ON THE SYSTEM OF RISK ASSESSMENT IN THE FIELD OF FUNCTIONAL SAFETY OF TRAIN TRAFFIC

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ABSTRACT

The structure of risk assessment method in the field of functional traffic safety on the infrastructure of JSC Russian Railways, related to the competence of the management of track and structures, is considered. Modeling of probability of risk is made with the help of the tree of events, and the formation of a model adequately describing the integrity and risk function is based on analysis of the technology of the protective complex. To analyze the dynamics of risk in the most critical positions and identify priority areas for implementation of corrective measures, matrix of significance of factors determined by the function of risk is used.

Keywords: railway, infrastructure, traffic safety, risk assessment, permissible risk, assessment of the importance of factors, control of probability of violations, corrective measures.

Background. *At present, the system of assessing the functional safety risks for infrastructure economies is based on the results of many years of work conducted under the leadership of JSC Russian Railways and concerns the regulatory framework in the field of traffic safety [1–6], URRAN normative documents [7–11], as well as other national and industry standards and techniques [12–16].*

In accordance with the tasks set, the system should not only establish a certain level of risk, but predict it and determine the measures by which the losses associated with transport incidents and events would remain within the zone of acceptable risk, corresponded to the indicators adopted in December 2015 the updated strategy of ensuring guaranteed traffic safety in the holding of Russian Railways [4].

Objective. *The objective of the author is to consider the system of risk assessment in the field of functional safety of train traffic.*

Methods. *The author uses general scientific methods, comparative analysis, evaluation approach, scientific description.*

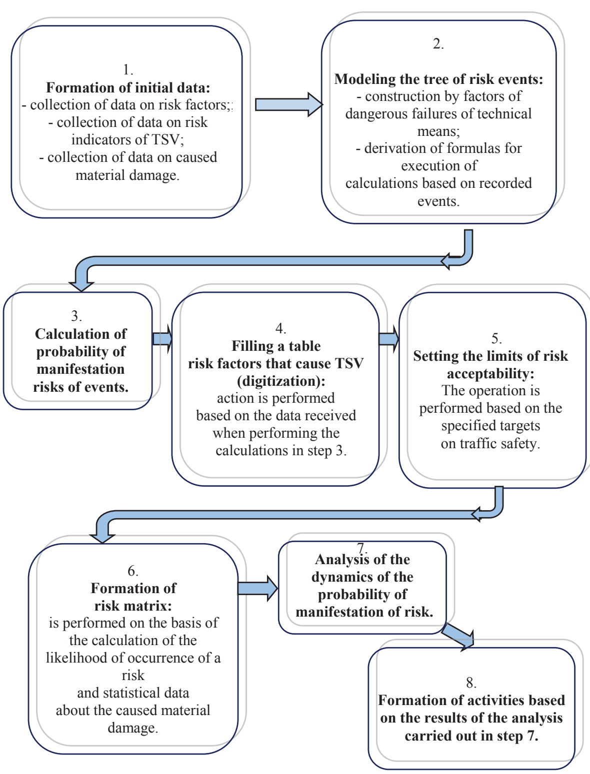
Results.

The assessment of risks in the area of functional traffic safety on the infrastructure of JSC Russian Railways, according to the control scheme of track and structures, contains the stages shown in Pic. 1.

Modeling of probability of risk with the help of a tree of events is conducted in order to adequately reproduce the process of occurrence of traffic safety violations (TSV) and to determine the risks for each identified factor, to analyze the dynamics of their occurrence, and to formulate priority directions for implementing corrective actions.

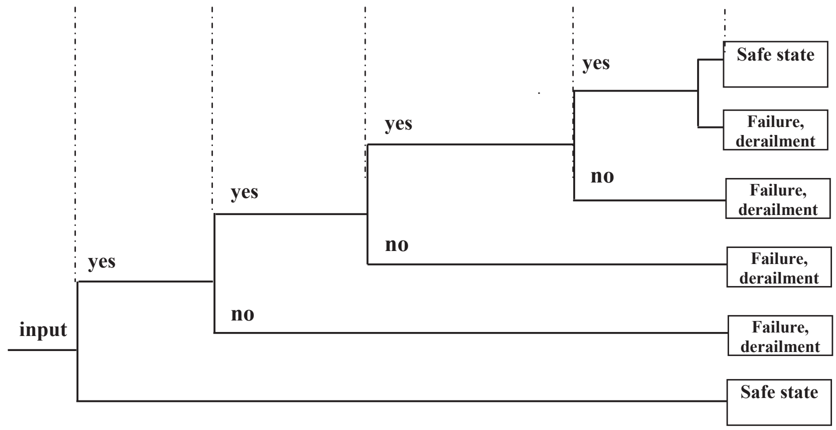
The form of a deterministic model of risk assessment is the logical function of the integrity of the system [20–22].

The method of constructing this function uses binary random events with two inconsistent outcomes (normative state – abnormal state, action is performed – action is not performed, a deviation from the normative state is detected – not detected, performed timely – not timely, speed limited – unlimited, etc.).

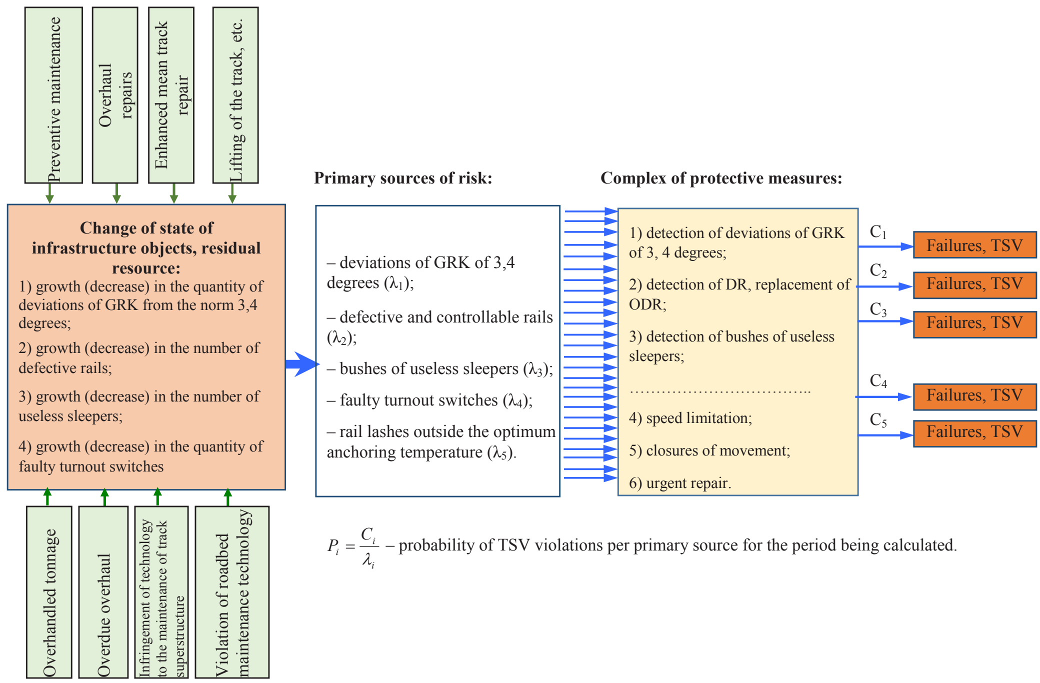


Pic. 1. Stages of risk assessment in the field of functional traffic safety on the infrastructure of JSC Russian Railways.

The probability factor for failure of the technical component (wear, tonnage, wooden sleepers)	Factor of detectability	Timeliness factor of restrictive measures	Timeliness factor of repair	Factor of compliance with the technology of repair
Deviation of the 3rd degree occurred	Is detected in time? (all kinds of inspections, car-laboratory, removable means)	Is speed limited?	Is repair made in time?	Is the technology of repair observed?



Pic. 2. The tree of events of the first level.



Pic. 3. Scheme for calculating the values of probability control of TSV.

In a typical tree of events in the track economy, there are five generalized factors for a single case of failure or derailment (Pic. 2):

1) factor of appearance of a violation of the technical component;

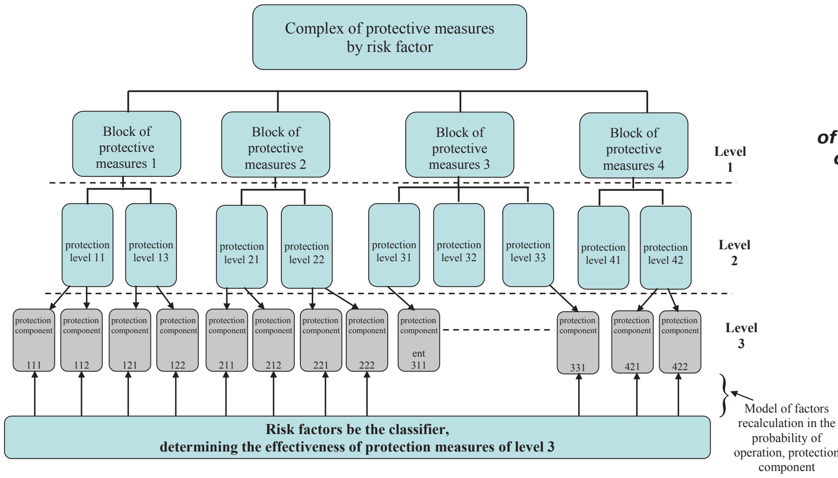
2) factor of detectability;

3) timeliness factor of restrictive measures;

4) timeliness factor of repair;

5) factor of compliance with the technology of repair.

Supplement to the traditionally used apparatus of the tree of events is:



Pic. 4. The graph of protective measures of protection by the factor of risk.

1) tree representation in a block way on three levels, which simplifies the formation of the risk function;

2) use of statistical control at the 1st and 2nd levels, where the probability of adverse events is compared with the data obtained on the basis of a standard statistical analysis of traffic safety risks.

The main way to create an adequate prototype is to build a structural risk model using an object-oriented approach developed by NIIAS [6].

The scheme, on the basis of which the criteria for statistical control of risk values calculated using the event tree are formulated, is shown in Pic. 3.

The main stages of risk analysis using the tree of events are as follows [7]:

1. A first-level event tree is constructed, the initial event of which is the primary risk factor, the final one is a set of states that are characterized by greater or lesser probability of TSV, failure, or lack of such probability. The main functions of monitoring, protective systems should be reflected in the structure of the tree.

When preparing information for constructing a tree, a structure is first made in the form of a graph, the whole complex of protective measures for the dangerous factor is divided into blocks, and those in turn – into the levels of such activities within themselves. Then, each lower-level activity is broken down into components that are associated with grass-root factors (indicators of factor development) according to the scale of the NIIAS classifier [7]. The scheme of such a graph is presented in a general form in Pic. 4.

Accordingly, the tree of events of the first level of transformation of a single factor in TSV is shown in Pic. 5.

All factors are divided into two groups: primary, initiating TSV (groups 1–7, 10 according to the NIIAS classifier), and factors of the complex of protective measures (groups 8, 9).

2. Each block of protective measures is also structurally divided into technological elements of the lower level, trees of events of the second level are constructed from these elements. In general, for block i, aone tree is shown in Pic. 6.

3. For each level of protection of all blocks of the second level, a third level event tree is formed to assess the probability of activation of the protection level. The input for the tree of the 3rd level is the output of the protection level from the previous level, and the outputs coincide with the outputs of the branch point to which the third level tree is tied at the 2nd level.

4. For a given event structure, the risk function is generated by factor.

The results of calculating the probabilities of converting primary sources into risks are already recorded digitized in the classifier of factors at the place that stands at the intersection of the line of the type of risk and the factor chosen by the initiator in constructing the tree of events.

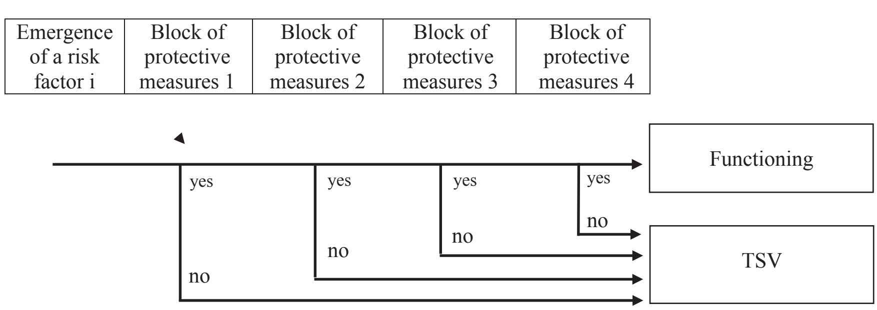
All such intersections with the «+» sign in the NIIAS classifier are filled in.

5. The risk matrix is formed on the basis of the analysis of frequencies and risk losses depending on the factors.

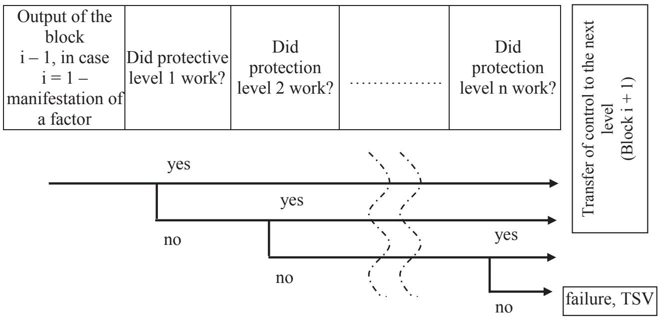
6. The order of analysis of the dynamics of the probability of manifestation of risk depending on the influence of factors is established by analyzing the behavior of the risk function – depending on the change in the values of the factors that are the arguments of this function.

$f(PiF_{j,k}) = F(x_1, x_2, \dots x_n)$, (1)

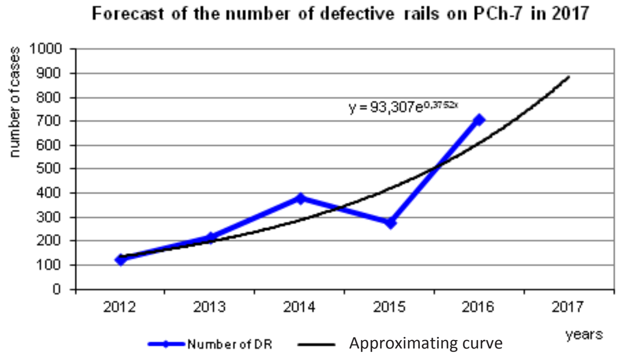
where x_i – the argument corresponding to the factor i.

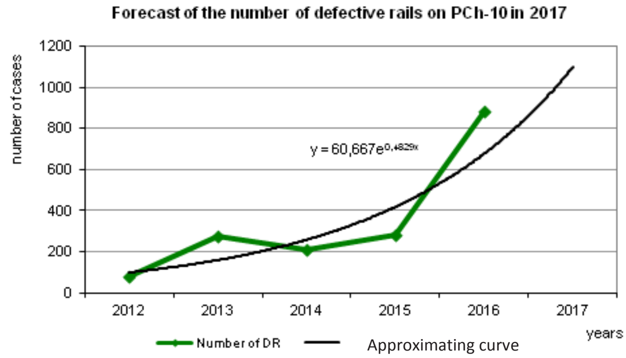


Pic. 5. Tree of events of the first level.



Pic. 6. Tree of events of the 2nd level.





Pic. 7. Forecast of the number of defective rails in 2017: a) on PCh-7; b) on PCh-10.

The analysis is performed as follows:

• partial derivatives are taken over all variables;

• the values of these derivatives at the point (x_{10}, x_{20}, … x_{n0}) are calculated, reflecting the current value of the factors;

• the maximum values are selected from these values;

• for variables whose derivatives exceed the others, the risk function is recalculated, with a certain step;

• the rate of change of risk is compared with the change of various factors;

• those values are selected that correspond to a possible change in the quantitative value of the factor in real control.

Since the maximum values of the partial derivatives correspond to those variables by which the risk exposure is maximized, the factors corresponding to these variables exert the maximum influence on the probability of occurrence of TSV of the type being analyzed.

7. Directions for implementation of corrective actions are based on development of measures that affect the reduction of the contribution of selected factors to the risk. Since these factors have the greatest impact, the effectiveness of response parrying measures to ensure traffic safety will also be greatest.

* * *

The analysis algorithm shown in the article was used to calculate the risks of traffic safety violations on Moscow–St. Petersburg–Buslovskaya high-speed section of October Infrastructure Directorate (OPCh-1, PCh-3, PCh-4, PCh-7, PCh-10) with decomposition according to the main factors – the defectiveness of the railway economy, the deviation of the geometry of the track gauge of the 3rd and 4th degree, and the deviations in the maintenance of turnout switches.

Despite the fact that according to the main indicators the section is classified as low-risk TSV, some trends here require close attention and control. Thus, in Pic. 7, the forecast of the number of defective rails on PCh-7 and PCh-10 is given, which distinguishes two alarming positions.

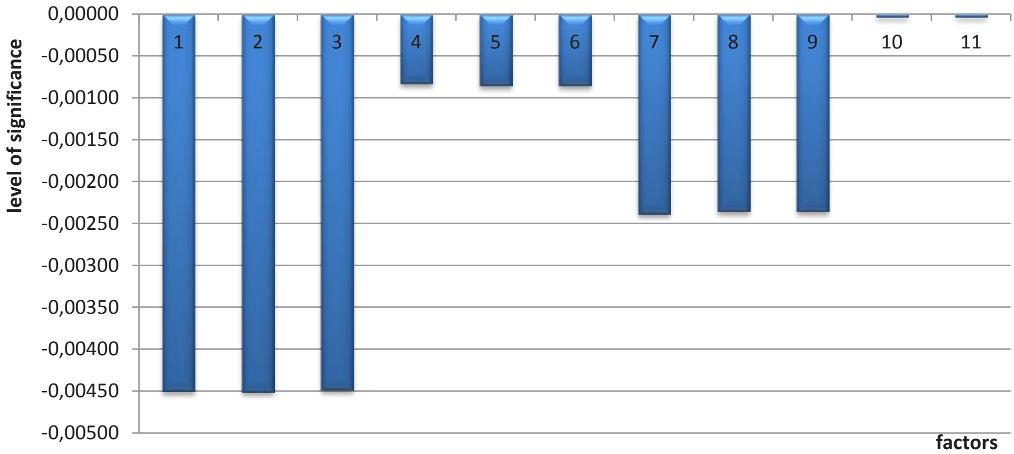
The main risks for the technical component in this sector are related:

1) with a sharp increase in the defectiveness of the rail on PCh-7 and PCh-10;

Table 1

Map of impact of factors on the risk of a traffic safety violation with digitization of the probabilities of derailment, rail fracture under the train

Types of traffic safety violations		Main factors	1		2	3							4			
			Deviations of GRK of 3,4 degrees		Defectiveness of rail economy	Disadvantages of training and qualification of staff							Level of material and technical support			
		Indicators determining the degree of development of factors	Number of deviations of 3,4 degrees	Number of repeats of deviations of 3,4 degree	Number of defective rails lying on the track per 1 thousand km of the main track	Incompleteness of the staff of the track servicemen	Incompleteness of the staff of track foremen	Incompleteness of the staff of road masters	Incompleteness of the staff of operators of track measuring trucks	Incompleteness of the staff of operators of defect detection trucks	Turnover of workers in the professions	Share of employees with experience in the position of less than 1 year	Insecurity with tools and means of small mechanization	Incompleteness PKZ, %	Failure to meet the delivery plan of material and technical resources, %	Insecurity with means of measurement of parameters of track and turnout switches
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Internal types of risks	2. Collisions of rolling stock with other rolling stock, derailment of rolling stock during train or shunting work, equipment or other movements		0,083	0	0,019	0,046	0,0069	0	0,0062	0,0138	0,0046	0,0414	0,0047	0	0,0051	0,0418
	3. Rail fracture under railway rolling stock		no	0	0,718	0,23	0,0344	0	no	0,0044	0,0229	0,21	0,0015	0	0,0016	no
Specials types of risks	2.1. Collisions and derailment of railway rolling stock laden with dangerous goods		0,0058	0	0,00095	0,0032	0,00047	0	0,00044	0,0009	0,00032	0,0028	0,00032	0	0,00036	0,0029
	2.2. Collisions and derailments of rolling stock in passenger trains		0,0652	0	0,0154	0,0368	0,0053	0	0,0049	0,0110	0,0036	0,032	0,00366	0	0,00040	0,033
	2.3. Derailment of railway rolling stock in front of artificial structures		0,01026	0	0,00237	0,0057	0,00084	0	0,0007	0,00017	0,00056	0,0051	0,00057	0	0,00063	0,0051



Pic. 8. The significance of the main factors in terms of impact on risks.

2) with a noticeable sharp increase in the number of defective parts of turnout switches.

In addition, a serious risk at the current time and in the short term is rail fracture under railway rolling stock, as well as derailment due to such a fracture (factor – the defectiveness of the rails). The risk of fracture of PCh-7, PCh-10 exceeds the average network by an order of magnitude.

With the help of the adopted methodology, a map of the influence of factors on the risk of a traffic safety violation was obtained with the digitization of the probabilities of derailment, fractures of the rail under the train. It is presented in Table 1.

An example of effectiveness of the methodology in assessing the impact (significance) of key factors on risks is shown in Pic. 8. The evaluation was carried out according to the indicators determining the degree of development of the factors:

– incompleteness of the staff of road masters;

– incompleteness of the staff of track foremen;

– incompleteness of the staff of operators of track measuring trucks;

– incompleteness of the staff of operators of defect detection trucks;

– turnover of workers in the professions;

– the share of employees with experience in the position of less than 1 year;

– insecurity with tools and means of small mechanization;

– incompleteness of PKZ, %;

– failure to meet the delivery plan of material and technical resources, %;

– insecurity with of means of measurement of parameters of track and turnout switches.

Pic. 8 shows that the main impact on risk at the current values of other factors in the «detectability» block is provided by: completeness of the staff of track controllers, serviceability of a measuring tool, turnover of track controllers, percentage of the plan's fulfillment by the track measuring truck, probability of equipment serviceability (technical availability ratio) of the track, probability error-free operation of the operator of the track measuring truck.

By factors of staffing and qualification, the risks are related to the turnover of foremen of track control, as well as operators of the defect detection trucks.

Based on the analysis, measures can be proposed to adjust the risk:

1) clarification of the reasons for the sharp increase in rail defectiveness, the formation of new reserves, taking into account the forecast of an increased failure;

2) formation of stocks for repair kits of turnout switches, taking into account the forecast of a sharp increase in the defectiveness of their parts;

3) preservation of the staff of track controllers, reduction of turnover in this profession;

4) solution of the issue of completing the measuring instrument for all PCh of high-speed run (now the average security is 50–60 %);

5) preservation of the completeness of the staff of operators of track measuring trucks, limitation of turnover in this profession;

6) maintaining the staff of track masters at the level of 100 % (reducing the turnover in this profession at least twice significantly reduces the risk).

Conclusions. *Summarizing the above, it should be noted that, at the moment, the application of the developed methodology for risk assessment in the field of functional safety of train traffic:*

a) requires manual processing of large amounts of information and is very laborious;

b) formation of a tree of events, individually for each railway, and even for individual sections where the technology differs;

c) risk assessment methods require high professional qualifications;

d) there are fundamental differences in accounting for primary sources of risk (in automated systems of economies), and this leads to the fact that the calculation of the forecast takes into account the state of the grass-roots factors only expertly, the assessment of their influence on the final result is taken into account «in general».

That is, in fact, the direction of the possible development of the evaluation system is the definition of such primary sources of risk and their accounting, which would adequately assess, first of all, the influence of grassroots factors of the functional safety of train traffic.

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