurrence of any dangerous event during a certain period or under certain circumstances was introduced in Ukraine at the legislative level.

More recently, risk management, through calculating it and setting the level of impact, began to be considered as part of the process of creating or using machines or units, but it has still not been considered under the aspect of determining the adequacy of the probability of occurrence of threats and taking into account the actual positive and compensatory impact of countermeasures.

That is exactly why solving issues of security and safety risk management, taking into account the principle of adequacy of probabilities, is an urgent problem.

Literature review and unsolved aspects of the problem. It is known that any activity is largely associated with uncertainty, that is, limited information about possible future events and their consequences, or risk, which is generally understood as the consequence of the impact of uncertainty on the goal to be achieved [3, 4].

The result of the action of the risk is a total failure to achieve results or partial achievement of the expected results of the activity, achievement of results untimely or with the accompanying overspending of resources; non-achievement of the target goal, which is accompanied by a loss, therefore the task of solving the issue of risk management, including the risk of man-made safety, through its careful study.

Safety riskology is becoming an important aspect of the modern world, especially in the context of wars, features of technological development, growing threats of technogenic accidents and disasters [4, 5].

The concepts of "safety"/"unsafety" are relative, they exist only where in the system of relationships there is such an "element" as a person who, for example, cannot cope with the emergency braking of a vehicle until it comes to a complete stop, because he/she uses a brake that was not intended for this [6]. It is known that a person is simultaneously the main source of dangers, the primary "source" of reducing their level and the main object of regard [7, 8].

The issue of safety and its provision as a whole is solved in a closed system: "... → person → experience → critical-intuitive thinking → decision-making → evaluation of the result → experience → person →..." [9, 10]. At the current level, this system represents a more extended set of elements: "... → person → experience → critical-intuitive thinking (risk-oriented approach, science, education, vocational training, knowledge assessment) → decision-making (personnel decision, management decision, risk-oriented methodology) → evaluation of the result (risk-oriented methodology, monitoring of the effectiveness of the decisions made) → experience (accumulation and systematization of data) → person →...". The inadequacy of any element of such a system to existing and predicted threats (dangers, risks) irreversibly leads to the diminution of safety [11, 12].

For the moment, the state risk-oriented approach in the field of civil protection (technological safety) in Ukraine still has a conceptual nature, which is declared by the Concept of managing emergency risks of technological and natural character [13, 14].

On the one hand, the Civil Protection Code of Ukraine (5403-17), Article 422, declares that emergency and fire risk management is carried out through risk analysis, risk assessments, and determination and realization (implementation) of measures aimed at reducing risks to an acceptable level, minimization of possible consequences. Moreover, it is declared that the procedure for managing the risks of technogenic emergency situations and fires, and the method of their assessment are approved by the central executive body, which ensures the formation of state policy in the field of civil protection. In Ukraine, this is the responsibility of the Ministry of Internal Affairs.

On the other hand, the Civil Protection Code of Ukraine (5403-17), Article 421, does not provide for the use of a risk-oriented approach as a method (mean) of state regulation during emergency forecasting.

Thereby, the legislator declares that:

- risk analysis is the systematic use of information to determine sources of danger and quantitative risk assessment;
- risk management is the process of making decisions and implementing measures aimed at reducing risks and minimizing possible losses (damages);
- risk assessment is carried out on the basis of the results of the risk analysis, the calculated value of the risk level, and the relevant decisions of the risk management entity;
- assessment of risks, among other things, is carried out taking into account the ranking of risks (comparison of risks by their magnitude, probability of occurrence, consequences);
- the main tasks during risk management are the following: creation of management mechanisms that ensure effective risk management; identification of threats and possible negative consequences, assessment of the opportunities of their prevention or minimization; development and assessment of measures to minimize losses (damages) in the event of man-made emergencies and fires; determining the expediency of introducing preventive (proactive) measures depending on the costs of their implementation in relation to the amount of possible losses (damages) taking into account insurance costs; determination of necessary resources to minimize risks, their correct distribution; development and implementation of a set of preventive (proactive) measures aimed at reducing the level of risks to an acceptable value and minimizing possible losses (damages); monitoring and analysis of the effectiveness of measures of risk management plans and their periodic updating;
- the terminological apparatus of the risk-oriented approach in Ukraine and other countries is established, including, in accordance with ISO Guide 73:2013, IDT;
- the legislator declares that during the risk assessment, it is possible to use one or more methods specified in EN IEC 31010:2019.

At the same time, the Code of Civil Protection of Ukraine (5403-17) and other normative documents of Ukraine establish neither the procedure for conducting an analysis of the causes of risk, nor the procedure for conducting an analysis of the risk itself, nor the procedure for the development, implementation (execution), and evaluation of measures (including preventive ones), which are aimed at reducing risks to an acceptable level.

At the same time, the legislator does not provide a transparent justification why certain levels of risk are considered acceptable or unacceptable.

In the end, the legislator allows the determination and forecasting of the level of risk of adverse technogenic events without comparing the level of risk and the level of positive compensatory impact of safety measures, as favorable events in the past, in the present, and in the future.

Since 2002, the Methodology for determining risks and their acceptable levels for declaring the safety of high-risk objects (v0637203-02) has been the only document in the regulatory field of Ukraine that contains instructions on the study of danger and quantitative assessment of the risk of technogenic accidents. Moreover, it is interesting that it is placed on the page of the Law of Ukraine "On objects of increased danger" (2245-14) of the website of the Verkhovna Rada of Ukraine in interconnected documents, but there are no references to it in the Law itself.

Purpose. The purpose of the study is to justify the need to apply the "principle of adequacy of probabilities" as a measure to improve the risk management methodology and to prevent (counteract) existing and promising risks (threats) to the safety of complex systems. According to the "principle of adequacy of probabilities", safety measures must be adequate and proportional to threats, correspond to their nature and scale, taking into account the actual and predicted probability of their positive compensatory impact and possible consequences. This will provide an opportunity to improve the risk management methodology. Practically, this will contribute to the process of more qualitative risk assessment using the new parameter, as well as the regulation and development of the concept of acceptable risk.

In order to achieve the goal, the following tasks were defined as those that must be performed:

- to conduct the grounding of the application of methodological approaches, taking into account the principle of adequacy of probabilities during the management of safety risks in various spheres of life;
- to conduct a study of the cause-and-effect relationships of risk events affecting the safety of rolling stock of rail transport at the fundamental level;
- on the ground that the principle of adequacy of the probability of the threats' occurrence, the probability of the actual positive compensatory impact of safety measures, to develop and take countermeasures against the identified threat to the safety of rail traffic, to check the effectiveness of the developed measures;
- to calculate the expected economic effect of the improved method for managing the safety of complex systems on the example of real operation of the traction rolling stock of rail transport enterprises.

The object of the study is the safety risk management process. The main hypothesis of the study is that the failure to take into account during risk management and establishing the system safety level such a parameter as the probability of a positive compensatory effect of countermeasures against threats (dangers) can lead to a biased assessment of both the level of safety of the system as a whole and the level security of its elements, in particular, which can lead to the degradation of the system under consideration.

At the present time, the methodology is generally chosen according to which risk management is carried out by comparing the level of risk with the subsequent selection of decisions to reduce it [15, 16]. An interesting fact is that this technique is built only on the principles of summing up and comparing the levels of risks of individual objects of regard, and also does not take into account the impact on the system of safety measures and for some reason allows for the purpose of determining the level of risk at all stages of its analysis to apply any methods known in scientific and technical, reference, regulatory and methodical literature applied for calculation and assessment of hazards, consequences and risk for objects of "regard", provided that their application is substantiated.

It is clear that, along with the fact that this technique is a progressive step towards technological safety, on the contrary, it cannot be called the one that ensures proper accuracy, correctness and repeatability of calculations.

Summarizing all above-mentioned information, it should be added that there is no requirement for business entities from the state to apply a risk-oriented approach in the field of civil protection (technogenic safety), as of now, it does not exist in the legislative field, and, accordingly, there is no responsibility, in other words, there is no controlled process. It proves that risk management is not carried out.

Thus, the risk management system is in a state of internal uncertainty (vacuum), not being able to rely on a single state policy, not having a workable risk-methodology ("mechanism") of decision-making, the system risks not having a chance to develop and implement adequate measures to counter internal and external threats when it moves to the final cycle of its existence. The highlighted problems concern both Ukraine and most other countries of the world that are at the stage of development.

Due to the slow rate of development of the global risk management policy and the lack of general regulation in this area, individual risk management policies of large domestic and non-domestic companies (for example, Ukrzaliznytsia Joint Stock Company) [17] are formed on the basis of harmonized (DSTU ISO 31000:2018), and non-harmonized [18, 19] international standards [20, 21]. Such standards are mostly declarative in nature, do not take into account the regulatory differences of countries and regional cultural features, have almost no sectoral (target) direction, or, on the contrary, take into account only the specific characteristics and moderate needs of various markets of individual industries [22, 23].

Thus, state bodies and business entities – operators of high-risk facilities or critical infrastructure facilities of Ukraine face risk management problems alone.

Having neither a scientific, normative (with a clear mechanism), nor a methodological (at all levels) easy-to-apply basis for a risk-oriented approach to security issues, having no trained management personnel, etc., entire corporations are forced to make ill-considered management decisions that are inadequate to the existing and predicted threats.

It was established that in Ukraine, and not only, during risk management (at all levels), such a parameter as the probability of a positive compensatory impact of measures to counter threats (dangers) is not taken into account, that is, risk assessment at all stages of the life cycle of complex systems is carried out without taking into account the need to check the adequacy of the measures used to existing threats, which leads to the gradual degradation of such systems.

Thus, the current scientific problem is determined by the need to improve the methodology of risk management at all levels of management of complex social and industrial systems by applying the principle of adequacy of the probability of the occurrence of threats to the actual positive-compensatory impact of measures to counter them.

These questions are related to the study of vulnerabilities, dangers, and threats, the choice of methods (criteria) for risk assessment, analysis of the causes of risk, the procedure for conducting risk analysis, the procedure for development, implementation (execution), and the evaluation of measures (including preventive measures) aimed at reducing risks to an acceptable level.

Description of the research procedure. During the research, a well-known methodological principle called "Ockam's Razor" was used as a simplification method. Assumptions for study management are as follows:

- the combined score of system safety is a function of the hyperbolic tangent of the product of the ratios (balance) between the values of the probability of occurrence of events caused by the action of external and internal factors and/or conditions (hereinafter referred to as threats) that may negatively affect the state (level) of security and operability of system elements at all stages of the system's existence. Moreover, they take into account all the needs of the system, and the value of the probability of a positive compensatory effect of appropriate measures to counter the specified threats, within the limits of modern professional concepts, knowledge, ideas and factors and/or other conditions characterizing the actual state of system protection against the action of the specified threats [24, 25];
- at the stage of development (formulation of the terminological apparatus) of the risk management methodology of complex systems, threats (dangers, risks) that threaten the fundamental basis of the existence of such systems, and threats (dangers, risks) that negatively affect the achievement of the goal of the existence of such systems (complete implementation system capabilities);
- relative safety of the system is the state of existence (functioning) of the system, which is characterized by the fact that countermeasures against threats compensate for them in such a way and to such an extent that the system remains capable of achieving the purpose of its existence, taking into account the absence of absolute security as such (as a phenomenon);
- measures of positive compensatory impact are actions, procedures, adjustments and their combinations aimed at reducing risks to an acceptable level, the probability of positive compensatory impact of which is proven in the prescribed manner and expressed in numbers;
- any, even insignificant, threat (danger) in an infinite perspective, without the use of countermeasures (compensation), will be inevitably realized.

In the course of the study, a complex method was used which included a formal and logical analysis of normative, scientific and technical literature, analysis of statistical data, synthesis, abstraction, experiment, observation, generalization of data, description.

Results. For the study there were chosen branches of industry where it is possible to conduct field tests, the purpose of which was to check the correctness of the assumptions, as well as the efficiency of the selected research methodology. The authors assumed that at the stage of developing the risk management methodology of complex systems, threats (dangers, risks) that threaten the fundamental basis of the existence of such systems, and threats (dangers, risks) that negatively affect the achievement of the goal should be considered firstly the existence of such systems (complete implementation of system capabilities).

The transport industry was chosen for the study, namely objects of rail transport (traction rolling stock), and specifically, the "wheel-rail" friction pair as the fundamental basis of rail motion, which is an element of the "locomotive (tramcar) – rail" system.

As part of the study, during the analysis of statistical data of selected enterprises, one of the threats (danger, risk) was identified, which simultaneously affects the existence of such a system due to traffic safety, and the full implementation of the system's capabilities due to the load on the wheel (axle), mass and speed of movement of rolling stock, level of operating costs, passenger flow, regularity of transportation, etc.

The next step was the development of operational test methods, their coordination (approval) at the level of the administration of rail transport enterprises. The following statements became the basic principles (conditions) of the methods (tests):

- tests must be carried out in the mode of real operation, without stopping the traction rolling stock, without making changes to the construction of traction rolling stock objects, without changes in the set of regulatory works and technological operations of the industry, the same operating conditions of test objects and control objects;
- the accuracy of the measurement of indicators, the instrument base, methods for recording and saving data must be standard for the field of testing, and meet the requirements of industry standards.

Research and testing were practical and did not require the use of special or unique software. The comparison of the obtained results was carried out according to the same indicators, both between the test objects and the comparison objects in the same time interval, and between the test objects (comparison) and the array of statistical data in the railway depot (tram traffic route).

The statistical analysis of the data of the experiment (tests) in the conditions of tram traffic was carried out taking into account the following restrictions:

- tests are carried out on tramcars not equipped with onboard flange lubrication systems, on which the technology of tire repair by surfacing was applied (not applied);
- the intensity value of the sharpening of flange of tramcar wheels is to be compared, expressed in terms of decreasing rate in the thickness of the flange in relation to the distance of the car-mileage (mm/thousand km);
- car-mileage of comparison and test cars must be at least 10,000 km;
- actual deterioration of rim of wheel tread is compared on the first and third wheel pairs of tram cars;
- comparison interval in the range of climatic seasons of the year “autumn-winter” is scheduled;
- for comparison, the rolling stock with a similar condition of wheel tires of wheel pairs within the pre-selected route is chosen.

The statistical analysis of the data of the experiment (tests), in the conditions of freight movement of locomotives, was carried out taking into account the following restrictions:

- tests are carried out on locomotives equipped with onboard lubrication systems SPP 12-5, GS-3, which are intended for direct and indirect lubrication of the ridges of the wheel flanges of rolling stock, the wheel treads of which did not use plasma strengthening technology;
- the intensity value of the sharpening of flange of tramcar wheels is to be compared, expressed in terms of decreasing rate in the thickness of the flange in relation to the distance of the car-mileage (mm/thousand km);
- the wearout rate of wheel flanges is compared on all wheel pairs of locomotives;
- comparison interval – at each TO-2 with subsequent generalization.

The data obtained during the tests were processed by the members of the test committee. At this stage, unreliable data, as well as those related to other inconsistencies unrelated to the investigated processes, were detected. In the course of work, the commissions analyzed information from current test reports and compared records from test logs.

The risk reduction of the effect of various factors was carried out as follows:

1) measurements are carried out by one type of measuring equipment;

2) tests are carried out according to the same scheme;

3) indicators of effectiveness of measures are brought to similar conditions of cargo (passenger) traffic;

4) tests are carried out on tramcars not equipped with onboard flange lubrication systems, on which the technology of tire repair by welding was applied (not applied) – on three cars where safety measures were applied and three where safety measures were not applied. The tests are carried out in the conditions of route No. 11 in the city of Dnipro. According to the characteristics of the longitudinal and transverse profile of the route, the route belongs to tracks with “difficult traffic conditions”;

5) tests are carried out on three locomotives equipped with on-board lubricators – one locomotive for each test depot, and, accordingly, on three locomotives not equipped with onboard lubricators – one locomotive for each depot of test locomotives operating under similar freight traffic conditions. The tests were carried out on the tracks of the Dnipro, Odesa and Pivdenna railways.

Confirmation of the effectiveness of the developed safety measures was the established fact of their positive compensatory effect on the identified threats (dangers, risks) taking into account the cost of their implementation.

It is known that the process of interaction between the wheel and the rail is the physical (fundamental) basis of rail motion, this is it that largely determines the safety of rail traffic. Moreover, the requirements for the indicators of the interaction of wheels and rails in different contact zones are diametrically opposed.

Either the grip of wheels with the rails should be such as to provide low resistance to movement, or in order to realize the traction force, it is necessary to ensure a high (stable) level of grip of wheels to the rails.

It is known that a railway (tram) wheel has two friction surfaces with a radial transition between them. The first is the rolling surface, where the friction force of the tire and the rail head should be as large as possible and as stable as possible, because the degree of implementation of traction forces and the braking distance depend on it, that is, the efficiency and safety of the rolling stock. The second is the tapered surface of the rib (flange).

The flange, in its turn, contacts the side surface of the rail head, forming a pair of frictions that keep the rolling stock from rolling out of the wheels onto the rail head (from the track) with a significant amount of transverse force during movement on curved sections of the track (Fig. 1).

During the single-point contact of the rail and the wheel (Fig. 1, *a*), the reaction of the rack F_R at point C is decom-

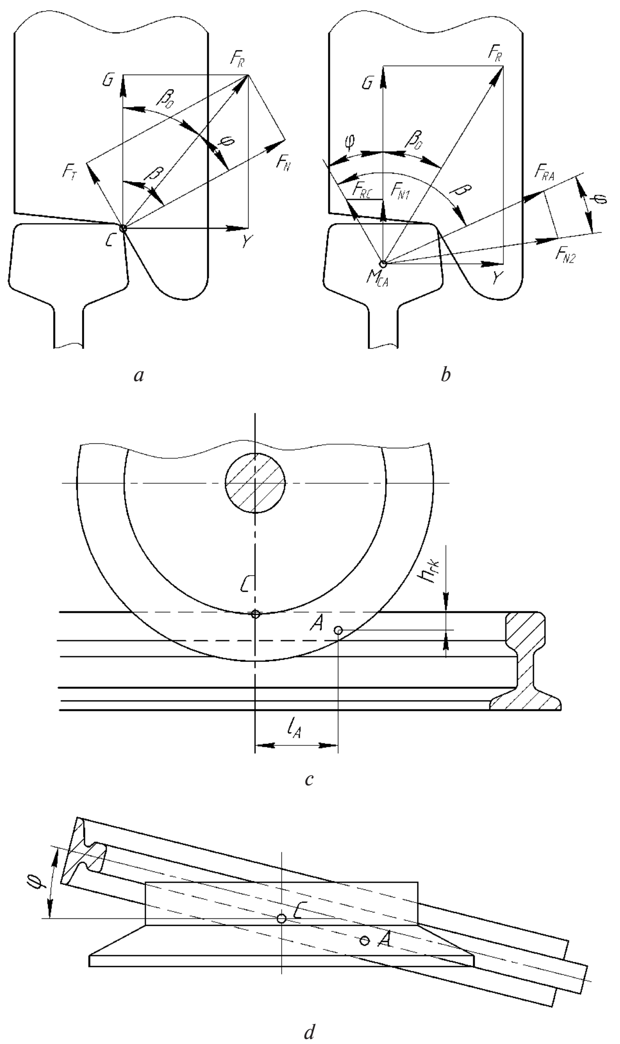


Fig. 1. Interaction of the wheel flange with the rail head on the curved wheel track:

a – section, single-point contact; b – section, two-point contact; c – side view; d – top view posed into vertical G and horizontal Y forces, or tangential F_T and normal to the point of contact F_N. In the case of the two-point contact (Figs. 1, *b, c* and *d*), point A is added to the main point of contact of the rail with the tread of the wheel tread C, which is the point of contact of the wheel flange with the inner side surface of the rail. It is located below the head of the rail at a distance of h_{rk} and precedes the first main point of contact in the direction of movement of the locomotive by the size of the flange run l_A. In this case, brought to the conventional center of gravity of the rail head (M_{CA} point), the forces of interaction of both points of contact between the wheel and the rail are decomposed into reactions (Fig. 1, *b*), where forces from the main point F_{RC} with its vertical component F_{N1} additionally appear, as well as from touching the rail with the flange at point A, marked as F_{RA} and its normal component F_{N2}.

The β_0 angle is the constructive angle of the appendage of the flange, and the φ angle is determined by the point of contact of the wheel flange and the rail head, that is, it depends on the radius of curvature of the rail track at the turn of the track.

At a defined (significant) value of horizontal force Y in the case of the two-point contact, the wheel can rise and roll with a flange not only on the side face of the rail head, but also on its rolling surface. In this case, it is possible for the wheel flange to crawl over the rail, which leads to the locomotive derailing.

The analysis of the processes of rail movement and wear of parts of the "wheel-rail" friction pair with the determination of characteristic types of wear shows that in the area of frictional contact, under the influence of load-speed, mechanical, temperature, dynamic, cyclic, corrosive and abrasive influences, specific tribo-physicochemical phenomena (processes) occur, resulting in wear and damage of contact surfaces.

For example, operation in extreme conditions is typical for tribocontact "wheel flange- rail" of railway transport. Some of them are as follows:

- contact pressure from 2.5 GPa to more than 3 GPa;
- the temperature at the point of contact is approximately 1,000 °C;
- sliding speed from 0.1 to 3.0 m/s.

In the course of the research, it was established that the wear of the wheel flange (rim) prevails over the tire tread rolling wear, since the pressure of the wheel flange on the rail at the moment of fitting into the curve sometimes exceeds the pressure of the wheel tire on the rolling surface of the rail many times over. And considering the fact that the contact area of the flange with the rail is at least massively smaller than the contact area of the heel of the wheel track with the rail, under otherwise equal conditions, the specific load on it is greater, and the sliding speed is much higher. It is because of the above that, in the general case, the wear of the flanges of the wheels of the railway rolling stock prevails over the wear of the tires themselves, and, accordingly, that is why it limits both the resource of the tire and the resource of the wheel pair as a whole.

With regard to the movement of tramcars, the physical processes in the "wheel flange-rail" pair are generally similar to railway movement, and the characteristic differences are lower axle loads and lower speeds.

That means that the wear of the flanges (ribs) of the wheel tread of the traction rolling stock of rail transport affects both the safety of traffic due to reliability and the achievement of the purpose of the system's existence, due to its level of safety.

Accordingly, the high intensity of the processes of wear of the flanges (ribs) of wheel treads is a safety threat both for the elements of the rail rolling stock system separately and for the system itself as a whole.

The analysis of risks during the operation of main line locomotives was carried out using previous studies by the authors [26, 27]. It has been established that the measures of positive compensatory effect of counteracting the threat of high intensity of the processes of wear of flanges (ribs) of wheel treads and measures to increase the level of safety of traction rolling stock of rail transport enterprises can be served by effective technological solutions aimed at reducing (changing the application vector) the force of friction between the wheel flange and the rail head.

Comparative tests of domestic and foreign lubricants for flange lubrication on JSC "Ukrzaliznytsia" locomotives, which are equipped with on-board lubrication systems for the wheel flanges of wheel pairs of domestic production (SPP 12-5), were also analyzed.

Agrinol Relsol M (TU U 23.2-30802090-055:2006) and Puma-M lubricant (TU U 23.2-30802090-075:2007) were used as lubricating oils for these lubricators.

The maximum proven anti-wear effect from the use of the specified lubricants according to the protocol of the meeting of the STG section of State Administration of the Railroad Transport of Ukraine "Ukrzaliznytsia" dated 1804.2012 for No. 3/6 is, respectively, for "Agrinol Relsol M" lubricant on locomotive VL 10 No. 1479 – 9.59 %.

For "Puma-M" lubricant on locomotive VL 10 No. 1477 – 10.26 %. The obtained results show that the lubricating material [26] Mariol NT TU U 23.2-31709624-002:2009 (Amendment 4, 2020) demonstrated significantly higher efficiency. The experimental application of the lubricant "Mariol NT" in the SPP 12-5 and GS-3 lubrication systems, according to the protocol of the meeting of the STG section of JSC "Ukrzaliznytsia" dated May 31, 2021 under No. CCTech-01/19, showed a 240 % reduction in wear rate. According to the test report, the maximum recorded antiwear effect from the use of the specified lubricant was recorded at the regional branch "Pivdenna Railway" (Kupiansk DEPO, the city of Kupiansk) in the GS-3 lubrication system on the VL 82 m locomotive No. 060. It was equal to 532 %, which is more than two times higher than that of the nearest known analogue of Relsol (Patent of Ukraine UA 39352).

The tramway cars of the Communal Enterprise "Dniprovskyi Electrotransport" of the Dnipro City Council are not equipped with onboard lubrication systems of flanges of wheel pairs. For technical reasons, the enterprise does not use any greasing as a lubricant for the contact surfaces of the "wheel-rail" friction pair or any other anti-friction measures in this direction. Considering the fact that during the contact of the friction surfaces of the wheel and the rail in the place of contact, a very high temperature operates on the lubricant (albeit cyclically and momentarily, but necessarily), this leads to an instant degradation of the lubricating ability of the lubricator, therefore the basic specialized lubricating material Mariol TU U 23.2-31709624-002:2009 was supplemented with heat-resistant solid lubricant fillers according to TU U 20.5-42277844-001:2019, which were specially developed for this purpose. The obtained lubricant was applied to the friction surface of the wheel treads as part of the lacquer coating (Fig. 2). The test results are shown in the table.

Consequently, on average, due to the use of a new lubricating material applied to the friction surface of the wheel treads as part of the lacquer coating, the wear intensity of the wheel flange of the tram wheels is reduced by 2.2 times.

The probability of no-failure operation is generally defined as $P(t) = P1(t) \cdot P2(t) \cdot \ldots \cdot Pn(t)$, where $P1(t)$, $P2(t)$, $Pn(t)$ are the probabilities of no-failure operation of individual elements of a car. In its turn, the probability of no-failure operation of a single wheel (or a pair of wheels for rail transport) is the product of coefficients that indicate the reliability of individual elements of this wheel. Among them, there is one that is responsible for the failure of a machine (a locomotive or a tram) as a whole due to the creeping of the running wheel flange on the rail.

Due to the use of lubricants, the reduction of flange wear per unit of time (or per unit of locomotive mileage) increases the value of the corresponding probability coefficient of no-failure operation and reduces the risk of traffic safety threats and, in fact, is a measure of positive compensatory influence.

But it should be understood that the wheel treads of rail transport always have a certain residual (unused) average statistical resource reserve at the time of their next maintenance in order to avoid failure – the malfunction of individual wheels even before the time for such maintenance.

This resource should be in the range of 30 to 40 %. This means that a slight increase in the life of the wheel flanges due to the use of lubricants (as well as other measures) by 10 or 20 % will not give a tangible result, the wheel will still be sent for regrinding of the flange (and, possibly, for additional welding of the metal). That is, only a significant increase in the resource (we denote it as the resource increase factor k_i) by more than 35 %, when the k_i exceeds the value of 1.65 will allow one not to carry out (skip) regular maintenance of the wheels.

Then the new value of the probability of no-failure operation of the wheel flange (i indicator) in comparison with the previous value can be approximately calculated using the hyperbolic tangent function as

$$k_i \geq 1.65, \quad p_{in} = p_i^{th}(p_i k_i).$$

For example, increasing the resource of the wheel flange of a locomotive or tram by two times ($k_i = 2$) will increase the value of the probability of no-failure operation of the wheel flange from 0.9000 to 0.9468.

The changed value of the probability of no-failure operation of the wheel flange after using the lubricating material applied to the friction surface of the wheel treads as part of the lacquer coating can be accurately calculated based on the results of additional experimental studies.

Table

Test results of the lubricating material applied to the friction surface of the wheel flanges as part of the lacquer coating

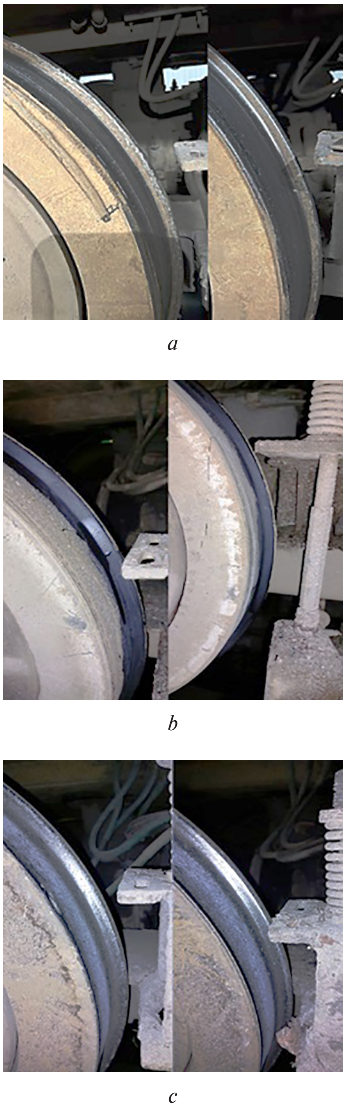
Types of comparison	Intensity of flange wear, mm/1 thousand km		Intensity of flange wear, mm/1 thousand km	
	wheel pair No. 1		wheel pair No. 3	
	1 (right)	4 (left)	5 (right)	8 (left)
2023–2024 – for repair rims of wheel pairs, test wagons/comparison wagons				
Averaged over test cars (Nos. 1451, 1435)	0.18	0.20	0.16	0.10
Averaged over test cars (Nos. 1475, 1471, 1477)	0.25	0.40	0.11	0.51
Frequency of wearout rate reduction	1.40	2.00	0.00	5.10
On repair rims of wheel pairs, test wagons/other wagons of route. No. 11, Dnipro (2021–2024)				
Averaged over test cars (Nos. 1451, 1435)	0.18	0.20	0.16	0.10
On other cars of the route (2021–2022, 2023–2024)	0.34	0.36	0.28	0.37
Frequency of wearout rate reduction	1.90	1.80	1.70	3.70
On new rims of wheel pairs, test wagons/comparison wagons. (2021–2022, 2023–2024)				
Tatra T4D MT, inv. No. 1425 – actually	0.12	0.15	0.12	0.16
Tatra T4D MT, inv. No. 1451,1475 – averaged	0.37	0.33	0.33	0.32
Frequency of wearout rate reduction	3.00	2.20	2.70	1.90

Such an approach makes it possible to determine in an experimental way the numerical value of the ratio between the probability of the occurrence of an event caused by the action of an identified threat, which negatively affects the state (level) of safety and operability of system elements at all stages of its existence, and the probability of a positive compensatory effect of the developed measure to counter the identified threat.

If, in the case of locomotives, the use of additionally installed wheel flange lubrication systems is an effective measure of positive compensatory effect against the identified threat of wheel flange wear, then in the case of tram cars, the application of solid lubricating material to the friction surface of the wheel flanges as part of the lacquer coating was for the first time carried out and tested.

The generalized anti-wear effect of the application of the specified lubricant composition for the wagons of route No. 11 in Dnipro, according to the report of tests conducted by the authors at the Communal Enterprise "Dniprovskyi Electrotransport" of the Dnipro City Council regarding the mixture of paint and varnish TU U 20.5-42277844-001:2019, amounts to a 220 % reduction wear of flanges of tram wheels, which, accordingly, led to a decrease in costs for their repair and regrinding.

Based on the conclusions of the protocol of the Scientific and Technical Council of JSC "Ukrzaliznytsia" dated 31.05.2021 under No. CCTech-01/19 regarding the effectiveness of the lubricant "Mariol NT", we can state that the use of the specified material in flange lubrication systems will help to reduce the intensity of wear of flanges of wheel pairs by an av-



a *b* *c*

Fig. 2. The friction surfaces of the rims of wheel tread of the tram route:

a – unprocessed; b – colored; c – processed during operation erage of 2.4 times and, accordingly, will ensure an increase in the periodicity between tyre turning of wheel pairs. Taking into account the turning cost of UAH 2,700 for one pair of wheels, the reduction of operating costs for repairing wheel treads during maintenance of the locomotive is UAH 74,500.

The estimated cost of repairing wheel pairs (replacing tread) is UAH 496,000. Without taking into account the saved costs for the time of the forced downtime of the locomotive, the expected economic effect of using the lubricant "Mariol NT" is UAH 768.9 thousand per year.

The proposed approach based on the principle of adequacy of the probability of the occurrence of threats to the probability of the actual positive compensatory effect of safety measures can be used additionally in other fields of knowledge [28, 29], as well as in manufacturing industry [30].

Conclusions. By an experimental approach, the main risk-event was determined – the high intensity of the processes of wear of the flanges of wheel treads, which is a threat to the safety of both the elements of the rail traffic system separately, and the existence of the system as a whole. It was determined that the "principle of adequacy of probabilities" as a measure to improve the methodology of risk management, prevention (countermeasures) of existing and prospective risks (threats, dangers) during the safety assessment of complex systems is currently not applied.

Based on the principle of adequacy of the probability of the threat occurrence and the probability of the actual positive compensatory impact of safety measures, countermeasures against the identified threat to the safety of rail traffic were developed and implemented, and a positive technical result was obtained. A reduction in the wear of wheel pairs of main rail and communal electric transport was achieved by no less than 2.2 times due to the use of new solid lubricating materials.

The effectiveness of the improved method for managing the safety of complex systems has been proven, taking into account the principle of the adequacy of probabilities, which allows expecting an economic effect from the use of the lubricant "Mariol NT" in the amount of 768.9 thousand UAH per year in the conditions of the JSC "Ukrzaliznytsia" enterprise due to the reduction of wheel flange wear by 2.4 times

References.

1. Przetacznik, S. (2022). The evolution of risk management. Zeszyty *Naukowe Małopolskiej Wyższej Szkoły Ekonomicznej w Tarnowie*, *53*(1-2), 95-107. https://doi.org/10.25944/znmwse.2022.01-2.95107.

2. Bohnert, A., Gatzert, N., Hoyt, R. E., & Lechner, P. (2017). The relationship between enterprise risk management, value and firm characteristics based on the literature. *Zeitschrift für die gesamte Versicherungswissenschaft*, *106*, 311-324. https://doi.org/10.1007/s12297-017-0382-1.

3. Golinko, V., Cheberyachko, S., Deryugin, O., Tretyak, O., & Dusmatova, O. (2020). Assessment of the Risks of Occupational Diseases of the Passenger Bus Drivers. *Safety and Health at Work*, *1*(4), 543-549.

4. Bazaluk, O., Tsopa, V., Cheberiachko, S., Deryugin, O., Radchuk, D., Borovytskyi, O., & Lozynskyi, V. (2023). Ergonomic Risk Management Process for Safety and Health at Work. *Frontiers Public Health, 11*, 1253141. https://doi.org/10.3389/fpubh.2023.1253141.

5. Popov, H., Lyon, B., & Hollcroft, B. (2016). *Risk assessment. A Practical Guide to Assessing Operational Risks*. Hoboken, New Jersey: John Wiley & Sons, Inc. ISBN 9781119220916.

6. Samorodov, V., Bondarenko, A., Taran, I., & Klymenko, I. (2020). Power flows in a hydrostatic-mechanical transmission of a mining locomotive during the braking process. *Transport Problems*, *15*(3), 17-28. https://doi.org/10.21307/tp-2020-030.

7. Aven, T. (2015). On the allegations that small risks are treated out of proportion to their importance. *Reliability Engineering & System Safety*, *140*, 116-121. https://doi.org/10.1016/j.ress.2015.04.001.

8. Taran, I., & Klymenko, I. (2017). Analysis of hydrostatic mechanical transmission efficiency in the process of wheeled vehicle braking. *Transport Problems*, *12*(Special Edition), 45-56.

9. Florio, C., & Leoni, G. (2017). Enterprise risk management and firm performance: The Italian case. *The British Accounting Review*, *49*. https://doi.org/10.1016/j.bar.2016.08.003.

10. Bohnert, A., Gatzert, N., & Hoyt, R. E. (2018). The drivers and value of enterprise risk management: evidence from ERM ratings. *The European Journal of Finance*, *25*, 1-22.

11. Belikov, A. S., & Matsuk, Z. M. (2024). Optimization of a risk-oriented approach to the management of critical infrastructure objects. *Protection of the population, territories and objects of critical infrastructure – education, science, practice: International science and method conference*, May, 23–24 2024. Kyiv: NAU. Retrieved from https://er.nau.edu.ua/bitstream/NAU/63684/1/Belikov.pdf.

12. Zhuravel, O., Derbaba, V., Protsiv, V., & Patsera, S. (2019). Interrelation between Shearing Angles of External and Internal Friction During Chip Formation. Solid State Phenomena. *Materials Properties and Technologies of Processing*, *291*, 193-203. https://doi.org/10.4028/www.scientific.net/SSP.291.193.

13. Ferdman, H. P. (2020). The essence of the concept of transport safety: the state-management aspect. *Law and public administration. Collection of scientific works,* (2), 231-236. https://doi.org/10.32840/pdu.2020.2.34.

14. Dubois, D. (2010). Representation, Propagation, and Decision Issues in Risk Analysis Under Incomplete Probabilistic Information. *Risk Analysis*, *30*(3), 361-368. https://doi.org/10.1111/j.1539-6924.2010.01359.x.

15. Castro, L., Gulías, V., Abalde, C., & Jorge, J. (2010). Managing the Risks of Risk Management. *Journal of Decision Systems*, *17*(4/2008), 501-521. https://doi.org/10.3166/jds.17.501-521.

16. Schiller, F., & Prpich, G. (2014). Learning to organise risk management in organisations: What future for enterprise risk management? *Journal of Risk Research*, *17*(8), 999-1017. https://doi.org/10.1080/13669877.2013.841725.

17. AT "Ukrzaliznytsia" (2024). *Risk management*. Retrieved from https://www.uz.gov.ua/about/risk_management/.

18. *Federation of European Risk Management. A Risk Management Standard* (FERMA). Retrieved from https://www.iso.org/organization/667793.html.

19. *Organizational Resilience: Security, Preparedness, and Continuity Management Systems – Requirements with Guidance for Use (ASIS SPC.1-2009)* (2009). Retrieved from http://surl.li/tswez.

20. *NFPA 1600: Standard on Disaster. Emergency Management and Business Continuity. Continuity of Operations Programs* (2019). Retrieved from http://surl.li/tswfp.

21. Yang, S., Ishtiaq, M., & Anwar, M. (2018). Enterprise Risk Management practices and firm performance: The mediating role of competitive advantage and the moderating role of financial literacy. *Journal of Risk and Financial Management*, *3*(11). https://doi.org/10.3390/jrfm11030035.

22. Hameed, W., Waseem, M., Sabir, S. A., & Dahri, A. S. (2020). Effect of Enterprise Risk Management system and implementation problem on financial performance: An empirical evidence from Malaysian listed firms. *Abasyn University Journal of Social Sciences*, *1*(13), 12-24. https://doi.org/10.34091/AJSS.13.1.02.

23. Matsuk, Z. M. (2021). The concept of safety and energy resource efficiency of the oil and gas industry of Ukraine. *Ukrainian Journal of Civil Engineering and Architecture,* (4), 46-57. https://doi.org/10.30838/J.BPSACEA.2312.310821.46.789.

24. Belikov, A. S., Matsuk, Z. M., Shalomov, V. A., & Kharchenko, V. V. (2023). Increasing the safety of rolling stock due to a risk-oriented approach to "friction management" in the "wheel-saw-rail" friction pair. *Zaliznychyi transport Ukrainy, 3*(148), 23-37. https://doi.org/10.34029/2311-4061-2023-148-3-23-36.

25. Eckles, D. L., Hoyt, R. E., & Miller, S. M. (2014). The impact of enterprise risk management on the marginal cost of reducing risk: Evidence from the insurance industry. *Journal of Banking and Finance*, *43*, 247-261. https://doi.org/10.1016/j.jbankfin.2014.02.007.

26. Belikov, A., Kreknin, K., Matsuk, Z., & Protsiv, V. (2022). Lubricants for rail transport liquid (plastic) for friction pair "wheel – rail". *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (2), 63-68. https://doi.org/10.33271/nvngu/2022-1/063.

27. Belikov, A. S., Kravchenko, O. G., Zavaliy, O. B., Likharev, M. V., Matsuk, Z. M., Protsiv, V. V., & Kozechko, V. A. (2020). Lubricants are liquid and plastic. *Express selection method. Mining electromechanics and automation. NTU "DP"*, (103), 107-114.

28. Silva, J. R., da Silva, A. F., & Chan, B. L. (2019). Enterprise Risk Management and firm value: Evidence from Brazil. *Emerging Markets Finance and Trade*, *3*(55), 687-703. https://doi.org/10.1080/1540496X.2018.1460723.

29. Saeidi, P., Saeidi, S. P., Sofian, S., Saeidi, S. P., Nilashi, M., & Mardani, A. (2019). The impact of enterprise risk management on competitive advantage by moderating role of information technology. *Computer Standards & Interfaces*, *63*, 67-82. https://doi.org/10.1016/j.csi.2018.11.09.

30. Naumov, V., Taran, I., Litvinova, Z., & Bauer, M. (2020). Optimizing resources of multimodal transport terminal for material flow service. *Sustainability (Switzerland)*, *12*(16), 6545. https://doi.org/10.3390/su12166545.

Адекватність заходів загрозам як один із фундаментальних принципів ризикології безпеки

З. М. Мацук[*1], *А. С. Бєліков*[1], *В. В. Проців*[2], *В. В. Северін*[1], *В. В. Харченко*[1]

1 – Державний вищий навчальний заклад «Придніпровська державна академія будівництва та архітектури, м. Дніпро, Україна

2 – ТАФЕ НСВ (Технічна та додаткова освіта Новий Південний Уельс) Ліверпульський коледж, м. Сідней, Австралія

[*] Автор-кореспондент e-mail: matsuk.z.n@gmail.com

Мета. Обгрунтування необхідності застосування «принципу адекватності ймовірностей» як заходу вдосконалення методології керування ризиком, запобігання (протидії) існуючим і перспективним ризикам (загрозам) безпеки складних систем.

Методика. Використано відомий методологічний принцип під назвою «Бритва Оккама». У ході проведення досліджень був використаний комплексний метод, що включає в себе формально-логічний аналіз нормативної та науково-технічної літератури, аналіз статистичних даних, синтез, абстрагування, експеримент, спостереження, узагальнення даних, опис.

Результати. У ході досліджень була ідентифікована одна із загроз (небезпека, ризик), що впливає одночасно і на існування системи через безпеку руху рухомого складу підприємств рейкового транспорту, і на повноту реалізації можливостей системи через навантаження на вісь, масу та швидкість руху транспорту, рівень експлуатаційних витрат, пасажиропотік, регулярність перевезень тощо. Експериментальне застосування мастильного матеріалу «Mariol NT» у системах лубрикації СПП 12-5, ГС-3 підтвердило його ефективність під час експлуатації магістральних локомотивів і трамвайних вагонів і показало зниження інтенсивності зношування на 240 %. За рахунок застосування нового змащувального матеріалу, що нанесений на поверхню тертя бандажів коліс у складі лакофарбового покриття, інтенсивність зносу реборд бандажів трамвайних коліс зменшується у 2,2 рази, а у локомотивів – у 2,4 рази.

Наукова новизна. Визначено, що «принцип адекватності ймовірностей», як захід удосконалення методології керування ризиком, під час оцінки безпеки складних систем на сьогоднішній день не застосовується, але його врахування допомагає запобіганню (протидії) існуючим і перспективним ризикам (загрозам) безпеки складних систем.

Практична значимість. Використання «принципу адекватності ймовірностей» дає можливість теоретично та експериментальним шляхом визначити чисельне значення співвідношення між імовірністю настання події, викликаної дією ідентифікованої загрози, що негативно впливає на стан (рівень) безпеки та працездатність елементів системи на усіх етапах її існування, та ймовірністю позитивно-компенсаційного впливу розробленого заходу протидії ідентифікованій загрозі.

Ключові слова: *рухомий склад, змащувальний матеріал, безпека, ризик, загроза, ймовірність*

The manuscript was submitted 28.05.24.