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Eva NEDELIAKOVA[1], Lenka LIZBETINOVA[2], Renata STASIAK-BETLEJEWSKA[3], Adrian SPERKA[4]

APPLICATION OF THE REASON MODEL WITHIN RISK MANAGEMENT ON RAILWAY CROSSINGS – A CASE STUDY

Summary. Despite constant efforts to improve safety in the railway environment, various accidents and incidents happen, resulting in material damage and in the worst case, loss of human lives. This article emphasises the need for proper identification of risks, their constant monitoring, and evaluation of all causes that arise at railway crossings. Furthermore, this paper aims to apply the Reason model to the problems of railway crossings within the case study on the railway network in Slovakia. The timeliness of the problem lies in the possibility of preventing such issues in the operation of rail transport using this model. Prevention is an effective way of averting the serious consequences of accidents in the future.

Keywords: railway transport, safety, railway crossing, human factor failure

[1] Faculty of Operation and Economics of Transport and Communications, University of Žilina, Univerzitná 1, 010 26 Žilina, Slovakia. Email: eva.nedeliakova@fpedas.uniza.sk. ORCID: https://orcid.org/0000-0001-5588-0939

[2] The Institute of Technology and Business in Ceske Budejovice, Faculty of Corporate Strategy, 370 01 České Budějovice, Czech Republic. Email: lizbetinova@mail.vstecb.cz. ORCID: https://orcid.org/0000-0001-8969-2071

[3] Czestochowa University of Technology, Dąbrowskiego 69 Street, 42-201 Częstochowa, Poland. Email: renata.stasiak-betlejewska@wz.pcz.pl. ORCID: https://orcid.org/0000-0001-8713-237X

[4] Faculty of Operation and Economics of Transport and Communications, University of Žilina, Univerzitná 1, 010 26 Žilina, Slovakia. Email: adrian.sperka@fpedas.uniza.sk. ORCID: https://orcid.org/0000-0001-9596-9081

1. INTRODUCTION

Railway undertakings encounter different types of risk when providing services. In general, while respecting global definitions, the risk can also be described as a potential safety breach in rail transport. The risk can be defined both quantitatively and qualitatively. It represents a certain expression of the threat level. Risks can arise at all levels of railway undertaking management and are very specific in the transport market environment [8,11,13,20,21,22,24]. Therefore, their early identification and knowledge of the degree of risk are essential [2]. This determines the extent the risk can be accepted and the threshold at which it becomes unacceptable for the railway undertaking [5].

Research has shown that the number of deaths and serious injuries concerning rail traffic has been on the decline since 2010. However, the elimination of railway infrastructure risks is a topical issue. From the safety point of view, the most dangerous place on the railway track is level crossing with a road (railway crossing). From the perspective of customer satisfaction, each risk affects the perception and decision-making of the use of rail transport in the future [10]. Even in the case of rail transport, accidents have different consequences. Accidents at railway crossings where railway and road vehicles come together have many consequences. This is due to the irresponsible behaviour of road users. Therefore, the authors of this research focused on the possibilities of risk elimination at railway crossings. Risk management is an area of management that focuses on risk analysis and mitigation, using a variety of risk prevention methods and techniques that eliminate existing or detect future risk-increasing factors [12]. Railway staff seek to prevent accidents and incidents by using various mnemonic techniques, procedures, and principles [26]. This article deals with the model that was applied in the research, which is the Reason model or the Swiss Cheese model.

This article aims to show how the Reason model can help in rail conditions, and thus, indicate the stage of a system or individual failure at which an accident could be prevented [14]. It describes if any opportunity to eliminate the consequences exists. In a selected railway accident, this model will be applied with an emphasis on the border between the possibility and impossibility of averting the accident. Only after a thorough risk analysis can a set of measures be adopted that will eliminate it to an acceptable extent in the future [15]. The basic pillar is a suitable procedure that systematically establishes steps applicable to rail transport. Presently, railway undertakings usually take risks when an accident or safety hazard occurs, which is, however, connected with the consequence of demanding financial measures or even personal injury. Primarily, world-class companies invest in preventive measures that will never be as expensive or safety-intensive as the consequences that need to be addressed [1]. The result should be a consistent approach to improving the quality of risk prevention measures, eliminating uncertainty and ultimately improving customer service.

It should be remembered that the mission of railway undertakings is to create an integrated offer of railway infrastructure capacity and services for the transport of passengers and goods by rail based on the highest safety, efficiency, reliability, and environmental acceptability [7]. Risk elimination in rail transport is associated with safety and interoperability. These are the basic pillars of the European integrated railway area.

Risk elimination refers to the use of the human factor in rail workplaces where the service is carried out by railway staff under the established mode of work. This includes regular monitoring, supervision, and supervision during working hours [23]. Further risk elimination is possible by technical means through permanent or intermittent monitoring of critical infrastructure elements utilising camera devices monitoring the movement of persons, devices for signalling intrusion of the object. A combination of the foregoing may also be used, by adopting measures aimed at eliminating anti-social activity in the perimeter of railways, ensuring the continuity and safety of rail transport and preventing and eliminating incidents in rail transport. It is precisely a combination of several measures and aspects as a means of preventing the occurrence of an accident at a level crossing [9].

This research characterises extraordinary events in railway transport and the categorisation of accidents. Furthermore, it examines the dependence of accidents on various circumstances of non-compliance. And assesses a serious accident that has become as a collision on a railway crossing.

2. THEORETICAL BACKGROUND OF THE REASON MODEL APPLICATION

The Reason model (Swiss Cheese model) is a model showing accidents with their causes. It was primarily developed for use in the aviation sector. It is being used in other areas, such as risk analysis and risk management, engineering, healthcare, and computer security as well. It compares the systems and human management to several cheese slices stacked in a row. Therefore, it is justifiable to make an attempt to formally describe specific parts of cheese components, which are necessary for various types of analyses. Such a description allows us to create models that may be more or less developed. The risk that the threat becomes a reality is mitigated by these layers with varying degrees of protection. Thus, if the threat begins to spread through individual layers, it does not mean that it will result in an accident, but that one of the layers will avert the spread of the threat [19].

Reason assumed that the causes of accidents are based on one of four areas [25]:

- organisational effects – training of drivers at the lowest possible cost,
- control – inexperience, lack of finesse,
- assumptions – fatigue, communication failure,
- concrete procedure – non-compliance, excessive compliance.

In this model, emergency protection monitors through the obstacles (protective means) represented by the slice of cheese. The openings in the section represent weaknesses in the different parts of the system and differ in size and position across the sections. The system allows failure when the hole in each plate momentarily aligns, allowing an accident trajectory. Danger passes through holes in all sections, leading to failure [25].

According to its international background in transport cases, the model includes active errors and latent errors.

While active errors are obvious and can occur suddenly for various causes, latent errors are characterised by their latency. At a certain period, the error may not be visible and may then be reflected. Tab. 1 gives examples of errors.

Tab. 1

Examples of errors that occur in the Reason model

Active errors	Latent errors
ETCS failure	cracks on the vehicle
burning a light bulb on a signal	bomb on board
dispatcher error	virus spread

Every undertaking has directives and individual procedures, the application of which seeks to avoid mistakes and prevent accidents. Fig. 1 is a graphical illustration of the Reason model.

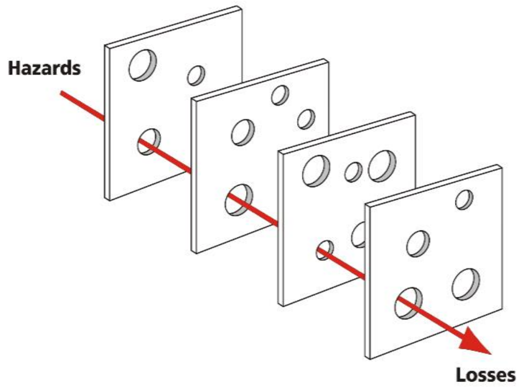


Fig. 1. Emmental Swiss cheese model [25]

From the figure, it is clear that passing the red arrow through all the holes will cause an extraordinary event. Unless it passes through all the holes, there will be no extraordinary event.

3. CLASSIFICATION OF EXTRAORDINARY EVENTS IN RAILWAY TRANSPORT

The railway sector is known for its strict approach to safety. Under the conditions of the infrastructure manager (entity managing the railway infrastructure) of the Slovak Railways (hereinafter referred to as ŽSR), the Department of Safety and Inspection was established.
Amendment to the Act on Railways 513/2009 Coll. instructed the railway operators and carriers (railway undertakings) to issue an internal regulation containing [15]:

- procedures for identifying the causes of an accident and an incident;
- a detailed categorisation of accidents and incidents,
- the method of reporting accidents and incidents,
- the roles of organisational units of the railway operator and carriers involved in the identification of the causes of accidents and incidents.

These and other obligations resulting from the abovementioned Act and Decree 250/1997 Coll. are in the ŽSR conditions elaborated in the regulation “From 17 Accidents and extraordinary events”. This regulation was effective from 1 January 2011 [16].
According to this regulation, were defined [6]:

- extraordinary circumstance - is a sudden event or chain of such events that originate in the operation of rail infrastructure and rail transport, but which have the same consequences as accidents (road wash, lightning strike, violent damage to infrastructure equipment...),
- accident - is a serious accident, a minor accident and an incident involving a moving railway vehicle with the consequences of death, injury, danger to life and health of persons,
- incident - is an event that adversely affects the safety and fluidity of rail traffic, it can be an unforeseen event or an undesirable event,

- operational failure - is an incident that is not subject to the legal provisions of the Slovak Republic (hereinafter the Slovak Republic) and the European Union (EU) on the registration, reporting, investigation and statistical processing.

Tab. 2 categorises the different types of incidents according to Regulation Z 17 with examples of incidents.

Tab. 2

Categorisation of accidents

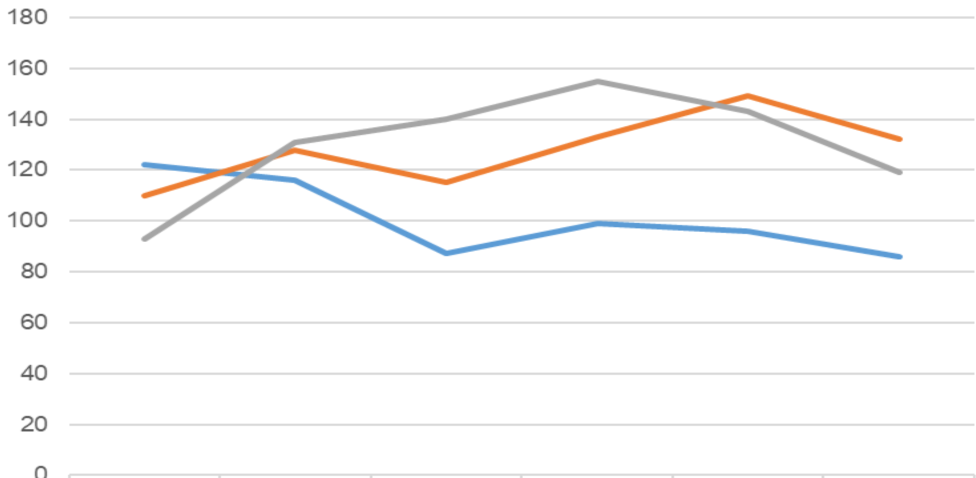
Category of accident	**Consequences**	**Examples**
A – Serious accidents	fatal injury	train crash
	severe injury to at least 5 persons	derailment of the train
	widespread damage to railway vehicles	collision of a railway vehicle with users of the crossing
	extensive damage to the railway infrastructure	fire of a railway vehicle
	extensive environmental damage	personal injury caused by the movement of a railway vehicle
	extensive damage to the property of third parties	
	interruption of traffic on the 1. category of lines for 6 hours or more	
B – Minor accidents	severe injury of up to 4 persons	train crash
	damage to railway vehicles and railway infrastructure	derailment of the train
	damage to the environment and property of third parties to the extent of greater damage of at least € 2,600	collision of a railway vehicle with users of the crossing
		fire of a railway vehicle
		personal injury caused by the movement of a railway vehicle
C – Incidents	minor damage	quarry rails
		track deformation
		signalling error
		passing the signal STOP
		wheel and axle fractures

As operational failures are not serious enough to be considered subject to the legal provisions of the Slovak Republic and the EU, it will not be dealt with further. The investigation of individual incidents is an indispensable document, the Accidents "Cover". It is a summary of the prescribed aids, documents and forms needed to identify causes and report accidents and incidents on the railway [16].

The steps of determining the causes of accidents can be described in a simplified way as follows [4]:

- inspection of the scene of the accident and creation of a record of the inspection,
- collection of documentation and records;
- measurement at the scene of an accident - commission inspections and records;
- writing notes with employees;
- finding damage,
- preparation of documentation,
- determining the causes and responsibilities for the occurrence of an accident,
- closure of an accident.

For comparison purposes, an accident graph is presented in Fig. 2 showing the cases of category A-C incidents in 2014-2019.



	year 2014	year 2015	year 2016	year 2017	year 2018	year 2019
Serious accidents	122	116	87	99	96	86
Minor accidents	110	128	115	133	149	132
Incidents	93	131	140	155	143	119

Fig. 2. Development of extraordinary events on ŽSR network

The chart shows that year-on-year, compared to 2018, there was a decrease in serious accidents (by 10), minor accidents (by 17) and incidents (by 24) in 2019. One of the reasons for this is the ever-increasing provision of train movements in the intermediate sections. Besides, the infrastructure manager (ŽSR) is particularly concerned with preventing the occurrence of extraordinary events [27].

4. DEPENDENCE OF ACCIDENTS ON DIFFERENT CIRCUMSTANCES

The most common accidents include a collision between a train and a road motor vehicle on a railway crossing. We classify such types of accidents on the ŽSR network in category B. The emergence of such accidents has several causes, for example:

- driver inattention,
- not respecting light signalling,
- vehicle breakdown directly at the railway crossing.

Tab. 3 shows the individual values of the number of accidents at railway crossings and the number of locomotives destroyed in 2017.

Tab. 3

Data to create a graph of linear dependence

Month	**Number of railway crossing accidents**	**Number of locomotives destroyed**
1/2017	10	7
2/2017	3	3
3/2017	2	2
4/2017	6	2
5/2017	3	2
6/2017	5	4
7/2017	3	1
8/2017	4	2
9/2017	3	1
10/2017	1	1
11/2017	2	1
12/2017	8	5

The most accidents were in January, while the least accidents were in October. Damage to locomotives likewise corresponds to this condition. Using the Fisher test, the following table will determine the dependence between the monitored indicators. Tab. 4 shows the individual variables.

Tab. 4

Variables used to determine dependency

Variable	**Value**
R^2	0,79
k	1
n	12
n-(k+1)	10
F	37,39
F_{TAB}	4,97

where:

- R - reliability equation,
- k - coefficient,
- n - number of measurements,
- F - calculated Fischer test value,
- F_{TAB} - table value of the Fischer test.

The Fischer value is calculated by relation 1. If the calculated test value is higher than the table value, there is a dependence between the monitored indicators.

$$\frac{\frac{R^2}{k}}{\frac{1-R^2}{n-(k+1)}} \tag{1}$$

Fig. 3 shows the graph of correlation between selected factors that influence accidents at railway crossings.

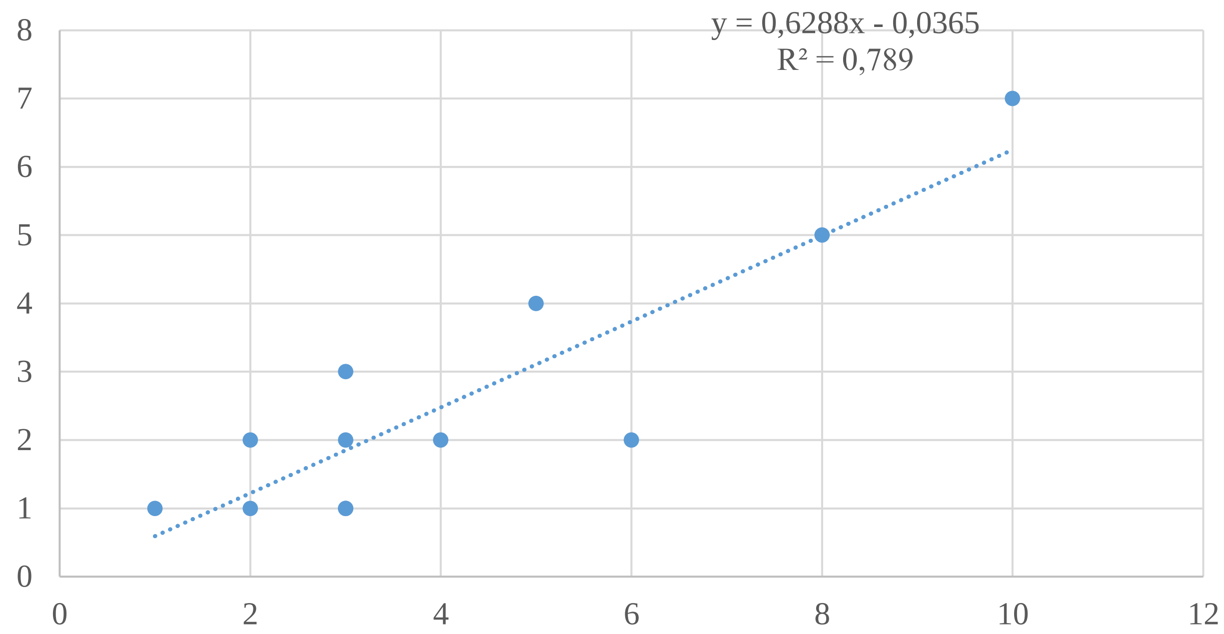


Fig. 3. Graph of linear dependence between the number of accidents on the level crossings and the number of locomotive damages

There is a dependence between the number of accidents at the railway crossings and the number of damaged locomotives as seen in Tab. 4. Other dependencies could similarly be detected in this manner. For example, the dependence between the number of passengers and the number of deaths on railway crossings or the dependence between the amount of delay and the number of accidents on railway crossings. These circumstances are the direction of the next research.

5. APPLICATION OF REASON MODEL FOR RAIL ACCIDENTS – A CASE STUDY

Although this model was originally set in the air transport environment, its application is possible in other modes of transport. The article will analyse the accident of category A3, which happened on February 21 at the unprotected railway crossing in Polomka.

Basic data [6]:

- date and time of the incident: 21. 2. o 9:04,
- place of accident: unprotected railway crossing at km 17.938 km in the Heľpa - Polomka interstate section,
- train type: Os 7353 (Červená Skala - Banská Bystrica),
- type of road motor vehicle: Bus Karosa LC 736.

Course of the accident [3]:

- the train driver in the direction Závadka nad Hronom - Polomka noticed that the incoming bus does not stop in front of the crossing and is entering the crossing,
- the driver had applied fast-acting braking from a distance of 72 metres before crossing at 70 km per hour,
- despite the measures, the passenger train crashed into the left centre of the bus,
- the bus overturned to the right side and the motor car derailed,
- The driver of the bus has been identified as the main culprit, since the road safety device was functioning correctly at the time of the accident.

Fig. 4 shows the number of people killed and injured in this accident.

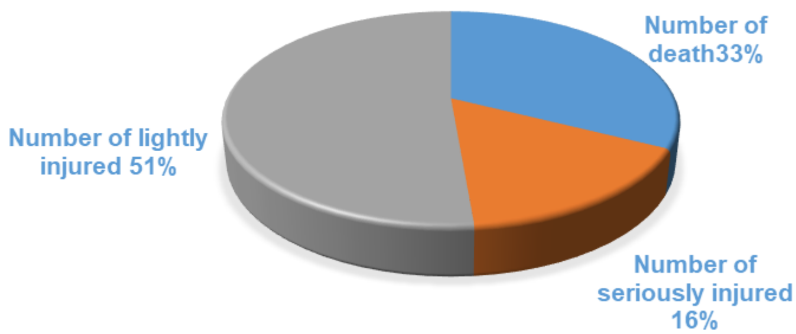


Fig. 4. Number of deaths and injuries [4]

Most people were injured lightly (19 in total) and 6 people were seriously injured. Unfortunately, up to 12 people suffered life-incompatible injuries. This accident was described as the most tragic in the history of ŽSR. The application of the Reason model is shown in Fig. 5 by a flowchart.

In the sense of the Reason's model, the accident involved 3 slices of cheese. Tab. 5 shows the structure of penetration through cheese holes.

Tab. 5

Penetrating through the holes in the cheese

Slice of cheese	Circumstance	Possibility of turning away
1	the driver entered the crossing despite the warning	respecting the alert
2	the train was coming	train failure before crossing
		crossing test
3	applying the handbrake by the driver	train stop

Penetration through the slices in the cheese resulted in an accident. However, if even one penetration did not get an accident, it would not happen. Fig. 6 shows a photograph of the accident site.

The investigation for ŽSR was closed on 20 March 2009. Subsequently, the bus driver was accused because he did not respect the crossing prohibition despite the correct functionality of the roadside interlocking device.

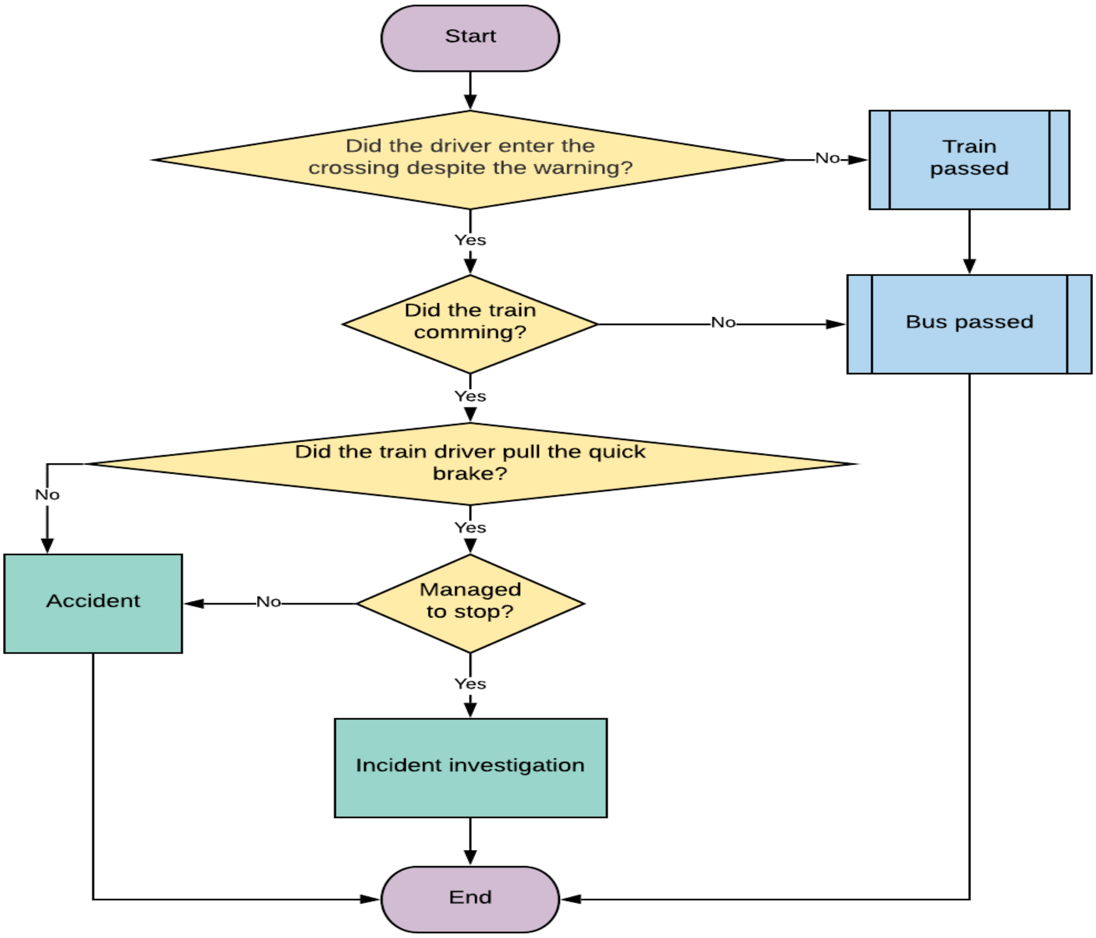


Fig. 5. Flowchart of causes and consequences of an accident

Fig. 6. Place of the accident [17]

6. CONCLUSION

Research poses a likely risk that could lead to their occurrence at railway crossings. It is an open issue, especially, necessary to deal with it. As much as future technical solutions contribute, research finds that human potential is the greatest. According to Gadek-Hawlena, human´s knowledge about the correct behaviour in different situations, both the everyday ones and the ones being a consequence of collisions or traffic accidents, is very important. It is proven that even on fully secured railway crossings there are many accidents caused by irresponsible human behaviour. The most common failures in almost any activity are human failures. The advancement of science and technology has therefore replaced human labour with automated work in several areas of human life. However, there are still areas where human work is indispensable and irreplaceable, despite the progress being made.

The use of the Reason model is versatile. It can be stated that the aim of this research was fulfilled. This model is also applicable to railway transport. It shows the circumstances that have occurred and caused the accident, and also shows the threshold where an impending emergency can be averted and where it cannot. In the future, it is possible to examine in this way other circumstances and effects of risks at railway crossings. Research gives room for further progress in this current and serious issue.

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