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Risk identification methodology regarding the safety and quality of railway services

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Abstract
The paper deals with the implementation of a modified FMEA methodology according to the EU Commission Regulation no. 402/13 on a common safety method for risk assessment and evaluation in the railway sector. The basic goal is to create a methodology for risk identification regarding the safety of services in railway transport concerning railway crossings. Reason for this research was the fact that the manager of the railway infrastructure in Slovakia has problems related to accidents at railway crossings including problems with the quality of services when trains are delayed. Based on previous research, this area has been defined as a priority for risk identification. Accidents at level crossings are often the result of complex interactions between several factors. The results of the authors' long-term research bring direct impact on the safety and quality of rail transport services. The first effect of the research is a detailed investigation of the causes of accidents, on which the new methodology is based. This is important because understanding the causes of accidents is the first step in eliminating them. The proposed new framework of the methodology provides guidance to the railway infrastructure manager on how to identify, analyze, evaluate and eliminate the risks of their effects.

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1. Introduction

Railway undertakings face different types of risk when providing services (Dolinayová et al., 2016). Risks can arise at all levels of the railway undertaking's management and are very specific in the transport market environment (Buganová, 2011). Therefore, it is essential to identify them in a timely manner and to know the extent of the size of the risk, ie the extent to which the risk can be accepted and from what level it becomes unacceptable to the railway undertaking (Bartol, 1991; Feigenbaum, 1991; Broh, 1982; Framework, 2012; Gitlow et al, 1989).

The manager of railway infrastructure in Slovakia has long recorded problems related to accidents at railway crossings (ŽSR, 2021). Railway safety depends on a reliable infrastructure and reliable systems (Smejkal, 2010; Smejkal, 2013). The main task of the level crossing security system (signaling system) is to ensure the safety of traffic at the point of level crossing of two different modes of transport: road and rail (Griffin, 1990). From the point of view of safety, it is the most dangerous place on the railway line (Soušek, 2010). From the point of view of customer satisfaction and quality of services, each risk affects the perception and decision-making on the use of rail transport in the future (Varcholová et al, 2008; Matuczny, 2020).

Therefore, the paper deals with this issue, where based on research, this area has been defined as a priority for risk identification. A level crossing is a very dangerous and critical place where a rail vehicle can collide with a road motor vehicle (Dolinayová, 2015). Accidents and deaths at level crossings account for more than a quarter of all rail accidents on EU railways (Novák, 2011). Almost 300 people die each year at level crossing accidents (EU) (Nedeliaková et al, 2021). In recent years, an average of six fatal accidents have occurred at rail crossings in Europe each week, and a further six are seriously injured. Accidents in general have a negative impact not only on the railway sector itself and its operation, but also on people and material values (Pitra, 2007). The economic damage is estimated at 1 billion € per year (Soušek et al., 2010). In connection with the damage caused, it is not only possible to talk about the costs associated with damage to the vehicle and infrastructure, but also indirect costs related to the interruption of traffic (Svozilová, 2011). Extraordinary events, accidents and failures can lead to the loss of name, customer, and business partners (Juran, 2005; Hammer et al., 1999; Knop, 2021). Railway development and confidence building depend on a high level of quality and safety (Hnilica et al., 2009; Jones et al, 2000; Tzanakkis, 2021).

Countries with the lowest accident rates usually have comprehensive safety strategies, which are reflected in a low number of poorly or insufficiently secured crossings (Profillidis, 2016). The methodology is based on the principle of the modified FMEA method. The narrowing of the issue of risk management is based on the requirements of the railway infrastructure manager. This issue resonates as a societal problem for a long time, as crossings represent a place of safety threat with an impact on the services provided by rail transport (Donabedian, 1980; Dvořák, 2010; Gatewood, 1995; Harausová, 2012).

Only after a thorough analysis of risk can a set of measures be taken (Luczak et al., 2008). This will eliminate its level to an acceptable one in the future. The basic pillar of the paper is an algorithm that systematically establishes the gradual steps of the modified FMEA method applied in railway transport.

2. Current state

Looking at the detailed data of categorized rail accidents at EU in 2019, it is clear that the most accidents with an injury are caused by the movement of rail vehicles (Nedeliaková et al., 2012). These represent 53% of all accidents. The second most common cause of accidents in 2019 was accidents at railway crossings which were caused mainly by road transport (Gašparík et al., 2008; Drljača, 2019). According to Figure 1, these accidents account for almost a third of the total number of serious accidents.

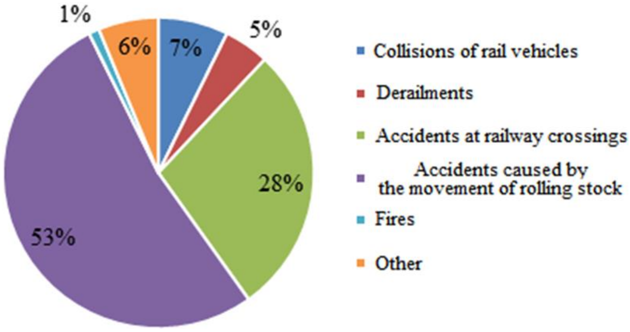

Fig. 1. Accidents by type in the EU-28

According to Figure 2 (Appendix A), in the EU in 2019, most people died on the railways in the categories "accidents caused by the movement of rail vehicles and accidents at level crossings" (Nedeliaková et al., 2021).

Over the years 2010-2019, 3035 lives have been lost and 2905 people injured at level crossings in the EU (Kafka, 2009; Nedeliaková et al., 2021). According to Figure 3 (Appendix B), 141 passengers and 81 employees of railway undertakings died at railway crossings.

3. Methodology

The results of the paper consist of the following partial outputs, which are:

- Defining a set of factors influencing the emergence of risk at crossings,
- Defining a formula for calculating risk priority number,
- Design of a modified Failure Mode and Effect Analysis (FMEA) methodology in manager of railway infrastructure (MI) conditions (EU Commision, 2013).

In the conditions of the Slovak Republic, a model that would focus exclusively on risk assessment in railway transport has not been created so far (Nedeliaková et al., 2013). The risks are monitored separately by the infrastructure manager and separately by the carriers (Nedeliaková et al. 2009). As this is a broad issue, the area of risk identification has been narrowed down to level crossings as proposed by the Railway Infrastructure Manager (ŽSR) (Pyrgidis, 2019; Ruth et al, 2019).

Risks are most often identified using various methods (Brainstorming, Point Method, Causal Layered Analysis, What-If, Failure Tree Analysis, Hazard and Operability Study (HAZOP), Method Organised Systematic Analysis of Risk (MOSAR), Process Hazard Analysis (PHA), Event Tree Analysis (ETA), Delphi Method, SWOT and others) (Mulačová et al. 2009). Several have been assessed, but the most suitable for risk assessment in rail transport is the FMEA and its elements. The method can be applied not only to analyze the causes of defects already identified, but also in order to prevent defects that are likely to occur in the product (Krynke et al., 2014; Jain, 2017; Kowalik, 2018). The best results are achieved by a combination of several methods and techniques.

Risk identification is not a one-off matter, but it is an activity that is carried out periodically or continuously, depending on the purpose and need (Kollár, 2013). In connection with the identification of operational risks at railway crossings, several methods were used in the work.

Several carriers, the infrastructure manager, were interviewed and subsequently provided internal risk lists, management review reports, annual reports and safety audit reports for the research. The involvement of all stakeholders is a prerequisite for the success of this phase.

Benchmarking research has identified a total of 75 hazards that can be grouped into one of five categories, namely risks related to technical problems of level crossings, risks related to the location of crossings that affect visibility, risks due to human failure, risks due to non-compliance and other risks (Nedeliaková et al., 2021). The biggest threats are the technical risks and the human factor. Based on the data set, a list of risks was prepared. Table 1 shows a sample of the most frequently identified hazards that occur at level crossings. During the research, the causes of errors at railway crossings, which may arise in connection with the technical condition, errors of drivers, employees and other causes, were monitored. The results are focused on risky situations at railway crossings as mentioned above. In this phase, several interviews were conducted with ŽSR employees. The infrastructure manager provided the company's internal materials for research (Safety Audit, Annual Reports, Reports on the state of railway safety and others) and a data database, which contained 11-year statistics on accidents at level crossings.

Table 1. List of the most frequently identified risks at level crossings

Absence of luminescent and reflective elements on passages (night use)	Unsatisfactory construction solutions at crossings and passages
Absence of road traffic signs	Unsatisfactory viewing conditions
Absence of safety signaling system	Low level of public discipline of road transport participants
Road vehicles pass through a level crossing when barriers are being lowered or lifted	Limited visibility of traffic lights (due to the presence of physical barriers)
Barrier lowering or lifting time	Limited visibility of an incoming train (large turning angle or road angle)
Traffic jam at the railway crossing	Limited visibility of railway signals to the driver (due to the presence of physical obstacles)
Pedestrians, cyclists and motorcyclists ignore the safety signaling system	Locomotive fault (brakes, light or audible warning device not working)
Other obstacles at the crossing (animal, rock, tree ...)	Safety signaling system does not work
Non - compliance with standards by road infrastructure managers	Slope ratios
Non-compliance with ŽSR standards	Technical failure of the vehicle
Malfunctioning train detection system	Drivers ignore safety signaling system
Adverse weather effects	Bad and insufficient maintenance of safety signaling system
Incorrectly (insufficiently) lowered barriers	Poor and insufficient maintenance of railway crossings
Unsatisfactory railway superstructure / level crossing structure	Poor road condition causing problematic vehicle crossing

The database includes 518 records of traffic accidents at railway crossings, data on the cause and consequences of the accident, description of the damage, information on the type of crossing, data on the place of the accident, date, and time. These data became the source of the design of the modified FMEA method in the conditions of the infrastructure manager.

Research has shown that accidents most often occur at crossings secured by traffic lights without barriers and unsecured crossings. The fewest accidents are registered at crossings equipped with barriers. In the case of unsecured crossings, accidents most often occur with reduced visibility, viewing conditions and due to ignorance of local conditions. Minor problem can be occasional failures at railway crossings, when the safety system is activated even without a real train running. Another threat is the disproportionately long time when the barriers are down. This situation often leads drivers to break the rules and to cross the vehicle with the warning lights activated. The problem of crossings is also the change of local conditions (creation of a shopping center, sports and recreational area, new house construction), which can fundamentally change the traffic and thus the safety at the crossing. Roads of I. and II. classes are administered by SSC (Slovak Road Administration), Roads of II. and III. classes are administered by self-governing regions, local municipality, which in accordance with Act no. 135/1961 (Road Act) are obliged at the time of the national census to carry out a census of road transport on roads owned, in their own name and at their own expense. The data collected from the census are often incomplete or do not correspond to reality. Almost all accidents at crossings were caused by road users, the main reason being non-compliance with road traffic rules. Drivers of cars and vans, pedestrians, cyclists and truck drivers caused the most accidents.

Our own research shows that several of the most risky railway crossings with a frequent occurrence of traffic accidents have shortcomings in terms of construction design. These are crossings:

- in residential areas of towns and villages,
- in localities with a higher intensity of road traffic
- on sections that run parallel to the road,
- there is a crossroads near the crossing,
- with insufficient viewing conditions,
- with insufficient and outdated security,
- with insufficient space to escape in the case of oversized road vehicles.

The calculation of a risk priority number (RPN) is based on indicators of fault occurrence, fault detection and fault severity. The following subsections provide a detailed explanation of the modified version.

The following calculation is enshrined in the proposed methodology for identifying risks at level crossings. According to the resulting RPN risk factor, the risk effect is evaluated according to Table 2 and the recommended action is taken.

Table 2. RPN evaluation

Evaluation	Measure	RPN total
High risk	Necessary intervention in the process is required.	**>150**
Moderate risk	Process control is required.	**121-150**
Low risk	No special measures required.	**120**

The severity criteria were based on historical statistics provided by the Infrastructure Manager from the EVINEHOD software and the Infrastructure Information System (Crossing Passport). The criteria in Table 3 were consulted with the head of the Safety Risk Assessment Center. The table shows the scale for the severity of the failure when safety is compromised. It can be endangered by an extremely serious event or on the contrary an event that does not have a significant impact on railway traffic. In the right column there are points used for the calculation.

The accident assessment criterion was objectively determined from past measurements and statistical surveys provided by the infrastructure manager from the EVINEHOD software and from the infrastructure information system

(Crossing Passport). Based on brainstorming with employees of the Railway Safety Department, the Safety and Inspection Department of the ŽSR, the criteria for assessing the occurrence of an accident were determined in Table 4.

Table 3. Severity of the disorder

Severity of the disorder	Description	Pts.
Extremely serious	The impact of the danger is very serious and can lead to a drastic decrease in safety (eg serious railway accident, death) / in case of death or property damage by € 2,000,000 in points 9, above € 2,000,000 in points 10.	10 9
High	The impact of the danger is serious and leads to a reduction in safety (railway accident and serious injury) / in the case of personal injury or property damage up to € 750,000 in points 7, over € 750,000 in points 8.	8 7
Moderately significant	The impact of the hazard is significant and can lead to a reduction in the level of safety (for example: incident, injured people) / in case of injury or property damage up to € 100,000 in points 4, up to 250,000 in points 5 and up to 500,000 in points 6.	6 5 4
Little significant	The impact of the danger is small and leads to a reduction in the level of safety (eg failures during operation) / in the case of property damage up to € 10,000 in points 2, up to € 50,000 in points 3.	3 2
Insignificant	The effect of the hazard has no significance for safety. No cost.	1

Table 4. Accident assessment criteria

Accident occurrence	**Description (frequency of accident)**	**Points**
Very high	**Once in 3 months**	**10**
	Once in 6 months	**9**
	Once in a year	**8**
High	Once in 2 years	**7**
	Once in 3 years	**6**
Moderate	Once in 4 years	**5**
	Once in 5 years	**4**
Low	Once in 6 years	**3**
	Once in 7 years	**2**
Negligible	Once in 8 years	**1**

The next step is to determine the fault detection score. The aim of the new methodology is to better understand the risk of accidents at level crossings and to eliminate it. This proposal aims to make the crossings gradually safer for society as a whole. Detection criteria were objectively determined based on brainstorming. It was based on Annual Reports, Reports on the state of railway safety, Safety Audit, Audit Reports and other documents related to accidents, operation and maintenance of railway crossings. The criteria for the evaluation of fault detection were determined in Table 5.

Table 5. Risk detection score

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Low			Moderate			High			

The fault detection score examines three categories:

- Type of crossing and its level of security,
- Assessment of the crossing visually and whether it is in accordance with the applicable standards and the registration sheet of the crossing,
- Frequency of crossing failures according to the model (type of safety system).

The output of each examined area (type of crossing, crossing assessment, crossing failure rate) is a score (risk detection model A, B and C). The resulting detection score D is the arithmetic mean of the three risk models (the resulting number is rounded to the nearest whole number). The authorized safety technician of ŽSR will prepare an inspection report, which contains a map of the crossing location, crossing ID, photo documentation of the current situation, description of the traffic situation and surroundings, construction technical condition of the crossing and current traffic volume (cars, pedestrians, cyclists, trains). Finally, it will propose measures to increase the safety of level crossings and reduce risk factors. The detection score D is calculated according to the formula:

$$D = \frac{A+B+C}{3} \tag{1}$$

where:

D detection score

A, B, C fault detection models

Table 6 shows the "Fault A detection model", which defines the risk according to the type and level of safety (signalling) system (in the left column there are types of the systems used in Slovakia). Fault A detection model was verified by Pareto analysis. The data source was statistics provided by the infrastructure manager from the EVINEHOD software and from the infrastructure information system (Crossing Passport). In the case of repeated accidents at selected types of crossings, the risk is higher by one degree.

Table 6. Fault detection model A

Accidents by type of safety signaling system	Points
PZS 2 (recurrence of accidents - more than 1)	**10**
PZS 2	**9**
Crossing K	**8**
PZS 2Z (recurrence of accidents - more than 1)	**7**
PZS 2Z	**6**
PZS 3 (recurrence of accidents - more than 1)	**5**
PZS 3	**4**
PZS 1	**3**
PZS 3Z	**2**
PZM	**1**

4. Results of the research

The research showed that the most risky crossings according to Table 9 are PZS 2 and crossing K (table 7).

Table 7. Number of accidents by type of safety signalling system

Type	Number	Relative abundance	Cumulative relative abundance
PZS 2	196	37.84%	38%
Crossing K	174	33.59%	71%
PZS 2Z	67	12.93%	84%
PZS 3	48	9.27%	94%
PZS 1	18	3.47%	97%
PZS 3Z	11	2.12%	99%
PZM	4	0.77%	100%

The Lorenz curve in Figure 4 (Appendix C) shows that 80% of accidents occur at the PZS 2 and K crossings.

The ALARA (As Low As Reasonable Available) principle can be applied to risks that take up to 80%. This principle states that risks need to be reduced to a level where investment in reducing risk becomes disproportionate.

"Fault detection model B" defines possible bottlenecks at a level crossing based on a critical assessment. It consist of a Check List Analysis (CLA). The source of data for CLA processing was data provided by the Infrastructure Manager and the Transport Authority. For the purpose of the article, the CLA is not included, however it contains technical issues such as reduced speed, unsatisfactory construction and technical solution of the road, damaged lights, non-compliance with legislature, high age, etc.

An authorized ŽSR safety technician will perform an analysis of the level crossing using a Check List Analysis once a year in case an accident has not occurred. They work with the registration form of the crossing, visually checks the situation at the crossing with photo documentation, which was prepared due to the performed control and revision inspections. If photo documentation is missing, the designated team must conduct an on-site inspection of the crossing. One point is assigned for each positive answer in the CLA. The sum of all positive responses defines the risk detection model B.

Table 7 shows the "Fault detection model C", which defines the risk according to the number of failures of individual safety (signalling) system models. The C fault detection model was verified by Pareto analysis. The source of data was statistical data (list of faults) provided by the infrastructure manager from the ENVINEHOD software and from the infrastructure information system (Crossing Passport).

Table 8 shows the frequency of failures according to individual models of safety system models. The research showed that the most faulty models of the system in terms of numbers are AZD 71, ZSSR and AZD PZZ-RE.

The Lorenz curve in Figure 5 (Appendix D) shows that 80% of technical failures occur on the AZD 71, ZSSR and AZD PZZ-RE models.

Table 8. Fault detection model C

Poruchovosť podľa modelu PZZ	Points
AŽD 71	**10**
ZSSR AŽD PZZ-RE	**9**
ZWÚS SPA-4/SL	**8**
ELEKSA 93 S	**7**
VÚD AŽD PZZ-EPA	**6**
Two-wire	**5**
BETAMONT BT	**4**
BUES 2000	**3**
BOBEC I BOBEC II	**2**
AŽD PZZ-AC ALTPRO RLC23 SaZ PZZ-K VÚŽ-76	**1**

Table 9. Number of accidents by model of safety signalling system

Model	Nu mbe r	Relative abundance	Cumulative relative abundance
AZD 71	920	57.72%	58%
ZSSR	188	11.79%	70%
AZD PZZ-RE	186	11.67%	81%
ZWUS SPA-4/SL	82	5.14%	86%
ELEKSA 93 S	60	3.76%	90%
VUD	48	3.01%	93%
AZD PZZ-EPA	48	3.01%	96%
Two-wire	21	1,32%	97%
BETAMONT BT	18	1.13%	99%
BUES 2000	12	0.75%	99%
BOBEC I	6	0.38%	100%
BOBEC II	4	0.25%	100%
AZD PZZ-AC	1	0.06%	100%
ALTPRO RLC23	0	0.00%	100%
SaZ PZZ-K	0	0.00%	100%
VUZ-76	0	0.00%	100%

5. Discussion

This research is a guide to identify and systematically eliminate risks at level crossings. The objectives were fulfilled by creating a proposal for a risk identification methodology and a web application for risk monitoring. Some partial results have already been applied in the infrastructure manager environment.

In terms of further research, severity should not only measure property damage, fatalities and serious injuries, but also train delays and environmental damage, in line with the recommendations of the EU Railway Agency.

The results of this research clearly lead to the recommendation to extend the detection factor by other statistical parameters such as e.g. intensity of train and road traffic at the crossing. The condition is the availability of statistical data, while data from road transport could not be obtained for all crossings. As part of the verifiability of the effectiveness of the modified methodology according to FMEA in practice, it is recommended to perform a comparative study with other approaches. As confirmed by world authors Niel (2014), Flammini (2012) and Hall (2009), railway crossings still remain the most dangerous place on the railway line. That is why it is extremely important to constantly address this issue. According to research, reducing the risk at level crossings is often done by reducing the speed of trains. However, this trend is at odds with maintaining the competitiveness of the railway system and does not meet customers' requirements for quality services. It is necessary to realize that increasing the safety of railway crossings is possible only through a combination of investment measures, organizational changes, support of a legislative nature and public awareness (Nedeliaková et al., 2021). Many railway companies in the EU are already aware of this today. They increase safety at crossings beyond current EU legislation and have become a symbol of prestige for them (EU Commission Regulation, 2013).

The solution of the application of the modified FMEA method represents a simple procedure that can be extended to other types of risks (Kotler, 2011; Mateides, 2011). The aim of this research was to focus on the risks at crossings, but the methodology is so universal that it can be implemented in the environment of other processes of the railway infrastructure manager. The solution of the issue of safety at railway crossings is influenced by many factors of a legislative nature. According to the valid legislation, the security guaranteed only by a good viewing conditions should be maintained only on unsecured crossings. If the owner is not responsible for the road crossing or does not pay the railways for the maintenance of crossings, many facts cannot be practically solved (Mateides, 2015). As far as supervisory activities are concerned, the construction of the crossing itself is permitted and thus supervised as a construction by a special building authority under the Ministry of Transport and Construction of the Slovak Republic. In the case of secured crossings, the Transport Authority supervises the inspections. Unsecured crossings and their viewing conditions, i. observation triangles in individual quadrants, again checked by the Transport Authority. The performance of inspections takes place every year at selected crossings, but also only to the extent that there are personnel and financial possibilities, which significantly limits the process of solving the problem.

6. Summary and conclusion

The results of the research carried out show that a large number of accidents in railway transport occur at crossings. Accidents and deaths at level crossings account for more than a quarter of all rail accidents on EU railways. Accidents in general have a negative impact not only on the railway sector itself and its operation, but also on people and material values. In connection with the damage caused, it is not only possible to talk about the costs associated with damage to the vehicle and infrastructure, but it is also possible to include indirect costs related to the interruption of traffic. The total cost of rail accidents is estimated at around 3.8 billion €.

The paper proposes a solution in the form of a modification of the FMEA methodology, including procedures for risk identification and assessment. The proposed modification consists mainly in modifying the risk detection procedure. By evaluating the eleven-year statistics and the information provided by the infrastructure manager, a new FMEA methodology was proposed and applied to level crossings.

The aim of the methodology was to identify and eliminate risks at crossings. Several methods and different techniques were used in this work to identify risks. By creating a prediction model, the research results made it possible to statistically evaluate the influence of risk factors (occurrence, severity, detection) and thus to objectify the decision-making process in eliminating risks and increasing safety at crossings.

A properly prepared survey required a summary of a wealth of information and data on rail accidents. Only qualifiedly trained FMEA team employees can perform accident monitoring and recalculation according to the established methodology. This may cause limitations in future really high-quality data processing, which will bring a preventive character to the issue.

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Appendix A

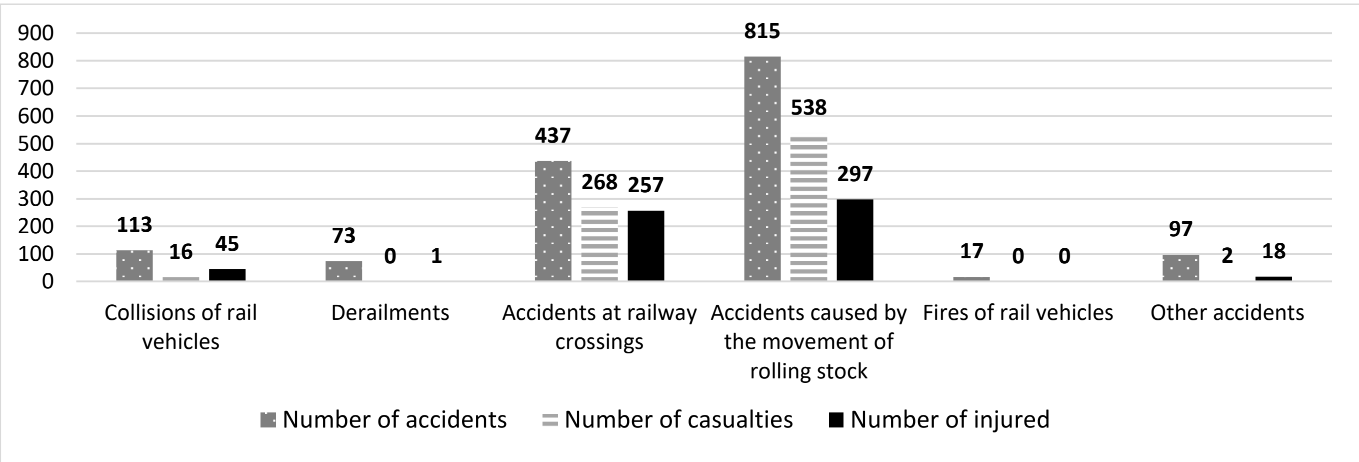

Fig. 2. Accident comparison in the EU-28

Appendix B

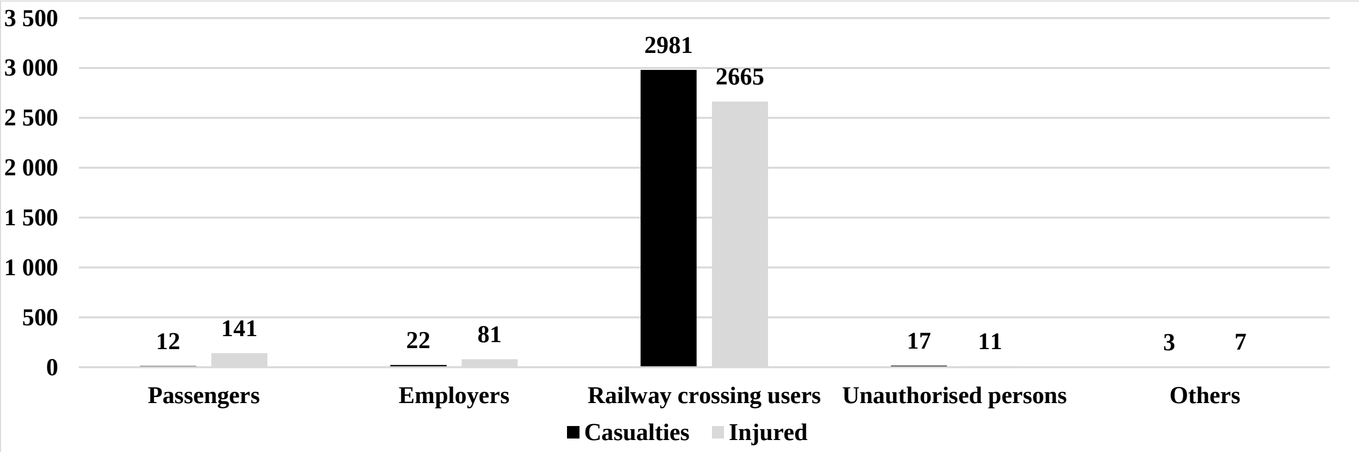

Fig. 3. Number of fatalities and injuries at crossings in the EU-28, 2010 - 2019

Appendix C

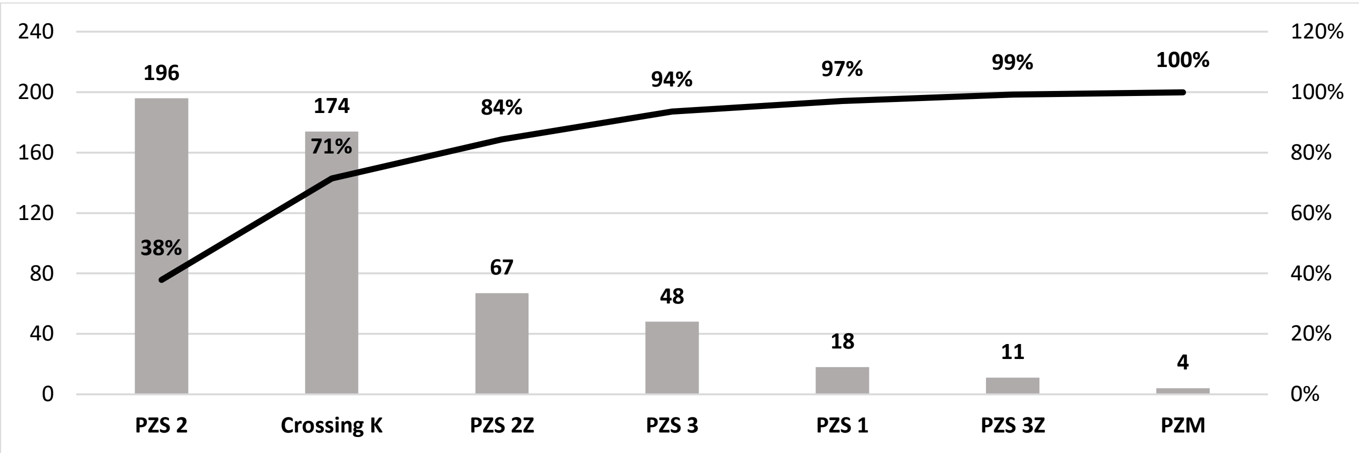

Fig. 4. Number of accidents by type of safety signalling system

Appendix D

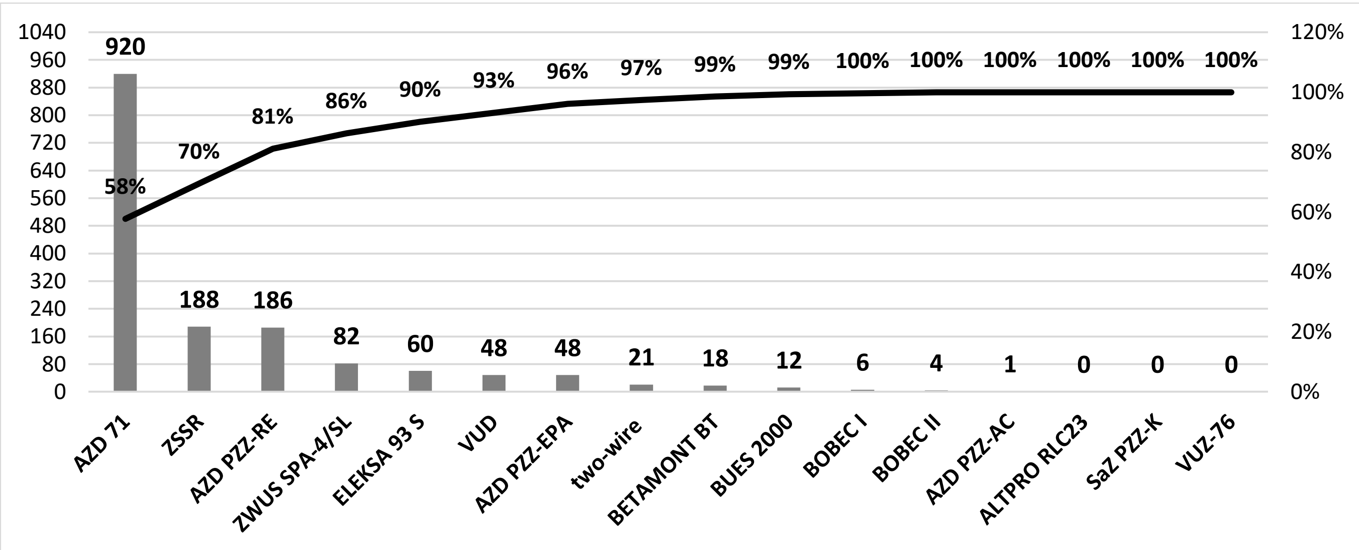

Fig. 5. Number of accidents by model of safety signalling system

关于铁路服务安全和质量的风险识别方法

關鍵詞
FMEA
方法
铁路
穿越
斯洛伐克

摘要
该文件涉及根据欧盟委员会第 1 号条例实施修改后的 FMEA 方法。 402/13 关于铁路部门风险评估和评估的通用安全方法。基本目标是创建一种方法，用于识别与铁路道口相关的铁路运输服务安全性的风险。进行这项研究的原因是，斯洛伐克铁路基础设施的经理存在与铁路道口事故相关的问题，包括列车延误时的服务质量问题。根据先前的研究，该领域已被定义为风险识别的优先事项。平交道口事故往往是多种因素复杂相互作用的结果。作者长期研究的结果对轨道交通服务的安全和质量带来直接影响。研究的第一个效果是对事故原因的详细调查，这是新方法的基础。这很重要，因为了解事故的原因是消除事故的第一步。拟议的新方法框架为铁路基础设施管理者提供了如何识别、分析、评估和消除其影响风险的指导。