GUIDELINES FOR ACHIEVING SUCCESSFUL DECISION-MAKING ON RISK ACCEPTANCE IN RAIL TRANSPORT UNDERTAKINGS

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ABSTRACT
Operation of railways is inevitably linked with the possibility of occurrence of a wide variety of hazards, some of which have high potential to cause accidents with very serious consequences. It is acknowledged that the elimination of all hazards and risks connected with them is virtually impossible. However, this well-known fact does not mean that the technical operation of railways there should be only reactive attitudes towards safety as a whole and risks in particular. The potential hazards and associated with them risks must be reduced to a practically acceptable level. Solving this problem is associated with a very important element of the safety management, namely risk management. The present paper discusses the procedure and possible managerial ways to keep operational risks in transport undertakings on a reasonably practical level.

Key words:
Rail transport, Operational safety, Risk, Risk acceptance

ABSTRACT
Prevádzkovanie železničnej dopravy je nevyhnutne spojené s možnosťou výskytu širokého spektra ohrození. Niektoré z nich majú vysoký potenciál spôsobiť nehodu s veľmi vážnymi následkami. Je známe, že odstránenie všetkých hrozieb a rizík s nimi spojenými je reálne nemožné. Avšak, neznamená to, že nie je možné s nimi pracovať. Možné ohrozenia a s nimi spojené riziká musia byť znížené na prijateľnú úroveň. Riešenie tohto problému súvisí s veľmi dôležitým elementom bezpečnostného manažmentu, a to s riadením rizík. Článok pojednáva o postupoch a manažérskych metódach na udržanie prevádzkových rizík v železničnej doprave na prijateľnej úrovni.

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Kľúčové slová:
Železničná doprava, prevádzkové riziká, aceptovanie rizík

1 INTRODUCTION

The successful safety management of transport companies requires two basic things - firstly, reliable information about events and phenomena occurring within the operation process, and secondly, proper analytical tools for their analysis and assessment. In a more specific sense, where decision-making on issues of operational safety is necessary, the availability of information regarding the hazards and risks for the transport process is a basic requirement.

Historically, railway managers have always relied on "sufficient expertise and information" for this type of industry, especially when it is necessary to evaluate the risks associated with the operation of technical equipment and its usage by the operating personnel. In other words, thanks to its long history and specific characteristics, railway transport has always had a great success in maintaining a significant amount of "fundamental knowledge" on safety. However, recent decades have been marking a significant growth of the new technical and technological solutions used within rail industry. The lack of adequate and typical for their specifics knowledge about their safe behavior leads to the need for development of new analytical and forecasting techniques, the majority of them based on the concept of risk and the principles of its management.

Therefore, the proper understanding of the nature of risk, its elements and principles of management, and also the peculiarities of the process of decision-making in this area are essential for achieving an acceptable level of system safety in railway undertakings. The essence of risk and related concepts, approaches and applicable decision-making methodologies are subject of discussion in the present paper

2 PRACTICAL GUIDELINES FOR DECISION-MAKING IN SYSTEM SAFETY

From a practical point of view, within safety management system of a rail undertaking (infrastructure manager or carrier) there are three major issues whose proper understanding and relevant actions are the fundamental for successful decision-making in system safety management. They could be expressed by the next three questions: What the terms hazard and risk mean?, How the hazards could be identified and the concomitant risks ranked? and How to make successful decision in the most appropriate manner to reduce the highest risks on a practicably reasonable level?

2.1 HAZARD AND RISK ESSENCE

It could be said that there is no a broadly accepted definition of risk. The literature review in the field of safety shows that the concept of risk is used in many fields and areas of human activity, but in a number of cases quite descriptively, and mainly for interpretation of partial tasks and problems. The author of present paper reckons that in terms of the practical issues of rail safety, the most appropriate understanding of risk is as referred to as triplet (s_i , p_i , c_i), whose elements are: s_i - *i*-th accident (incident) scenario, p_i - probability of occurrence of scenario *i*, c_i - consequences (effect) after scenario *i* [5].

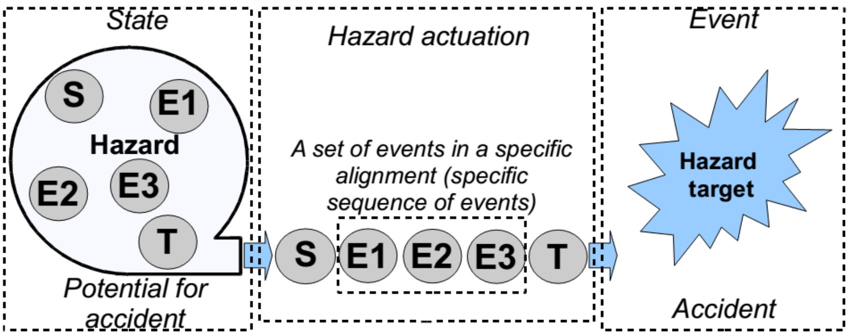
Risk is an inevitable attribute of every hazard. The latter is an ongoing (but unwanted) state of a technical or technological system and is usually the initial stage of an accident scenario. The probability of hazard existence depends on system design and its attributes, and may be just 1 (hazard exist in the system) or 0 (hazard does not exist in the system). Every hazard has three major components and the comprehensive knowledge about them makes the hazard recognizable. They are:

- *Source of hazard (Hazardous system element).* This is the major hazard element creating the impetus for its occurrence, such as a mechanism whose specific failure may be hazardous regarding system functioning.

- *Actuating mechanism.* This is a unique sequence of events (initiating and successive) transforming a hazard from dormant (principally existing) state to an active accident state.

- *Target*. It could be a person or an object that is vulnerable to injury and/or damage, and it describes the severity of the accident happening after hazard actuation.

Railway accident (incident) happens when all components of the actuating mechanism of a hazard (generally randomly oriented with respect to the corresponding process having specific relation with the entire transport process) are "arranged" in a logical order. This order is known as accident scenario. The accident scenario contains an initiating (trigger) event and one or (usually) more intermediate events leading to the final mishap state. The concepts of *hazard actuating mechanism* and *accident scenario* are illustrated in Figure 1.



S-source of hazard, **T**-hazard target, **E**-element (event) of hazard actuating mechanism

Fig.1.*Hazard – Accident* actuation

2.2 IDENTIFICATION AND RANKING OF HAZARDS

This is one of the most important stages of the overall process of risk analysis. This is an analytical and sometimes complex to implement process of "visualization" and "knowledge acquisition" concerning a hazard on the basis of certain statistical information on incidents (accidents) and knowledge about the studied technical or technological system (subsystem, individual element). In addition, the correct identification of hazards requires extensive knowledge on both the general methodological issues of risk management and the existing analytical approaches (and also methods) for description of hazards elements. There are a number of practical approaches to identify hazards within the scope of the technical operation in a railway undertaking, the most common of them are based on:

-available information on adverse events and gained operational experience;

-known or priori facts regarding the causal chain "source-target" that is typical for a hazard;

-analysis of good practice existing in the risk management;

-concentration on potential and conceivable adverse results (events) within the corresponding studied process.

-verification and analysis of common or partial safety criteria, norms, regulations, provisions, rules, principles and objectives, etc.

The identification of a concrete hazard should contain a description of its all three components. The description should be clear and concise, yet comprehensive enough to be used as a basis for further risk analysis. Unidentified hazards or misstatement descriptions may lead to extremely undesirable consequences, such as: expenditure of time and resources for activities (mitigation measures) associated with low-risk hazards and skip the implementation of adequate measures in respect of other high-risk hazards. In that sense, one of the most essential elements of safety management system of a railway undertaking is the so called *hazard record*. It should describe in the most complete manner all possible hazards that may occur within the implementation of transport process. *Hazard record* plays the role of a knowledge foundation on the basis of which the decision-making for safety improvement is made. Therefore, the correct description of hazards is an important element not only of the theory, but of the practice of risk management.

Activity (Source of hazard)	**Risk Rank** (Score)
A1	20
A2	1
A3	67
A4	10
A5	8
A6	3
A7	15
A8	4
A9	4
A10	3

Tabl.1.Risk ranks table

There are quite a few methods of hazard identification and analysis. The analyst must carefully choose the appropriate analytical tools to achieve the objectives of performed analysis.

Another essential practical problem that is to be solved and is situated between the procedures of hazards identification and decision-making for defining mitigation measures for safety improvement is hazards gradation (ranking) with respect to the level of their risks. In any railway organization or undertaking, there are usually a great number of conceivable hazards and the concomitant risks have to be ranked. This is necessary because some of them (those having the highest level of risk) will demand immediate actions and allocation of resources. A very powerful tool used to rank and prioritize risks is the so called *Pareto Analysis*.

The *Pareto analysis* is based on *Pareto principle* named after Dr. Juran (well known scientist in the field of quality management) [4]. That principle applies very widely to many types of activity and can be stated as: “Most of the effects are due to a few of the causes.” The *Pareto principle* is also known as the 80/20 rule because it is based on the idea that 80 percent of a situation's problems can be traced to 20 percent of the causes.

In safety management of a given railway organization, the *Pareto Analysis* could be implemented through the next steps:

◦ Preparation of a list of hazard (risk) sources according to the specific activities

Activity (Source of hazard)	**Risk Rank** (score) *descending order*	**Cumulative Risk Rank** (score)
A3	67	49.630
A1	20	64.444
A7	15	75.556
A4	10	82.963
A5	8	88.889
A8	4	91.852
A9	4	94.815
A6	3	97.037
A10	3	99.259
A2	1	100.000

Tabl.2.Cumulative ranks, %

of studied railway undertaking, e.g. activities (sources of risk) from **A1** to **A10**.

◦ Assessment of the magnitude of every activity’s risk (Table 1). This stage could be fulfilled by the usage of some methods. The simplest one is by the utilization of rank matrices - providing capability to evaluate as the ranks of individual elements of risk and also the total risk rank (score).

◦ Ranking of the sources of hazard in descending order of risk score (Column 2 of Table 2).

◦ Calculation of the cumulative scores - starting from the top of Table 2 (Column 3 of Table 2).

◦ Analysis of which sources have contributed to 80% of the total risk. In the example presented in Table 1, almost 80% of the total risk in rail undertaking has been contributed by just four (sources of hazard: **A3**, **A1**, **A7**, **A4**) of the total ten sources of hazards, that is, 80% has been contributed by 40 % of the sources.

◦ Emphasis on those activities (sources of hazard) which contribute most to the total operational risk (safety) in studied railway undertaking.

The *Pareto Analysis* is a starting point to a more detailed analysis (if applicable and necessity). Of course, the initial intention has to be emphasized on undertaking activities (sources of hazard) with highest risk (those contributing to 80% of the total operating risk). Further actions should be focused on activities with calculated low total risk but having high potential for great severity of consequences. Additional analysis about their probability of occurrence has to be performed, and if it turns out high or there is great uncertainty concerning its magnitude some appropriate measures should be put in place.

3 DECISION-MAKING ON RISK ACCEPTANCE

It must be recognized that the evaluation procedure regarding acceptability of risk as a whole and in particular the choice of approaches and criteria to implement that evaluation are the most controversial elements of the entire process of risk management. Work [3] summarizes the complexity of these elements.

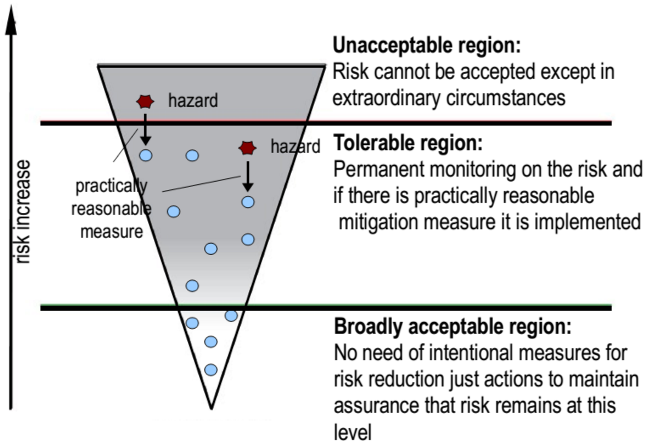


Fig.2.ALARP regions

The assessment of risk acceptance has two main elements*: approach (principle) of acceptance* and *criterion of acceptance*.

The *criterion of risk acceptance* is a pre-accepted benchmark $R_{benchmark}$ against which the risk under assessment $R=f(s_i , p_i , c_i)$ is to be compared. Generally, the criterion can be of any kind: value of a parameter, characteristics of a technical or technological system, rules for risk management, etc. In most standards for risk analysis, assessment and evaluation, the criterion of risk tolerability is defined in advance as an essential element (touchstone) of the entire safety management procedure (Figure 2).

The *approach (principle) of acceptability* determines the manner by which the criterion for risk evaluation is interpreted. In this sense, there are three main approaches, namely*: MEM principle*, *GAMAB principle* and *ALARP principle*.

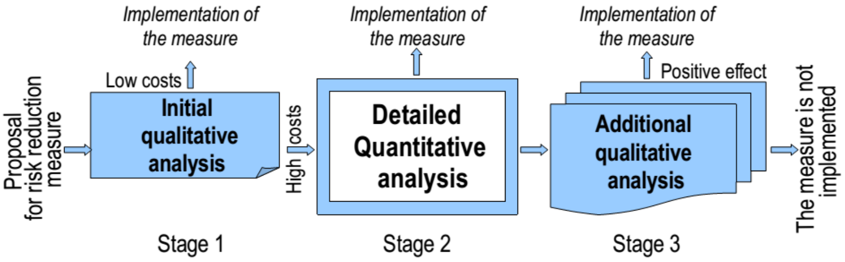


Fig.3.Procedure of application of ALARP principle

ALARP principle is the most suitable for practical application, easy to understand and providing capability for comparatively accurate results within safety management system of a railway undertaking. ALARP is an acronym for *as low as reasonably practicable* and says that the risks associated with the functioning of a system should be reduced to a level that is as low as reasonably practicable, i.e. if the risk reduction achieved by implementing certain safety measures is insignificant compared to the costs of these measures, it would not be reasonably practicable to implement them. In other words, a risk reduction action is not reasonable (it does not lead to a reasonably low level of the risk) if there is a gross imbalance between the risk reduction and the related costs allocated to this reduction action. The ALARP principle defines three risk levels which can be illustrated by Figure 2.

In most cases, the risk is situated on certain level in the field of tolerable ALARP region (for the upper and lower limits of which there are quite a few proposals, e.g. [6], [9]). As mentioned above, this fact implies the need for continuous monitoring, analysis and evaluation of the risk to justify the need to define and implement measures for its reduction. This need is sometimes obvious, but in many cases further analysis is required, and for this purpose many engineering and economic approaches and methods are applicable. That problem is discussed in lots of scientific papers, e.g. [7], [8], [10], [11], [12] and [13].

The structure of procedure for applying the ALARP principle for justifying risk reduction activities in railway undertakings can be summarized as follows (Figure 3):

◦*First stage*: Performance of a qualitative analysis of the benefits and problems of application of a certain measure for risk reduction. If the cost of measure is not considered to be significant - the measure is implemented. It is deemed that there is no significant disproportion between the costs and benefits of the measure.

◦*Second stage*: If on the previous stage the costs have been defined as significant, an additional economic analysis should be performed. Depending on the criterion (indicator) there are several possible approaches for further analysis, the most used of which are:

-*Cost Per Unit Risk Reduction* - E_{CPURR}:

$$E_{CPURR} = \frac{NPV}{M_{equivalent}}, \tag{1}$$

where: $NPV = \sum_{t=0}^{n}\left[(B_t - C_t)(1+r)^{-t}\right]$ -*Net Present* Value (NPV) of implementing a risk control measure, computed on the basis of B_t - total costs in period t, C_t - total benefits in period t (without economic benefit of reduced number of fatalities), t - time horizon for the assessment of studied risk reduction measure (0- first year and n - last year of the assessment period), r - discount rate;

$M_{equivalent} = M + S/10 + L/200$ - *Equivalent mortality*, computed through: M - number of *Fatalities*, S - number *of Major injuries*, L - number of *Minor injuries* [1].

Obtained for different risk reduction measures E_{CPURR} is used for decision making in the process of safety management and most specifically whether the implementation of respective mitigation action (measure) is economically expedient.

-*Implied Cost of Averting a Fatality* - E_{ICAF}:

$$E_{ICAF} = \frac{E_{annual}}{M_{reduction}}, \tag{2}$$

where: E_{annual}- annual cost of the mitigation action;

$M_{reduction}$- reduction in annual fatality number.

The practical application of this approach requires a criterion by which to determine the effectiveness of the studied mitigation action. In specialized literature, there are some proposals for such a criterion. [2] proposes that a certain risk reduction measure with $E_{ICAF} \leq USD\,3\,milion$ could be deemed as cost-effective and because of that implemented to reduce the risk from one ALARP level to another. References [14], [15] and [16] present some other analytical tools that could also be used on this stage of ALARP principle application.

◦*Third stage:* Performance of additional qualitative analysis in the event that the approach and criterion of the second stage did not show conclusive results on the effectiveness of studied risk reduction action. At this stage, lots of analytical techniques could be in help of analyst and decision-maker, for example: *What-if analysis*, *Check List Analysis*, the like. In any case, it is necessary to address as many aspects of measure effectiveness as possible, for instance: Presence of uncertainty about the influence of certain phenomena, events and conditions on the specifics of risk and how the proposed measure will reduce this uncertainty; Connection of the measure with the best available technical and/or technological solutions; Practical applicability of the measure to improve quality of undertaking's safety management system; Presence of potential for "residual" problems after the implementation of measure and especially within the operational safety; Presence of potential conflicts between different branches of the technical exploitation after measure implementation.

If the additional qualitative analysis shows possibility (or presence) of positive trends in result of mitigation action (measure) implementation, the action is adopted as effective, i.e. there is no significant disproportion between the costs and benefits of measure.

4 CONCLUSION AND DISCUSSION

The process of risk management is vital for safety management in a given transport undertaking. It allows to obtain a comprehensive picture about risks to the operational process caused by the behavior of technical equipment and human-operator working together to meet the major purpose - safe transportation process. Moreover, the risk management allows comparing the levels of a type of risk before and after occurrence of specific events and/or conditions. This is particularly important for safety management, because it allows assessment of the effectiveness of risk reduction measures. The latter is of great importance regarding overall functioning of railway undertaking, simply because safety improvement is a controversial matter - always required but at the same time connected with costs (sometimes very large). The operating experience shows that in many cases safety experts meet serious difficulties to justify the need to define and implement safety measures. The main reason for that is the presence of uncertainty regarding many of risk evaluation aspects. The present paper discusses the approaches and stages of the practical implementation of procedure for decision-making regarding risk and safety improvement in rail undertakings.

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