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An Estimate of the Number of Accidents and Serious Accidents in Railway Traffic

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Abstract

The aim of this paper is to investigate the relationship between the number of extraordinary events and the total number of accidents and serious accidents in railway traffic. The purpose of the paper is to estimate the total number of accidents and serious accidents on the track network of Croatian Railway Infrastructure (HŽI) until 2027. The results of the research are based on secondary data that are the subject of processing using statistical methods of correlation and regression analysis. The main finding of this paper points to the existence of a strong and positive relationship between the number of extraordinary events and the total number of accidents and serious accidents in railway traffic. The estimated number of extraordinary events and total number of accidents and serious accidents until 2027 indicates a trend of their further reduction.

Keywords

railway traffic, HŽI rail network, extraordinary events, accidents, serious accidents

1 Introduction

Railway transport has numerous economic, ecological and energy advantages compared to other branches of transport. Safety is an essential component of the definition of sustainability (Torok and Pauer, 2022). Transport safety as a modern phenomenon in transport (Pupavac, 2009) is also an important factor in the competitiveness of railway transport in the transport market. In order to provide continuous service and optimum reliability, the rail industry must assure its safety against accidents occurring on its property (El-Koursi and Bruyelle, 2016). Safety is the main issue of railway transportation. The safety of railway transport can be defined as the highest possible probability that the entire transport system or a certain subsystem of it will function safely, with predetermined working conditions. If, for any reason, there is a threat to the proper development of railway traffic, the built-in devices must be designed, programmed and implemented in such a way that they unconditionally, reliably and automatically switch to a higher level of security, even at the cost of total suspension of traffic. Despite this, and primarily due to human or technical factors, accidents do occur. Unfortunately, when railway accidents happen, they result in great material damage, serious injuries and loss of human life.

Railway traffic in the Republic of Croatia has been neglected for a long time. It most often comes into the focus of the scientific and professional public after an extraordinary event that resulted in an accident or a serious accident, when discussing traffic safety. Extraordinary events are divided into three basic groups: incidents, accidents and serious accidents. A serious accident is an extraordinary event in railway traffic in which at least one person is killed, and/or five or more persons are seriously injured, and/or the material damage exceeds two million euros. The accident is an extraordinary event in rail transport with harmful consequences such as serious physical injuries to up to four people and material damage that can be estimated at a value of up to two million euros. "Incident" is any event, except for an accident or a serious accident, related to the development of railway traffic that affects its safety (Croatian Railway Infrastructure, 2013).

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Accordingly, this paper will investigate the connection between the number of extraordinary events on the one hand and the total number of accidents and serious accidents on the other hand. The research results are based on secondary data for the period from 2008 to 2021. The collected data were processed using methods of descriptive statistics and methods of correlation and regression analysis. Analysis and synthesis methods and comparative methods are also applied in the work.

2 Theoretical background and research problem

The first railways began to be built in England. The development of industrial production required large-capacity means of transport. Thus, the railway is a product of industrial development. The development of railway transport became the originator of regionalization and globalization in the 19^{th} century (Rodrigue, 2016). The "high technology" of that time opened the door to unprecedented economic growth. Today, a modern, well-organized and fast railway transport network is a significant prerequisite for integration and economic growth. A safe and sustainable railway can help the world out of the economic, climate and social crisis it is facing today. Rail transport reduces the emission of greenhouse gases from traffic. Rail and public transport are key to the radical, green, and modal change that is needed in transport.

A safe and sustainable railway is a new economic and social model for the 21^{st} century. Therefore, it is not surprising that the International Federation of Transport Workers of the Railway Section emphasizes "Safety First" as its main goal (slogan). Accordingly, profit does not stand out as the first goal of railway companies. When it comes to rail transport, profit can and must be only a by-product. Rail promotes economic and social equality through access to employment, skilled jobs and higher wages. On average, every job created in the rail sector creates another job in manufacturing, trade or other sectors. Rail also provides citizens with the mobility needed to access jobs and livelihoods.

Safety during transportation is never absolute, it can only be relative (Božić and Novaković, 1999). As a rule, safety in transport depends on the technical features of the means of transport, mode of movement, driving speed, organization of transport, measures taken to ensure the movement of vehicles, etc. As risk can never be zero, security can never be perfect. Security by definition is the absence of unacceptable risk. The railway system must operate in the safety zone, but a certain level of residual risk cannot be avoided. But it is certain that this remaining (residual) risk must be minimal. The level of safety of the railway system of the European Union is one of the highest in the world. Compared to other modes of transport, railways regularly stand out as the safest mode of land transport in the EU (Quinet and Vickerman, 2004), with the passenger fatality rate gradually approaching that of airplanes. The level of safety in terms of fatal accident rates has also improved continuously since 1990, with an average annual reduction of more than 5%. Data from the International Union of Railways (UIC), which includes 32 European, Asian and Middle Eastern railways, also confirms this trend (cf. Table1).

A similar trend can be seen on the HŽI rail network. Taking into account the fact that traffic is a real phenomenon, with real elements, it is necessary to strive to eliminate the causes of undesirable phenomena or events as much as possible, with the aim of achieving the safe development of railway traffic as close as possible to absolute safety and reliability. This means that certain elements of the traffic system must always function reliably and safely, regardless of operating conditions.

According to UIC, the main causes of accidents are external factors (78.2%) that railway companies cannot control (cf. Table 2).

Table 1 Trend of accidents and rates (2016–2021)

	2016	2017	2018	2019	2020	2021
Number of significant accidents	2006	1971	1928	1726	1623	1765
Significant accidents per million train-km	0.44	0.42	0.41	0.36	0.37	0.38
Number of accidents with victims	1718	1688	1627	1417	1292	1381
Accidents with victims per million train-km	0.37	0.36	0.34	0.30	0.30	0.29
Number of victims	2119	1919	1915	1625	1433	1510
Victims per million train-km	0.46	0.41	0.40	0.34	0.33	0.32
Number of fatalities	1181	1086	1081	966	905	897
Fatalities per million train-km	0.26	0.23	0.23	0.20	0.21	0.19
Number of million trainkilometres	4610	4725	4757	4788	4353	4700

Table 2 Main causes of accidents

2021	Causes at first level	Causes at second level
External causes (78.2%)	Third parties (75.4%)	Trespassing (44.7%)
		Vehicle (LC accident) (18.0%)
		Pedestrian (LC accident) (9.2%)
		Pedestrian on public railway area (2.2%)
		Other or not specified (1.3%)
	Weather and environoment (2.9%)	Environment (2.4%)
		Weather (0.5%)
Internal causes (19.9%)	Infrastructure (4%)	Tracks and structures (2.5%)
		Energy system (1.1%)
		Other or not specified (0.3%)
	Rolling stock (4.1%)	Running gear (2.1%)
		Other or not specified (2.0%)
	Human factors (Railway staff and subcontracotrs) (10.3%)	Track and switch maintenance staff (1.4%)
		Traffic operating and signalling staff (2.0%)
		Train drivers (2.4%)
		Other or not specified (4.4%)
	Railway users (1.5%)	Passengers (1.4%)
		Other or not specified (0.1%)
Causes not identifited (19%)		

Based on the data from Table 2, it is clear that railroad crossings are the cause of 27.2% of accidents. The consequences of negligence at railway and road crossings are large material damage, loss of human life and the collapse of the railway's reputation as a safe form of transportation, although most of these accidents are caused by violations by drivers of motor vehicles or pedestrians (Liang et al., 2018). Level crossings represent a neuralgic point of railway traffic safety and require an urgent solution (Ghazel, 2009; Mekki et al., 2012). In 2012, there were more than 105,000 level crossings on the rail network of the EU-28 countries (ERA, 2020). On average, more than 300 people die at level crossings in EU countries every year (Liu et al., 2016). Accidents at level crossings are a problem that all European railways struggle with. This is interpreted as a special sociological problem (Samokovlija Dragičević, 2008).

The number of extraordinary events (incidents, accidents and serious accidents) is an indicator of safety in railway traffic (Pupavac and Knežević, 2021). The consequences of extraordinary events can be: death, serious bodily injury, minor bodily injury, material damage, environmental damage, traffic disruptions. According to Heinrich's law (Heinrich, 1931; 1941), for every one serious accident there are 29 minor accidents and 300 incident situations without accidents. According to Heinrich, incident situations in 88% of cases are the result of employee behavior, not an unsafe way, or human error. Based on the data from Table 2, it is clear that in 87.2% of cases, human errors are responsible for accidents in railway traffic.

Heinrich's law had a significant effect on building a culture of safety and health at work in companies during the 20th century, but today it is increasingly subject to criticism. For example, Manuele (2008) points out that focusing on minor incidents results in their reduction, but that despite this, the number of serious accidents remains the same or even increases slightly. A similar conclusion is reached by Ferguson (Alcoa Inc., 2007), who points out that numerous companies that are leading in the safety and health protection of workers still record severe injuries at work with fatal consequences, despite the reduction of less serious accidents and occupational diseases.

Heinrich's law can also be shown in relative proportions: 0.30% of all incident situations will result in one serious accident, 8.8% of all incident situations will result in 29 minor accidents and 90.9% of all incident situations will pass without injury. By applying this law in railway traffic, one could claim that 300 incidents, 29 accidents and 1 serious accident will occur out of 330 extraordinary events.

3 Data and research methodology

With the aim of estimating the number of accidents and serious accidents by 2027 on the HŽI railway network (Croatian

Table 3 Statistical presentation of extraordinary events for the period (2008–2021)

Year	Extraordinary events (EE)	Incidents (I)	Accidents (A)	Serious accidents (SA)
2008	1207	1103	94	10
2009	1366	1195	133	38
2010	1095	974	96	25
2011	1077	929	124	24
2012	1068	967	84	17
2013	1112	1009	88	15
2014	983	878	89	16
2015	983	900	70	13
2016	948	867	68	13
2017	1027	945	62	20
2018	860	787	55	18
2019	839	755	71	13
2020	754	685	59	10
2021	799	719	69	11

Railway Infrastructure, 2022), an overview of extraordinary events, incidents, accidents and serious accidents for the period from 2008 to 2021 was given (cf. Table 3).

Railway traffic accident prediction is the main issue of safety management (Feng et al., 2018). Many methods have been used for railway accident predictions. Accidents are stochastic processes and are hard to predict well. Besides, many methods are too complex for practical implementation. Therefore, the collected data will first be analyzed using the methods of descriptive statistics, namely the arithmetic mean and standard deviation. After that, the degree and direction of connection between certain types of extraordinary events will be measured using the method of correlation analysis. If this relationship is statistically strong ($r > 0.7$), then the regression model will analytically express the relationship between the total number of accidents and serious accidents and the total number of extraordinary events. Then, on the basis of Heinrich's law and the obtained regression model, an assessment of the total number of accidents and serious accidents on the HŽI railway network until 2027 will be made, noting that accidents and serious accidents will be monitored as serious and minor accidents.

4 Research result

Based on the data from Table 3, short descriptive statistics of extraordinary events, incidents, accidents and serious accidents on the HŽI railway network were compiled (cf. Table 4).

Based on the data from Table 4, it is clear that an average of 1,008 extraordinary events (SD = 166) occur annually on the HŽI rail network, of which an average of 100 (SD = 29) result in accidents or serious accidents. The lowest number of extraordinary events (754), incidents (685), accidents (55) and serious accidents (10) occurred during the COVID-19 crisis, i.e., during 2020. The largest number of extraordinary events (1,366), incidents (1,195), accidents (133) and serious accidents (38) occurred during the great global financial crisis, the devastating effects of which were felt in the Republic of Croatia in 2009. During the time between the two crises, a downward trend in the number of extraordinary events is noticeable. Thus, the number of extraordinary events on the HŽI rail network in 2021 decreased by 41.5% compared to 2009. The result is that in the observed period, the number of incidents decreased by about 40%, the number of accidents by about 48% and the number of serious accidents by about 71%. However, despite these encouraging data, the relative share of the number of accidents and serious accidents in the total number of extraordinary events did not decrease (cf. Fig. 1).

Based on Fig. 1, it is clear that the relative share of accidents and serious accidents in the total number of extraordinary events in the observed period ranged between 8.44% and 13.74% or an average of 9.95%. According to Heinrich's law, we can expect this percentage to be around 9.1%, so we can conclude about the validity of Heinrich's law on the HŽI railway network. In order to further examine the stated claim, a correlation analysis was also conducted between the number of extraordinary events, incidents, accidents and the number of serious accidents (cf. Table 5).

Based on the data from Table 5, a strong and positive correlation is evident between the number of extraordinary

Table 4 Descriptive statistics of extraordinary events, incidents, accidents and serious accidents on HŽI railway network (2008–2021)

	N	Mean	Min.	Max.	Stdandard deviation (SD)
Extraordinary events (EE)	14	1008.43	754.00	1366.00	166.03
Incidents (I)	14	908.07	685.00	1195.00	143.15
Accidents (A)	14	83.00	55.00	133.00	23.32
Serious accidents (SA)	14	17.36	10.00	38.00	7.59
Accidents & serious accidents (A&SA)	14	100.36	65.00	171.00	29.29

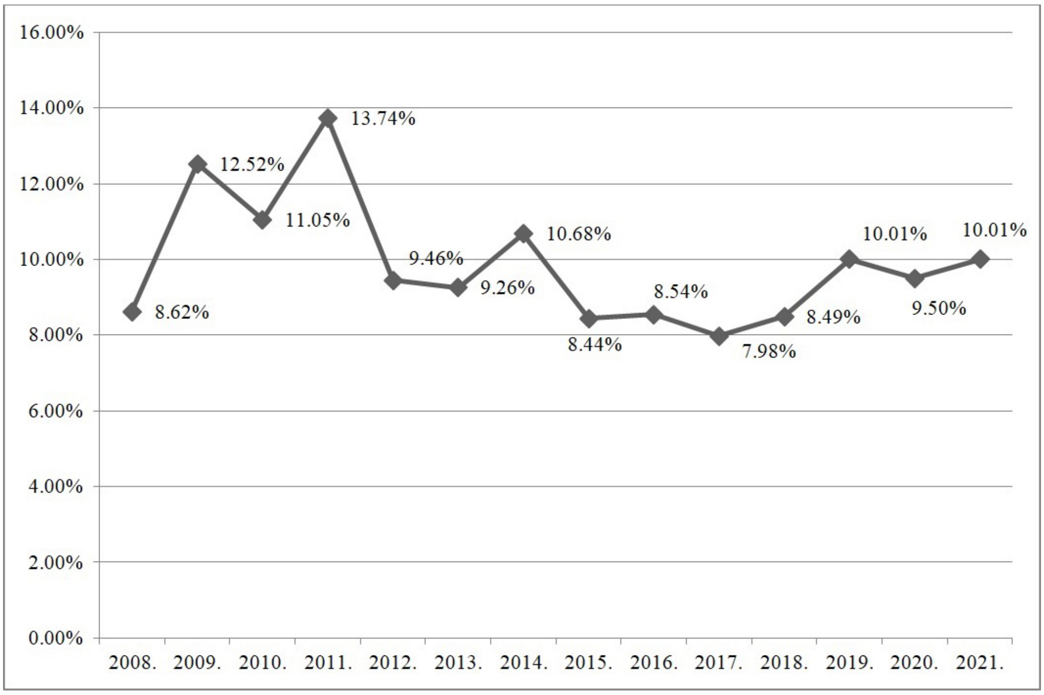

Fig. 1 Share of accidents and serious accidents in the total number of extraordinary events (2008–2019)

Table 5 Correlation between extraordinary events, incidents, accidents and serious accidents

	Mean	SD	EE	I	A	SA	A&SA
EE	1008.43	166.04	1.00	**0.99**	**0.80**	**0.68**	**0.82**
I	908.07	143.15	**0.99**	1.00	**0.73**	**0.61**	**0.74**
A	83.00	23.32	**0.80**	**0.73**	1.00	**0.73**	**0.98**
SA	17.36	7.59	**0.68**	**0.61**	**0.73**	1.00	**0.84**
A&SA	100.36	29.29	**0.82**	**0.74**	**0.98**	**0.84**	1.00

events and incidents ($r = 0.99$; $p < 0.01$), accidents ($r = 0.80$; $p < 0.01$), serious accidents ($r = 0.67$; $p < 0.01$) and the total sum of accidents and serious accidents ($r = 0.81$; $p < 0.01$).

Accordingly, a regression analysis was carried out in order to mathematically visualize the relationship between the number of extraordinary events as an independent variable and the total number of accidents and serious accidents as a dependent variable. The mathematical model has the following form:

$$\mathrm{A\,\&\,SA} = -44.7663 \\ +0.1439EE \; (r = 0.81;\; p < 0.01). \tag{1}$$

By applying the mentioned model, it is possible to estimate the total number of accidents and serious accidents on the HŽI rail network for the future period. However, in order to do this, it is necessary to first estimate the number of extraordinary events in the coming period. Based on the data from Table 3, the function of the linear trend of the number of extraordinary events on the railway network of HŽI was determined (cf. Fig. 2).

Based on Fig. 2, the obtained linear trend is:

$$EE = 1281.3 - 36.387X, \tag{2}$$

where *EE* is the number of extraordinary events, and *X* is the time.

If one starts from the realistic assumption that the observed trend of reducing the number of extraordinary events will continue in the future, then the estimated number of accidents and serious accidents, depending on the number of extraordinary events, would move in the manner shown in Table 6.

Based on the data from Table 6, it is clear that the assessment based on the regression model is more favorable than the one based on Heinrich's law. Accordingly, a confidence interval is given for the estimation based on the regression model. For example, based on the regression model for the year 2027, the total number of accidents and serious accidents was estimated at 35 with a confidence level of 95% that this number will range from a minimum of 4 to a maximum of 65. The confidence interval represents an objective assessment of (im)precision (Šimundić, 2008).

5 Conclusion

Traffic safety is never absolute, it is relative. The railway system must have a high level of safety by applying appropriate accident avoidance strategies – risk reduction strategies – failure avoidance strategies.With the goal of increasing safety in railway traffic, that is, approaching absolute safety, such solutions are necessary that will exclude the action of the human factor. Digitalization and new technologies can be a tool for such solutions. Safety should be the first and basic goal of railway companies all over the world. A safe and sustainable railway can be the carrier and driver of economic development for the 21st century. Data from the International Union of Railways indicate a trend towards a decrease in the number of accidents in railway traffic. Similar trends are observed on the HŽI railway network.

The number of extraordinary events is an indicator of safety in railway traffic. The relative share of accidents and serious accidents in the total number of extraordinary

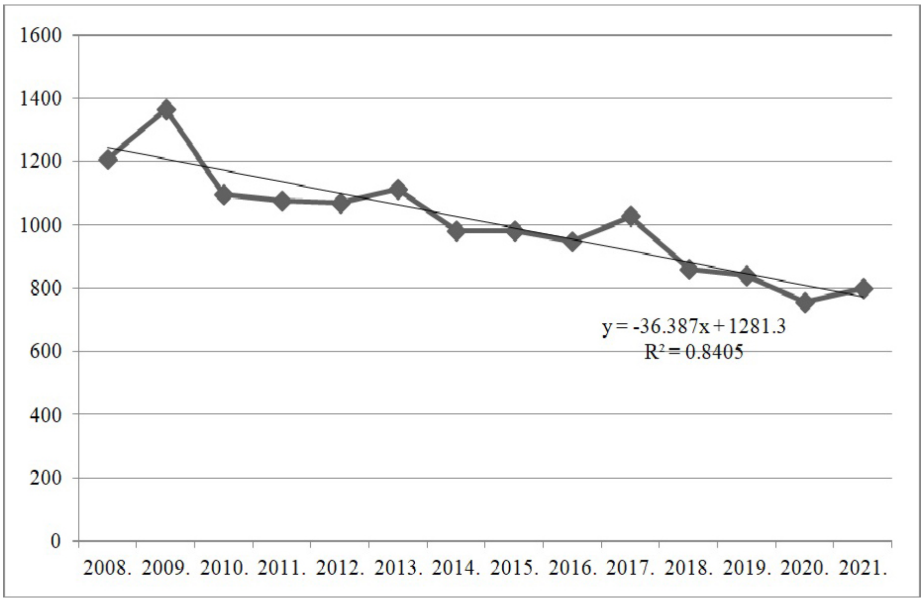

Fig. 2 Linear trend of the number of extraordinary events on the HŽI railway network (2008–2021)

Table 6 The estimated number of accidents and serious accidents on the HŽI rail network depending on the number of extraordinary events

Year	Number of extraordinary events	Accidents and serious accidents		Confidence interval (−95% – +95%)
		Heinrich law	Regrresion model (1)	
2022	735	67	61	40–81
2023	699	64	56	33–78
2024	663	60	50	26–75
2025	626	57	45	18–72
2026	590	54	40	11–68
2027	554	50	35	4–65

events in the period from 2008 to 2021 on the HŽI rail network ranged between 8.44% and 13.74%, or an average of 9.95%. According to Heinrich's law, we could expect this percentage to be around 9.1%, and a conclusion can be drawn about the validity of Heinrich's law on the HŽI railway network. This statement is further supported by the fact that there is a statistically strong and positive relationship between the total number of extraordinary events and the total number of accidents and serious accidents ($r = 0.81$; $p < 0.01$).

The assessment of the number of extraordinary events and the total number of accidents and serious accidents until 2027 indicates a trend of their further reduction. The assessment of the total number of accidents and serious accidents, which is based on a regression model, is particularly encouraging, as it indicates a decrease in absolute numbers, but also in relative terms in the total number of extraordinary events. The estimation based on the regression model seems more appropriate also because of the confidence interval, which represents the range within which the total number of accidents and serious accidents in railway traffic can be expected to occur with 95% probability. The fact that accidents are stochastic processes directs future research to simulation models for railway accident estimation.

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