Analysis of railway vehicle braking and assessment of technical solutions efficiency using risk-based methods for technical systems

Nickolay Gorbunov, Olga Prosvirova, Ekaterina Kravchenko

Volodymyr Dahl East-Ukrainian National University
Molodizhny bl., 20a, Lugansk, 91034, Ukraine, e-mail: gorbunovni@ukr.net

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S u m m a r y. This article provides analysis of the factors that affect probability of skidding and reducing the braking performance of the vehicle. The analysis of advisability of applying the theory of the risks is provided to estimate the braking process of a railway vehicle to determine the probability of fulfillment of the condition non-skidding braking and making for further design and operational decisions. The analysis of the risk-based methods is provided with practical recommendations on its usage in the railway transport science.

K e y w o r d s. Train braking, risk theory, skidding, reliability, cohesion.

INTRODUCTION

VNIIZHT together with scientists from the University of Newcastle (NewRail), the Czech research Institute of railway transport (VUZ Velim), the Spanish Foundation of Railways (FFE), Australian railway research centre (CRC for Rail Innovation), Japanese technical research Institute of railway transport (RTRI), Turkish state Railways (TCDD), the Korean research Institute of railway transport, the Slovenian research Institute of railway transport carried out large-scale study to prioritize areas of scientific research, the development of which will be primarily to promote the effective development of railway transport.

According to the research data, traffic safety and the interaction of the wheel-rail system occupy the 2nd and 6th places in ranged list of 20 basic directions of scientific researches, as well as leading position in their respective clusters.

These fields of study correspond to the analysis of the rail vehicle braking process with the purpose of definition of probability of occurrence skidding with methods of the risk theory for technical systems, which is described in the article.

The analysis of the risk-based methods is provided with practical recommendations on its usage in the railway transport science. This responds to other high-priority research direction - intellectualization of railway vehicle engineering process.

BACKGROUND RESEARCH ANALYSIS

Currently methods of risk management of technical systems are widespread. Specialists in different areas of industry are interested in this subject. Methods based on risk assessment allow you to define, assess risks and take reasonable decisions to take measures for their elimination or reduction [30]. H.M. Son, V.N. Lubenko, V.N. Tryaskin according to the results of the analysis of the basic methods used for risk-analysis of technical systems, make a conclusion about the positive results of the application of these methods in the safety of technical systems ensuring complex.

In the Karpychev V.A., Andreev P.A. works through the analysis of distribution of failures of the basic units of the brake system, trends in the development of rolling stock and scientific works in the field of braking equipment indicated the urgency of substantiation of the parameters of the braking system from the conditions of skidding prevention of wheel pair through one of the methods of system analysis [26, 29].

In this article the condition of skidding prevention is also considered using the fault-tree method is given as the basis for forecasting skidding-free braking.

Reliability of operation of the studied object, as a general system indicator allows to systematize the solving of the multifaceted problems. Specifically, it allows to cover adverse factors influencing on the object that have different origins, and to consider their causal relationships in operation.

OBJECTIVES AND PROBLEMS

The article aims to analyze the possibility of application of existing methods of the theory of risk for technical systems and to predict the negative phenomena arising during a rail vehicle braking. Factors affecting the probability of skidding are considered as sources of system failures.

The other objective is the analysis of the risk-based methods to consider practical recommendations on its usage in the railway transport science.

RISK-BASED METHODS FOR ANALYSIS OF RAILWAY VEHICLE BRAKING AND ASSESSMENT OF TECHNICAL SOLUTIONS EFFICIENCY

Skidding is railway vehicle wheels slide on rails, in which the linear velocity of wheels surface is lower then the speed of the support surface relative to the vehicle. Rail vehicles skidding causes abrasion of blocked wheels in place of their contact with the rail and the occurrence of flat spot on the wheel bandage - so-called slider. The presence of sliders (asymmetry of the wheel relative to the axis of rotation) causes the increase of noise, vibration, asymmetric wear of rails.

Physical nature of braking force, as it's based on the phenomenon of adhesion of the wheels with the rails, will always involve a certain probability of blocking of wheel pairs, and any change brake efficiency results in a corresponding change of this probability. It should be borne in mind that the relatively high probability of blocking is incompatible with the safety and leads to high costs for disassembly and repair of cars, small is conditioned by reduced brake pressing and, therefore, an extension of brake ways, negatively affecting the throughput capacity of railways [5-9]. Therefore, the task of ensuring the required traffic safety and the probability skidding-free braking arises.

The authors analyze the factors influencing the probability of skidding and methods of the decision on necessity of application of antiskid protection with the submission of risk theory for technical systems. To highlight the main groups of factors, it is necessary to analyze the condition skidding-free braking.

Mostly, blocking of wheel pairs is not instantaneous. Previously wheel-pair starts to slip, it's speed is less than its translational speed of rolling stock [31]. This increases the braking force by rising the coefficient of friction. Therefore, the maximum amount of braking force is limited by the terms of cohesion of wheels with the rails. Therefore in order to avoid a skid maximum braking clicking accept is cosidered such that the braking force does not exceed the force of cohesion of wheel and rail. This is described by the following rule [13, 20]:

$$F_T^{\max} \le F_c \tag{1}$$

or

$$\varphi P_T \le \Psi P, \tag{2}$$

where: φ is adhesion coefficient, P_T is braking pads pressure on the axis, Ψ is cohesion coefficient, P is axial load.

In the base of the cohesion process there is friction interaction taking place between wheels and rails. Adhesive force has the friction forces nature, and as noted above, in the first approximation it is equal to the multiplication of the normal pressure of the wheel on the coefficient of wheel and rail friction. However, these values are not fixed and depend on the properties of the rolling stock and railway. Analysis of the factors influencing on implementation of braking forces [19, 25] allowed to present rate of locomotive cohesion as following:

$$\psi = \psi_o(\mu) \cdot \eta, \tag{3}$$

where: $\psi = \psi_o$ is the basic cohesion coefficient, reflecting the influence of frictional properties of the surfaces of friction of the wheels and rails, μ is the coefficient of static friction of the central rolling path of wheel along the rail, η is resulting factor of coupling weight of the locomotive. This parameter should be seen as multiplied influences of factors characterizing the influence of design features of rolling stock and rail, as well as the mode of trains motion on the grade of realization of the limit cohesion coefficient.

Thus, according to the results of the analysis of researches [3-5] there are the following groups of factors affecting the probability of skidding-free braking. This is, first of all, factors affecting wheel and rail cohesion. These include major factors of coupling weight of the locomotive, specifically:

- the impact of differences traction motors characteristics,
- the difference in the diameters of wheel pairs bandages,
- irregularity of static hanging on the axes and the wheels of the locomotive,
- sustainable redistribution of vertical loads on the axes, caused by development of brake force [11].

Another group of factors affecting the value of the coefficient of cohesion, coupling weight of the locomotive dynamic factors. These include:

- redistribution of the weight of the carriage from the inertial forces [13],
- redistribution of the weight of the carriage from the longitudinal dynamic forces [12],
- vertical loads and efforts along the axes of locomotives periodic oscillations.

Other cohesion coefficient factors are:

- influence of the curvilinear section of the way on the value of the implementation of the braking force,
- the coefficient of static friction of the wheel rolling along the rail central path,
- statical and dynamical wheelset disbalancing [28],
- presence of the eccentricity of the circle of the axle [10],
- hardness of the way [23].

During the analysis of factors leading to significant fluctuations in the values of the coefficient of cohesion of the wheels and rails, it was found that a considerable influence on the implemented cohesion coefficients is a change of frictional properties of the surfaces of friction of the wheels and the rails, dependent on many external factors. Thus, the following group of factors influencing the coefficient of friction is the state of the wheels and rails [19]. Significant impact on the contact surfaces and, consequently, on the value of the cohesion coefficient is provided by:

- air, as wetted parts of the surfaces working in the atmosphere, air humidity and atmospheric phenomena,

- lubricant, grease and other organic substances that enter the contact surface,

- mechanical impurities minerals - dross, dirt, dust, the products of wear of brake pads and wheels, particles of the transported cargo, etc.

Also, in addition to the factors of cohesion coefficient, it is necessary to take into account factors affecting friction coefficient of friction pair of the brake, as the braking force depends on it [15-17]. It can be attributed to such factors as following.

- speed of movement,

- specific pressing force of the shoe,

- materials of friction elements.

To assess the impact of the factors given above on the probability of skidding mainly empirical research are used, the results of which are presented in the form of dependence of the coefficient of cohesion or friction from a particular factor or their group. To determine the most important factors that should be considered in the calculations of probability, risk, and other characteristics of skidding-free braking, expert ranging is often used.

Large class of riskology methods used for the analysis of technical systems [9] is based on formalized views of the simulated objects, processes, goals, properties in the form of a set of characters (nodes, vertices) and alleged or actual relationships between them. Models of processes in the studied systems should reflect the emergence of individual prerequisites and their development in a causal chain of incidents in the form of charts, cause-and-effect relations, influence diagrams. Widespread chart in the form of a stream of graphs (graphs of states and transitions), event tree (targets, properties) and functional networks of various purposes and structures.

The most widely used type of influence diagrams are «trees» - graphs with branching structure and with additional logical conditions. The main advantages of these models are:

- comparative simplicity of the building,

- deductive nature of identifing cause-effect relations of the investigated phenomena,

- the direction of their significant factors, ease of conversion of such models,

- visibility of reaction of the system under study on the changing patterns,

- decomposition of the tree and the process of its consideration,

- qualitative analysis of investigated processes,

- ease further formalization and algorithmization,

- suitability for processing on the computing facilities,

- availability for statistical modeling and quantification of the studied phenomena, processes and their properties.

To review the process of braking as a model of the influence diagrams, you can use the results of analyses of factors affecting the probability of skidding, after reducing them to an appropriate form of presentation [22].

As shown, the majority of factors easy yield probability estimates and weights, in which they can be used to build the chart of influence in one or more of the forms given above.

When the analysis and evaluation of uncertainties associated with the event, risk is the possibility of losses as a result of system failure, and may be measured in the form of pairs of factors, one of which the probability of occurrence of an event, and another potential outcome or consequence associated with the occurrence of the event. This pair can be represented by the equation [24]:

$$R = P \cdot C, \qquad (4)$$

where: P is the probability of occurrence of an unwanted event, C is the result of the occurrence of the event.

Risks of the system can result from interaction with dangerous natural phenomena of ageing and degradation or under the influence of human and organizational factors. Therefore, the risk can be classified as voluntary or nonfree, depending on the probability of events which lead to the risk under the control of persons at risk. Losses associated with events that can be classified as either reversible or irreversible, depending on the loss of property or life accordingly.

Risk assessment is a technical and scientific process in which the risks of this situation for the modeled system are considered. Risk assessment provides qualitative and quantitative information that decision-makers can use to manage risk. Risk assessment provides the answer to three questions:

- What can go wrong?
- What is the probability that this goes wrong?
- What are the consequences, if it's really going down?

To assess the risk the most frequently used methods are [31]:

- situational analysis - What-If Analysis,
- Checklist Analysis,
- Hazard and Operability Study (HAZOP),
- Failure Modes and Effects Analysis (FMEA),
- Fault Tree Analysis (FTA),
- Event Tree Analysis (ETA).

Risk assessment methods can be classified depending on how the risk is determined – by quantitative or qualitative analysis. In the framework of the risk analysis for the determination and assessment of the probability and consequences of the occurrence of an unwanted event is used expert opinion, quantitative analysis is based on statistical methods and databases. The choice of quantitative or qualitative risk assessment method depends on the availability of data for the assessment of risks and the level of convenience.

The situational analysis method [15] is a brain-storming, where the mapping information (hazard identification) is performed using a series of questions that begin with the «What if» words.

Questions are formulated based on experience. May be made any security considerations, even if it is not formulated in the form of a «What if» question. Questions are divided into specific areas of research, and a group of one or more knowledgeable people consistently refers to each area.

When using the situational analysis, the researchers are provided with a list of questions and answers regarding the issue. Also a tabular list of dangerous situations and their consequences, measures and possible recommendations to reduce risk can be received.

Analysis of the checklist [15] is a method, which is based on the features of the method of situational analysis associated with a brainstorming session, and that a more systematic, as it uses the checklist drawn up in advance on the basis of the experience. This checklist is a written list of items that can detect known types of hazards, the efficiency of the planning and potential emergency situations associated with the system, equipment or operations. It can be used to address specific elements of the system or procedures. Traditional checklists widely vary in depth and often used to determine compliance. Checklists are limited experience of experts, therefore, they must develop experts who have experience in various fields and experience in the analyzed systems. Checklists should be regularly checked and updated, which will ensure the possibility of their use at the moment. If the checklist is incomplete, units that are not listed, you can skip.

The results of this method are usually represented in the form of a table which includes the following:

- potential emergency situations,
- influence,
- safety measures in order to make an assumption about ways to reduce risk.

Analysis of hazards and operability (HAZOP) [15] is a formal systematic method for identifying hazards by enumerating the possible deviations from the normal course of operations and by assessing the consequences of these deviations. Deviation derived from a set of predetermined indicators, which help to structure and stimulate the creative process of finding potential deviations. Deviations are defined as those that are likely to have significant consequences, analyzing the future, identifying their possible causes.

The main activity is a key feature of the HAZOP is carried out by an interdisciplinary group of experts describe this system. HAZOP usually is carried out not for the physical system, and for a representative model of the system which is called «project model». Restrictions on its form do not exist, if it is clearly documented and understood by all members of the group.

The results of the method of HAZOP is that found the group of experts, including a list of identified hazards and issues arising during operations, the causes, consequences, security measures, as well as conclusions and recommendations for further analysis.

Analysis of the nature of failures and consequences (FMEA) [15] is a systematic method by which the analyst considers various situations and errors in the elements of the system components and evaluates the consequences of these errors.

FMEA is used in the analysis of individual errors in the system's components, which directly leads to an accident, or significantly contributes to its occurrence, but do not apply to the error message. Usually when analyzing hazards FMEA is used as a method of qualitative analysis, although it could be extended to rank the priorities allocated on the basis of the severity and probability of occurrence of errors.

FMEA allows analyzing the potential defects, their causes and consequences, to assess the risks of their appearance and is not detected in the design and manufacture, and also to take measures to eliminate or reduce the probability and damage from their appearance.

The results of FMEA analysis are presented in tables with a list of equipment, species and reasons for possible failures, frequency, effects, and criticality and means of detection of a malfunction (signaling and control devices etc) and recommendations for reducing the risk.

The probabilistic analysis is a riskology instrument as well. At the most fundamental level, the probability is expressed as a lifetime or annual probability of a fault.

Qualitative assessment of the probability of a malfunction, also called the probability of damage, can be defined as a measure of the propensity to damage to structures. The elements of a design may be subject to one or more types of damage, and in some cases they may be associated. In qualitative form of simple statistical analysis, combined with a technical judgment, can be used to assess the probability of a fault.

The classification scheme is the probability of a fault can be developed and contingent indicators can be defined for each category (Table 1). Classification probabilities in Table 1 includes four classes: an extreme, high, moderate and low.

In Table 1 there also presents the approximate scheme of indicators that can be applied to overcome probable damage.

Table 1. Example of the fault probability classification

Probability class	Probability indicator
Extreme	4
High	3
Moderate	2
Low	1

Expert opinion and experience, borrowed from other industries and the classification society rules, can be used as a guide for assigning probability of damage.

You can also develop a level of consequences. This is what happens implicitly when developing design standards. Consequently, different levels of security are depending on the severity of the anticipated consequences. The suggested approach (Table 2) these four levels: catastrophic, hard, significant, and low. To simplify the representation of the effects, introduced the category overall result.

Table 2. Example of the consequences classification

Consequences class	Consequences indicator
Catastrophic	4
Hard	3
Significant	2
Low	1

For assigning risk index each combination of the probability of a fault and fault consequences are used in Table 3. Risk indicators listed in the table are convenient to measure in a logarithmic scale. Risk indicators characterize the relative order of magnitude of risk. The choice of a logarithmic scale is not mandatory, but recommended for facilities due to the following mathematical properties of logarithms [2]:

$$R = P \cdot C,$$
$$\log R = \log P + \log C, \qquad (5)$$
$$R_I = P_I + C_I,$$

where: R_I is risk indicator, P_I is the probability, C_I is index of consequences.

The value of risk you can get on the Table 3 compiling a measure of the probability and consequences.

Table 3. Table of risks

Probability		Consequences			
		Low	Significant	Hard	Catastrophic
		1	2	3	4
Extreme	4	5	6	7	8
High	3	4	5	6	7
Moderate	2	3	4	5	6
Low	1	2	3	4	5

From the risks table we have the following.

- if $R_I \le 4$, object has a low risk level,

- if $4 < R_I < 6$, object has a average risk level,

- if $R_I \ge 6$, object has a high risk level.

For estimation of technical condition of designs of a ship is the main question of the admissible values of wear or other defect.

Risk indicator for an item can be obtained by summing up the measure of the probability of malfunctions and investigation faulty item [2]. This approach allows you to select the elements of design with the different values of risk indicators that can be used for different purposes.

The economic uncertainty entails the influence of certain risk factors on their future earnings. Investment risks threaten the decrease of profit in comparison with the possible or even losses. So when making decisions on investment management firms, investment funds must necessarily take into account the impact of the investment risk.

To calculate the possible variants of the riskiness of the investment project, depending on various circumstances, use the following approaches:

a) an analysis of sensitivity of the project to changes of individual factors that affect yield. Such factors include price, cost, production cost of the equipment etc. Assessment of the importance of the influence of these factors on the overall profitability of the project, and in accordance with the results of the measures are taken on a thorough study of investment plans, and reduction of risk associated with the identified factors,

b) analysis of the forecasting scenarios of development of economic environment and the implementation of the investment project. The calculation is carried out in three variants:

- basic calculation of averages, the most likely conditions,

- optimistic scenario for the best course of events for all the factors affecting the profitability of the project,

- pessimistic scenario, in which lays the worst possible situation in the country and in the particular market,

c) method of statistical tests, which with the help of computer equipment is rendered by the many choices of return of the project based on the performance indicators-factors in the specified ranges of their change. As a result, the average statistical characteristics of their variation and distribution for further analysis of the most important indicators of project profitability and riskiness of the project in different directions.

For a quantitative estimation of investment risks there are different statistical-mathematical methods that calculate indicators of project efficiency in conditions unfavorable for investments event. In particular, the authors propose the use of Monte Carlo simulation to calculate the economic risk of the investment project on implementation of new technical solutions in the railway transport.

According to this method, first, we construct a mathematical model of the resulting index as a function of variables and parameters. Then, a series of simulation experiments is hold. The mathematical model is recalculated each time a new experiment. The results of all of simulation experiments are combined in the sample and analyzed using statistical methods to obtain a probability distribution of the resultant value and calculation of the main gauges of risk of the project.

In the general case the numerical method of solving mathematical problems modeling of random variables is called Monte Carlo method.

The scheme of the use of Monte Carlo method in quantitative risk analysis is this: we construct a mathematical model of the resulting index as a function of variables and parameters. Variables are considered random components of the project, value of which there shall be deterministic. The mathematical model is recalculated each time a new simulation experiment, during which the importance of the major uncertain variables are randomly selected on the basis of random number generation. The results of all of simulation experiments are combined in the sample and analyzed using statistical methods to obtain a probability distribution of the resultant value and calculation of the main gauges of risk of the project.

Application of the Monte-Carlo method in calculations of projects on introduction of new technical solutions requires the creation of a special software.

Development of computer software is necessary for the following reasons:

1) is the repetition of simulation experiments (more than 100 iterations),

2) used models are complex (very large number of variables accounting for the distribution functions, conditions of correlation and etc),

3) processing of simulation results is greatly simplified,

4) easy demonstration of the method.

The process of risk analysis of Monte Carlo can be split into three phases: mathematical model, the implementation of the simulation, analysis of the results.

The first step in the process of risk analysis is to create a mathematical model. Because of the actual Monte Carlo simulation is used a computer program, the main process of simulation is precisely the formulation of the model project. Each investment project requires the creation of its unique model. Therefore, its specific view -is fully a product of creativity of the developer.

The main logic of the procedure of construction of the model is the following: the definition of the variables included in the model, definition of the distribution to which these variables are subjected to the definition of related (functional and stochastic dependence between the variables).

Following this procedure, you need to create a model that will look as follows:

$$NPV = f\,(x_1,\ldots, x_i,\ldots, x_n, a_1,\ldots, a_j,\ldots,a_m), \quad (6)$$

where: x_i are risk variables, n is number of risk variables, a_j are fixed model parameters, m is number of model parameters.

The definition of the variables included in the model is a separate stage of the risk analysis that reflects first of all the results of the study of risk at a qualitative level. For example, surveys of experts allow to select the most «narrow» place of the project.

In addition, an important role in the selection of key variables plays a sensitivity analysis, which calculation of rating of elasticities is made. On the basis of rating elasticities are selected most at risk variables, that is, those fluctuations that cause the greatest deviation of the results of the project. They can be included in the model.

However, the decision about inclusion of the variable in the model should be based on several factors, in particular:

1) the sensitivity of the project to changes in variables,

2) the degree of variables uncertainty (i.e. the possible ranges changed).

When forming a model, you must try to allocate as a risk variables only the most important, significant variables. The reasons for limiting the number of risk variables in the model are as follows:

1) increasing the number of dependent variables of the model increases the possibility of receiving contradictory scenario through the complexity in accounting and control dependencies and correlated,

2) increasing the number of variables grows costs (financial and time)required for a correct and accurate determination of their probability distribution and terms correlated.

If not specified condition of probabilistic dependency of the risk variables, it is considered that the variables are independent and follow some distribution.

Distribution law specifies the probability of choosing the values within a certain range. Standard investment calculations use one type of probability distribution for all project variables included in the estimated model is deterministic distribution when only the specific value of the variable is chosen with probability equal to one (p=1). Now, the basic model of the investment project can be regarded as a deterministic analysis and the private model for the deterministic risk variables.

For each risk variable is a random variable, in the process of creating a model, you must choose the type of allocation.

The task of selection of the distribution of the difficult primarily takes place due to the limited statistical data. In practice we often use such probability distribution laws as normal, triangular, uniform, discrete.

Algorithm for solving the problem of selection of the distribution is the following:

1) determine the possible limits of variation of risk variable (range),

2) choose a general view of the distribution law,

3) taking into account the range of variation of the variable and the overall evaluate the main numerical characteristics of the distribution law (continuous case) or assign a possible meaning of the risk variable probability of their implementation (the discrete case).

The problem of choosing the type of probability distribution is very important as the accuracy of the distribution law with the specified limits changes in the risk variables directly affects the quality of the model and the estimation accuracy.

The main stage of the simulation, in which with the help of computer program, the algorithm of the method of Monte-Carlo is set, is the stage of implementation of the simulation. It's performed as follows:

1. The generation of random numbers is done by computer operations to retrieve a random number of independent and uniformly distributed on the interval [0, 1] of values. Each received new random number is set as the value of the distribution function for the relevant risk variable.

2. The value of each independent risk variable is restored as an argument of the probability distribution functions of the risk variable. This takes into account the existence of probabilistic dependency.

3. The values of the variables are substituted into the model and integrated parameter of efficiency of the project is calculated.

4. Set out in paragraphs 1-3 algorithm is repeated n times. The simulation results (i.e. NPV or other indicator), thus calculated and saved for each simulation experiment.

Each simulated experiment is a random scenario. The number of simulation experiments or accidental scenarios should be large enough to make the sample representative in relation to the infinite number of possible combinations.

Size of the random sample of n depends on the number of variables in the model, the range of values in risk variables, and from the desired accuracy of obtaining the results.

At this stage there is a problem to determine the error of simulation results depending on the number of simulation experiments. The choice of n is of great importance for assessment of the quality of the model, i.e. the accuracy of the distribution of the NPV and its characteristics.

The final step in the process of risk analysis is the analysis and interpretation of the results obtained at the stage of the simulation.

Analysis of the results of the simulation can be divided into two types: graphic analysis and analysis of the quantitative indicators.

The result of carrying out simulation experiments is a sample of n NPV values (or another result indicator).

The probability that the project will result below a certain value of the results, where the value of the index was below this value is multiplied by the probability of the realization of one of the observations.

Building a graph of the cumulative distribution of the frequency of occurrence of the results, you can calculate the probability that the outcome of the project will be above or below the specified value.

To conduct graphical analysis it is necessary to construct a probability distribution functions of the resultant value (NPV or other).

Thus, it is necessary to build a histogram of NPV. Histogram is important in the analysis of the results of simulation modeling, because it allows you to choose the distribution of the resulting index.

Histogram is built by splitting of variation series on k grouping intervals. The choice of k is carried out in accordance with the recommendations of mathematical statistics. Further on the consistency of the empirical data to the selected distribution law with the help of χ^2consent criterion.

As noted, the analysis of quantitative indicators is carried out for such characteristics of the investment project efficiency, as NPV, but similar calculations can be performed for other performance indicators.

The probability of realization of inefficient project is calculated on the basis of the test results after conducting a simulation. This statistic is a good criterion to assess the riskiness of the project, as is dimensionless and defines risk as the possibility of losses. At the same time, the probability of realization of inefficient project can be regarded as an indicator of the sustainability of the project. The smaller the value is, the more stable the project is, and generally less risky.

The authors have developed a computer program for risk assessment and economic security of introduction of innovative projects, which defines the break-even point, effects and costs of the innovative project on implementation of new technical decisions on railway transport for predictable values of the factors of effect and cost, using the method of Monte Carlo, that is performed by receiving a large number of realizations of the stochastic process, which is formed in such a way that its probabilistic characteristics coincide with the identical problem to be solved.

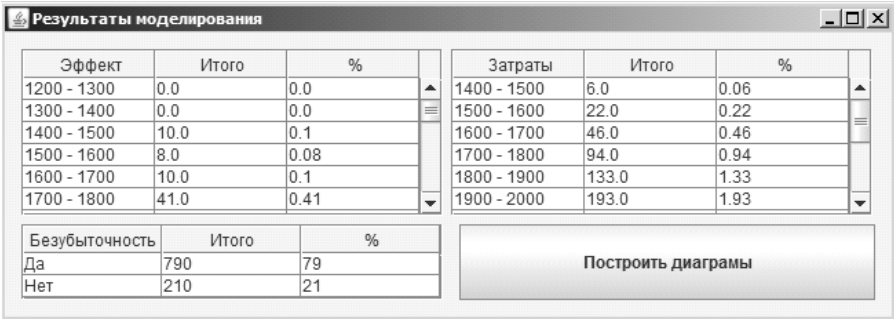
Fig. 1. Window of input parameters

In the first window of the program you must enter a minimum and maximum values of the factors of effect and costs, which are accounted for in the calculations (Fig. 1). Also for the factors of costs is the price.

In the next window, there are results of simulation of the stochastic process (Fig. 2). A law used to simulate the distribution of probabilities is converted normal. The tables contain data on the probability of the corresponding values of an effect or costs, break-even probability of the project.

For all tables are built columnar chart. The cost chart is illustrated (Fig. 3).

Thus, Monte Carlo method simulation is a development of scenario approach to risk analysis and simultaneously that could be attributed to the group-theoretic probability of risk analysis methods. On the basis of statistical data and expert estimates, analysts select laws of the distribution of some of the components of the project and on the basis of repeated simulation experiments with a given level of accuracy you can find the distribution of the resulting parameter and calculate its main characteristics: the expectation, variance, standard deviation.



Результаты моделирования

Эффект	Итого	%
1200 - 1300	0.0	0.0
1300 - 1400	0.0	0.0
1400 - 1500	10.0	0.1
1500 - 1600	8.0	0.08
1600 - 1700	10.0	0.1
1700 - 1800	41.0	0.41

Затраты	Итого	%
1400 - 1500	6.0	0.06
1500 - 1600	22.0	0.22
1600 - 1700	46.0	0.46
1700 - 1800	94.0	0.94
1800 - 1900	133.0	1.33
1900 - 2000	193.0	1.93

Безубыточность	Итого	%
Да	790	79
Нет	210	21

Построить диаграмы

Fig. 2. The results of modeling

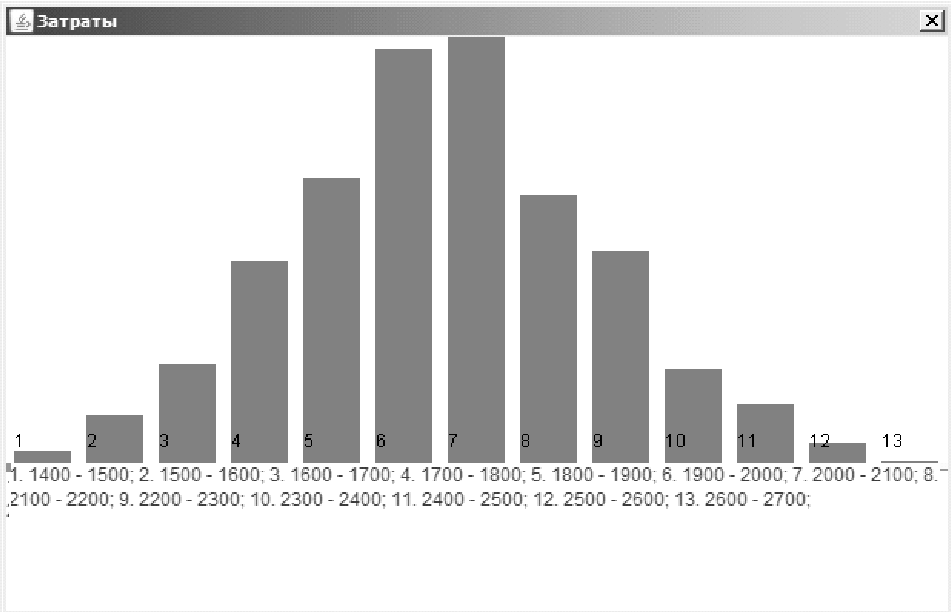


Fig. 3. Costs diagram

Simulation consists of three stages: the construction of mathematical model, the implementation of the simulation, analysis of the results.

At the stage of constructing a mathematical model of selected risk variables (random components of the cash flows of the project) on the basis of the rating and evaluation elasticities predictability variable, according to available statistical data and expert information for each risk variable is selected, the distribution, conditions are taken into account probabilistic dependency variables.

Simulation is performed using a specially designed computer program, which also contains estimates of the effectiveness of the project.

Integrated approach to risk assessment, implemented with the application of the Monte-Carlo method is that the analyst of different indicators: the probability distribution of the resulting design variable, estimates of the mean values of average standard deviation and coefficient of variation result indicator, any other special way designed measures of risk (ratio of expected losses, the probability of realization of inefficient project).

Investment decisions in railway transport can be based on the results of the visual analysis, i.e. the study of the risk profile and the cumulative risk profile, received in the result of the simulation.

Important gauge of integral project risk is the index of expected loss and the probability of realization of inefficient project.

CONCLUSIONS

1. Skidding of a rail vehicle leads to negative phenomena, such as abrasion of blocked wheels in place of their collision with rail, the arrival of the wheel bandages slide. Application of the theory of risk for technical systems for the analysis of the train braking of the vehicle to determine the probability of the skidding and the making a decision on the necessity of applying anti-skidding protection on the basis of the analysis of the factors affecting the fulfillment of the conditions of skidding-free braking allows qualitative analysis and quantitative assessment of the investigated processes are relatively easier to build, clarity, ease further formalization and algorithmization.

2. Analysis of existing methods of risk assessment for technical systems shows that the calculation of risk does not replace the existing system for the safety monitoring but is expanding its capabilities. Risk assessment allows developing the program of control of structural elements, starting with the initial control strategy and the last update of this strategy. In addition, according to the results of risk assessment, knowing zone structures with high level of risk, you can pre-plan the necessary volume of repair.

3. Analysis and determination of the values of the risk indicators allow not only assessing and forecasting the technical condition of elements of the system. On this basis it is possible to develop measures to increase the reliability of structures, justify the overhaul periods and to formulate the requirements to structural elements.

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АНАЛИЗ ПРОЦЕССА ТОРМОЖЕНИЯ ЖЕЛЕЗНОДОРОЖНОГО ТРАНСПОРТНОГО СРЕДСТВА и оценка показателей эффективности технических решений МЕТОДАМИ ТЕОРИИ РИСКОВ ТЕХНИЧЕСКИХ СИСТЕМ

Николай Горбунов, Ольга Просвирова, Екатерина Кравченко

Аннотация. В статье приводится анализ факторов, влияющих на вероятность возникновения юза и снижения тормозной эффективности транспортного средства. Рассматривается возможность применения теории рисков для анализа процесса торможения железнодорожного транспортного средства с целью определения вероятности выполнения условия безъюзного торможения и принятия дальнейших конструктивных и эксплуатационных решений. На основе анализа методов оценки риска предоставлены практические рекомендации по ее использованию в области железнодорожного транспорта.

Ключевые слова. Торможение, теория рисков, надёжность, юз, сцепление.