DOI: 10.21683/1729-2640-2016-16-2-49-53

Risk assessment of a system with diverse elements

Valentin A. Gapanovich, *JSC Russian Railways, Moscow, Russia*
Igor B. Shubinsky, *CJSC IBTrans, Moscow, Russia, igor-shubinsky@yandex.ru*
Alexey M. Zamyshlyaev, *JSC NIIAS, Moscow, Russia, A.Zamyshlaev@vniias.ru*

Валентин А. Гапанович

Игорь Б. Шубинский

Алексей М. Замышляев

Abstract. *A measure of the safety of a system's object can be the value of an associated risk which is based on the risks of its constituent factors (elements). The main task of the paper is the definition of the integral risk of an object and a system as a whole. This is as follows. Summing up of risks of all elements is not acceptable, since they may have, for example, different measures (the number of fatalities during a certain period of time is a social risk, and the cost of losses is an economic one). We need some other methodological tool that can transform different measures of safety of objects (elements) into a certain single integral measure of a system's risk. Such tasks occur in medicine, food industry, in transport sector, etc. The paper offers a method to define the integral risk of a system based on the processing of a common field of the results of decisions taken on the level of risks of a system's elements. The results of decisions are based on ALARP principle. Each of these results is one of several further probable decisions, for example, one of four decisions: intolerable risk level, undesirable level, tolerable and negligible risk level. Digitalization of these decisions of constituent elements with consideration of nonlinear growth of danger of the risk approaching to the intolerable level is made using a power function. It helps to define a numerical value equivalent to a component risk level, and then to find a weighted mean resulting numerical value equivalent to a risk level for all system components and solve an inverse task of definition of the integral risk of a system. This article describes an example of how this method could be used to solve the task of the investment priority for the works on technical maintenance of railway track. This task is limited to the ranking of track sections by priority of overhaul performance depending on the level of risks of the following factors: number of defective and flawed rails per 1 track km.; number of defective clamps per 1 track km.; number of pumping sleepers per 1 track km; number of faulty wooden sleepers per 1 track km.; number of places of temporary repair; defects of roadbed; failure rate. Based on the risk matrices constructed by the method described above in relation to each of the listed factors, an integral risk matrix is formed for the list of sections, and based on the integral estimation each section gets a priority of an overhaul performance. The given example is indicative of the efficiency and practicability of the method offered.*

Keywords: *safety, risk, risk assessment, risk matrix, risk color, digitalization of risk color, color weight, element, system, integral estimation of a system's risk.*

For citation: *Gapanovich V.A., Shubinsky I.B., Zamyshlyaev A.M. Assessment of risk of the system with diverse elements // Dependability. 2016, no.2, pp. 49-53. (in Russian) DOI: 10.21683/1729-2640-2016-16-2-49-53*

Introduction

In different sectors of industry and transport in asset management one seeks to establish balance between expenses, possibilities, risks and a required assets productivity, in accordance with ISO 55000 [1]. For instance, on railway transport the implementation of URRAN project [2, 3] provides for consistent application of criteria of safety, technical and economic rationale ensuring when taking decisions on replacement (repair) or extension of a system's service life. Such algorithm of management of railway transport maintenance is realized in two stages. The first stage is to analyze capabilities, safety, reliability and productivity of a system based on processing of current data, and to make a decision on whether it is reasonable (or not) to invest in technical maintenance. If it is decided to be reasonable then the second stage of management takes place when one identifies a system's objects that are of greatest concern from the point of view of safety and require investment in the first place.

A measure of the safety of a system's object can be the value of an associated risk which is based on the risks of its constituent factors (elements). The main task of the paper is the definition of the integral risk of an object and a system. This is as follows. Summing up of risks of all elements is not acceptable, since they may have, for example, different measures (the number of fatalities during a certain period of time is a social risk, and the cost of losses is an economic one). We need some other methodological tool that can transform different measures of safety of objects (elements) into a certain single integral measure of a system's risk. Such tasks occur in medicine, food industry, in transport sector, etc.

Problem statement

Let system A generally consist of a finite set of diverse elements $A=\{a_1, a_2, \ldots, a_i, \ldots, a_j, \ldots, a_k\}$. And there may be a possibility of equivalence of separate constituent elements $a_i \Leftrightarrow a_j$. Safe operation of each system element is estimated by a certain risk value $a_i \to R_i$. Risk is understood as the combination of frequency (probability) of a hazard and its consequences $R=F\Lambda C$ [4]. For the illustrative purpose, the explanation will be restricted to a special case of risk determination in form of $R=F \cdot C$. Risks are formalized with the use of a risk matrix tool. The mathematical basis of construction of a risk matrix is described in works [5, 6]. Generally, a risk matrix contains m lines and n columns. Each line corresponds to a certain frequency of a hazard $f_1, f_2, \ldots, f_m$. Columns correspond to possible consequences (damage) $c_1, c_2, \ldots, c_n$. A measure of consequences depends on the object of analysis. It could be a price (in relation to economic, technical or anthropogenic risks), fatality in relation to social risks, number of negative consequences or negative occurrence of a hazardous event (in relation to moral risks) etc.

It is supposed that the frequencies of hazardous events and their consequences are estimated by a posteriori data. This let us define safety risks of all system elements as respective lines and columns cross. Risks for diverse elements are not equal among themselves, for example, $R_1 \neq R_i$ (risks of equivalent elements are equal $R_i=R_j$). Risk is assessed based on ALARP principle (Risk is as low as reasonably practicable) [4]. This principle includes four assessment levels (Figure 1): two unequivocal and two in-between levels.

The unequivocal levels are the levels of assessment of *intolerable risk* (above the red bar in Figure 1) and *negligible risk* (below the green bar in Figure 1). Areas of these risks are usually marked with red and green colors respectively. The in-between levels are the levels of ALARP area. Above the broken line there is a level of *undesirable risk.* The area of this risk is usually marked with orange color. Below the broken line there is a level of *tolerable risk.* The area of this risk is usually marked with yellow color.

The task is to assess the level of risk of a system based on the results of assessment of risks of its constituent diverse elements. Risks of the elements are supposed to be mutually independent.

Assessment of a system's risk

In many cases the system under study consists of diverse objects that differ in scales of consequences and types of risks (for example, technological or social ones). At present one can neither sum up the risks of constituent objects, nor form a common scale of consequences. To assess a system's risk by the risks of constituent diverse elements, it is necessary to have at least one common measure for all risks. If to consider risks in reference to the scales of measurement of f and c, such common measure is not available. A measure of consequences may be different. It also applies to the rates of hazardous events that can be different for elements a_i and a_j. However, under close examination of the constructed matrices of risks of a system's elements, we find a common measure of risk assessment that is contained in the levels of decision making.

According to ALARP principle, there are four levels of risk severities. A common field for combining the results is the colors of decisions (risk levels) for each of the objects. These levels are marked with green, yellow, orange, and finally with red color as their importance grows. The green

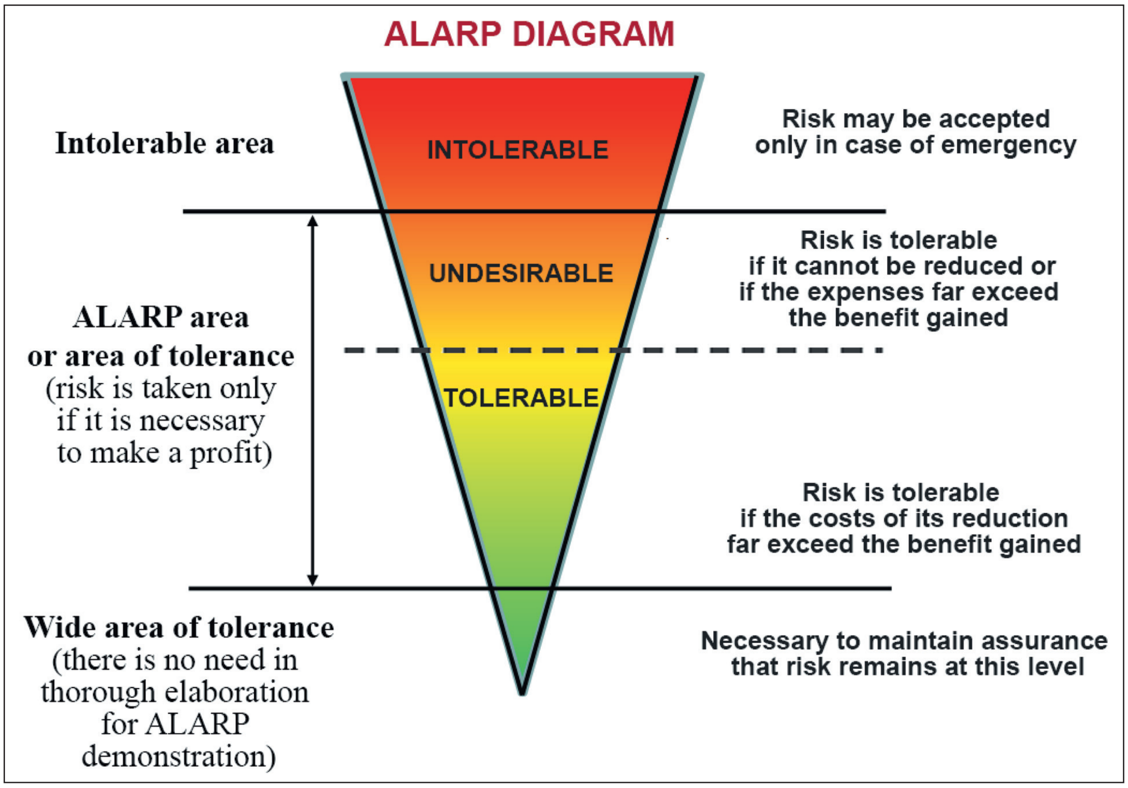

Fig.1. Risk assessment based on ALARP principle

color of a decision means that risk is so negligible that it can be discounted. The function of importance in green cells of a matrix should have low values (from zero up to a certain insignificant value). In addition to that, the orange color and especially the red color mean the highest degree of severity, and the function of importance in these matrix cells should have the maximum high values. There is a possibility of three strategies to construct the functions of the importance of decisions on a risk level in accordance with the accepted colors: 1 – linear; 2 – power; 3 – logarithmic. Figure 2 provides a conceptual representation of the functions of importance.

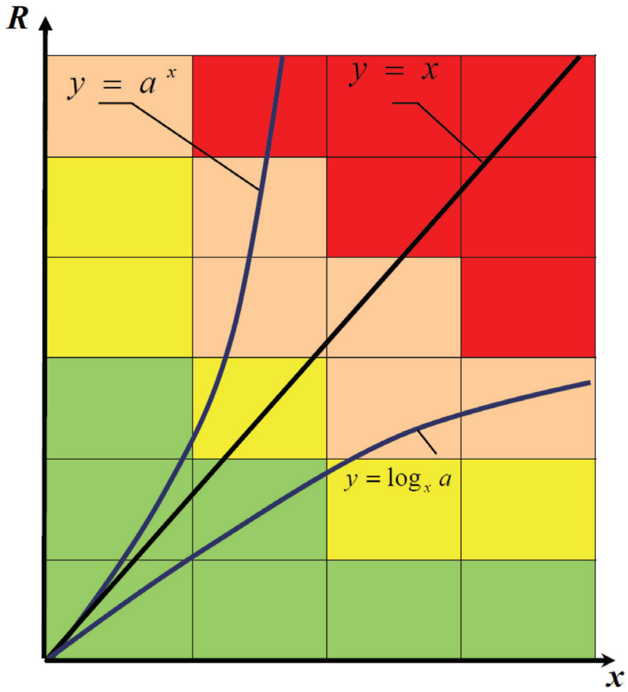

Fig. 2. Functions of importance of decisions on a risk level (concept)

Strategy 1 specifies an indifferent attitude to a change of importance of a decision color.

Strategy 2 specifies a responsible attitude to a change of importance of a decision color.

Strategy 3 should be considered as an irresponsible attitude to a decision taken on an object's risk level, as in this case the function of importance mitigates a severity of red color that reflects an intolerable risk level.

Therefore, to digitize the results of assessment of objects' risks expressed by one of the indicated colors, it is reasonable to use a power function (Figure 2). However, the degree of an importance function corresponding to one of four colors takes only integer values. That is why a power function itself should have a stepwise character based on $a > 1$ (for instance, $a = 1.1$; 1.5; 2; 3; …).

Figure 3 shows step functions of importance with the above indicated bases with four integer values of the degree of a function ($n = 0,1,2,3$).

Step functions with base $1 \leq a < 2$ do not provide a quick response to a change of the importance of a decision color (Figure 4), especially in the field of high risk levels. However, with base $a > 2$ there is an unreasonably quick response to an undesirable level and especially to an intolerable risk level and almost a neglect of the importance of a tolerable risk level (Figure 3). A compromise solution is to choose base 2 of the step function of importance of colors of decisions taken on a risk level.

A color weight is generally defined by formula (1)

$$w_n = \frac{m_n}{\sum_{n=0}^{3} m_n} \qquad (1)$$

where a digitized value of a risk level color, for instance *negligible* (marked with green color in Figure 3), with importance function $m_n = 2^n$ is equal: $m_0 = 2^0 = 1$.

Integral assessment of system risk can be calculated by formula (2)

$$R = \frac{\sum_{n=0}^{3} k_n m_n w_n}{\sum_{n=0}^{3} k_n m_n}, \qquad (2)$$

where k_n is a number of a system's elements with a risk level of the n-th coloration;

m_n is a function of the importance of risk coloration;

w_n is a color weight.

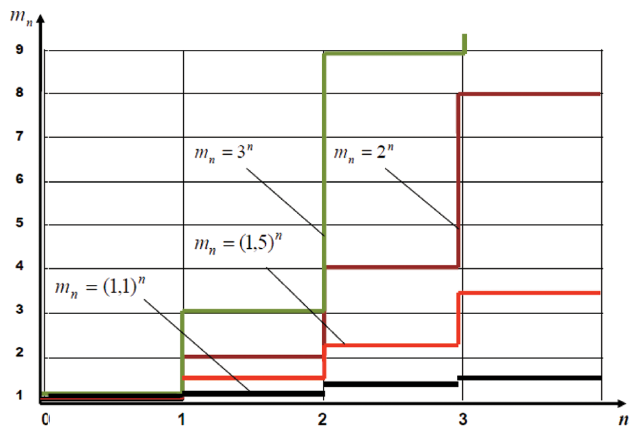

Fig.3. Step functions of the importance of risk level decision colors

Table 1 summarizes weights of colors of typical risk matrix cells as well as values of assessment of decisions taken on integral risk.

Within the limits of each of the second and the third risk levels the ranking of integral risks is made by a linear law in order of increase.

Example

Let us consider the assignment of works on technical maintenance of railway track. An assignment algorithm can be divided into two blocks. Within the first block using logical inequations, we compare real and control values of

Table 1

	Index, *n*	Digitized value, m_n	Color weight, w_n	Values of estimation of a decision taken on integral risk
	0	1	**0.067**	$w_0=R$
	1	2	**0.133**	$w_1 \le R < w_2$
	2	4	**0.266**	$w_2 \le R < w_3$
	3	8	**0.533**	$W_3=R$

the following indices: speed of passenger trains; speed of freight trains; direct expenses on running maintenance of 1 km of track; handled tonnage, mil. gross. t.; residual life of railway track.

Thus, within the first block we analyze such parameters as track group, track category, track class, handled tonnage after overhaul, estimation of residual life of railway track. For different groups depending on the type of underrail base, real state of track bed structure and engineering structures, speeds for freight and passenger trains are established. Infrastructure restrictions are checked for. Real direct expenses on running maintenance of 1 km of track are analyzed with consideration of cost of failure elimination on 1 km of track, cost of train delay due to failure, data about wages of track servicemen, cost of materials and cost of machine operation. Other expenses have been considered as conditional-constant or insignificant and are not taken into account.

The analysis results in identifying the reasons for speed restrictions for freight and passenger trains caused by poor status of engineering structures, roadbed and other track elements that require an overhaul. When a decision is made on impossibility of review of design speeds towards reduction, an investment request is formed and proceeding to the second block is made.

If all logical inequations are positively fulfilled, the algorithm is completed, running maintenance works are assigned and there is no need to proceed to the second block.

The second block of the algorithm is a family of risk matrices for the ranking of track sections by priority of overhaul performance depending on the level of risks of the following factors:

1 – number of defective and flawed rails per 1 track km.;
2 – number of defective clamps per 1 track km.;
3 – number of pumping sleepers per 1 track km.;
4 – number of faulty wooden sleepers per 1 track km.;
5 – number of places of temporary repair;
6 – failure rate;
7 – defects of roadbed.

Based on the constructed risk matrices by the method described above, an integral risk matrix is formed (Figure 4) for the list of sections, and based on the integral estimation each section gets a priority of an overhaul performance.

Reference number of a factor	Section 1	Section 2	Section 3	Section 4
1	0.13	0.53	0.13	0.07
2	0.53	0.13	0.13	0.07
3	0.07	0.27	0.07	0.13
4	0.13	0.27	0.27	0.07
5	0.27	0.53	0.13	0.07
6	0.27	0.13	0.07	0.07
7	0.07	0.53	0.13	0.07
Mean value for a section	0.32	0.43	0.14	0.09
Priority	2	1	3	4

Fig.4. Integral risk matrix

In this example the assessment of integral risks is carried out for four track sections. Despite a rather low risk of traffic disruption caused by track failures (factor 6), there are still active risks for section 2 that are related to defective and flawed rails (factor 1), defects of roadbed (factor 7) and number of places of temporary repair (factor 5), and for section 1 factor 1 is a problem (risk related to defective clamps). Assessment of integral risks has shown that for the first three sections they have an undesirable level, and an integral risk of the fourth section is close to the level that may be neglected. Ranking of risks of the first three sections shows that the priority of investment should be passed to the second section, then – to the first one and afterwards it could probably be passed to the third section if there is such possibility, since an integral risk of the third section is close to a tolerable level.

Conclusion

It is reasonable and convenient to estimate the safety of technical systems using risks. In practice the ALARP principle is widely applied. It helps to assess the rationality and sufficiency of economic expenses spent to reduce risks of violation of system safety. A convenient tool used to realize this principle and to support decision making is a risk matrix. A risk matrix is constructed for each element of a system. A system normally has diverse elements – frequency of negative consequences may have different scales, and the consequences may be defined by different physical values. It does not allow combining the risks of elements by addition to determine the integral risk of a system. The paper offers a method to define the integral risk of a system based on the processing of a common field of risks of a system's elements, i.e. a field of the results of decisions taken on risks that are expressed by colors. Digitalization of the colors of risks of constituent elements with consideration of nonlinear growth of danger of the risk approaching to the intolerable level helps to define its digitalized value, and then the integral risk level. The given example is indicative of the efficiency and simplicity of application of the method offered.

This method could be applied in other sectors, for example, in medicine, in assessment of integral risks in food industry, in assessment of efficiency of complex technical systems, etc.

References

1. GOST R 55.0.00-2014. Asset management [Text].-Intr.2015-04-01. – M.: Standartinform, 2015.-230p

2. Gapanovich V.A., Shubinsky I.B., Zamyshlyaev A.M. Construction and use of risk matrices in risk management system on railway transport // Dependability, – 2011. – No.4. – p.56-68.

3. Gapanovich V.A., Zamyshlyaev A.M, Shubinsky I.B. Some issues of risk and asset management on railway transport based on the state of operating reliability and safety of objects and processes (URRAN project) // Dependability, – 2011. – No.1. – p.2-8.

4. GOST R 54505-2011. Functional safety. Risk management on railway transport [Text]/- Intr.2012-08-01. – M.: Standartinform, 2012.-40p

5. Novozhilov E.O. Guidelines for construction of a risk matrix // Dependability, – 2015, – No.3. – p.73-79.

About the authors

Valentin A. Gapanovich – PhD, chief engineer, senior vice president JSC RZD, Moscow, Russia, tel. +7 (495) 262-16-43

Igor B. Shubinsky – Dr.Sci., professor, director of CJSC IBTrans, Moscow, Russia, tel.: +7 (495) 786-68-57, e-mail: igor-shubinsky@yandex.ru

Alexey M. Zamyshlyaev – Dr.Sci., Deputy director general JSC NIIAS, Moscow, Russia, tel.: +7 (495) 967-77-02, e-mail: A.Zamyshlaev@gismps.ru