The Impact of Human Factors on Safety at Railway-Road Crossings in the Western Part of Croatia

Vilke, Siniša; Dundović, Kristina; Knežević, Josip

Source / Izvornik: **Pomorski zbornik, 2024, 64, 47 - 62**

Journal article, Published version
Rad u časopisu, Objavljena verzija rada (izdavačev PDF)

ISSN 0554-6397
UDK: 004.032.26
Review article
Received: 15th January 2024.

Siniša Vilke
E-mail: sinisa.vilke@pfri.uniri.hr
University of Rijeka, Faculty of Maritime Studies, Studenska 2, 51000 Rijeka, Croatia
Kristina Dundović
E-mail: kdundovic@veleri.hr
Polytechnic of Rijeka, Vukovarska 58, 51000 Rijeka, Croatia
Josip Knežević
E-mail: josip.knezevic3@hzinfra.hr
HŽ Infrastructure Ltd., Krešimirova 1, 51000 Rijeka, Croatia

The Impact of Human Factors on Safety at Railway-Road Crossings in the Western Part of Croatia

Abstrac

Railway-road crossings over rail tracks are intersections of two separate transportation systems that, from a safety standpoint, represent a high-risk point for all traffic participants. In the absence of adequate levels of protection at railway-road crossings, the danger significantly increases, as evidenced by the number of traffic accidents occurring at these locations. The subject of research in this paper is the impact of the human factor on safety at railway-road crossings in the Western Region, which encompasses the areas of Karlovac County, Lika-Senj County, Primorje-Gorski Kotar County, and Istria County. The aim of this study is to determine the safety conditions at railway-road crossings in the Western Region and compare them with the rest of the Republic of Croatia. Subsequently, the goal is to ascertain the extent of the human factor's influence on their occurrence. The working hypothesis states that accidents resulting in fatalities occur at railway-road crossings with low railway and road traffic on county, local, and unclassified roads in or near settlements because drivers fail to comply with regulations. To support the hypothesis, the study utilized scientific methods such as analysis and synthesis, descriptive method, induction and deduction method, and comparative method. The research results are based on secondary sources of data for the period from 2014 to 2023.

Keywords: railway traffic, railway-road crossings, incidents, safety, human factor

1. Introduction

Railway-road crossings (RRCs) can be seen as points of intersection between two types of traffic at the same level. These locations essentially pose a very serious safety issue for both railway and, particularly, road traffic. They are critical points, or locations where there is a high risk of serious accidents occurring. These locations are particularly deadly for road traffic users, where road traffic participants are often involved, with frequently fatal consequences. Additionally, in the case of railway traffic participants, damages to railway vehicles, traffic disruptions, and mainly material damages typically occur. Safety represents a contemporary phenomenon in transportation. Due to the significant human factor involvement, safety in transportation cannot be absolute, especially in the intersection of two types of traffic such as railway and road traffic. In the literature [26] dealing with the issue of extraordinary events, the human factor's contribution to accidents and incidents is consistently estimated at a high percentage, ranging from 80% to 99%. For example, up to 95% of the causality of road accidents is attributed to human error, while at railway-road crossings, accidents and serious incidents are attributed to the human factor at over 95% up to 99% [12]. Railway traffic safety can be defined as the highest possible probability that the entire transportation system or a specific subsystem will function safely, under predetermined operating conditions. If, for any reason, there is a threat to the proper operation of railway traffic, the installed devices must be designed, programmed, and executed to unconditionally, reliably, and automatically switch to a higher level of safety, even at the cost of a complete traffic shutdown. The aim is for the railway's impact on the environment to be as minimal as possible. The most challenging task facing railway transportation regarding safety is undoubtedly to prevent conflict situations, both within the railway traffic itself and towards other modes of transportation with which the railway shares the same environment.

Concerning the safety of railway transport special attention should be consider on the impact of extreme weather conditions on ocerhead-line infrastrucutre in the process of planning and design of railroad corridors, as shown by the authors [27-29, 37]. Special attention, in addition to infrastructure, should also be paid to railroad safety related to the quality of traction of train wheels on the tracks [16, 33].

The interaction of pantographs and overhead routes, i.e., aerodynamics and active control of pantograph are new issues of contemporary research trends in rail transport [5]. Additionally, research addresses and analyze system maintenance, life cycle costs, and reliability [1, 8, 19, 36].

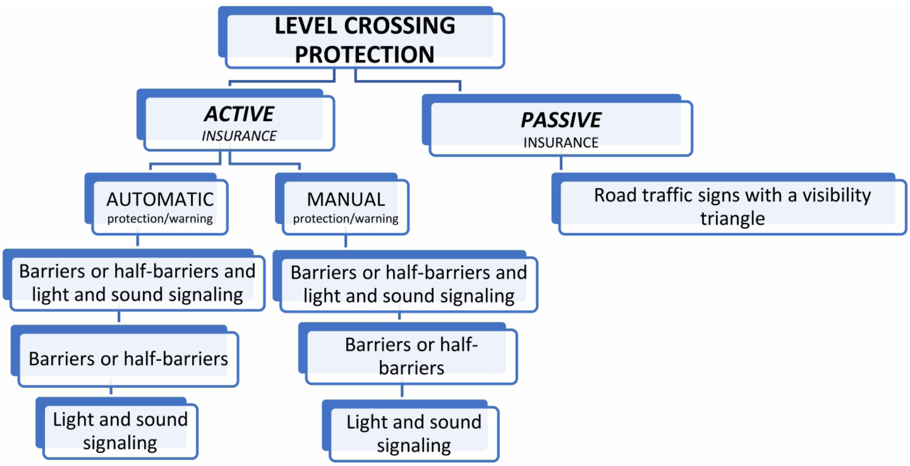
The western part of Croatia, i.e., the Western Region in railway terms, represents the railways passing through the geographic area from Zvečaj station in Karlovac County, and from Lovinac station in Lika-Senj County, all the way to Rijeka in Primorje-Gorski Kotar County and Pula in Istria County. Due to the large number of inhabitants passing through and living in the Western Region, and on the other hand, the high number of extraordinary events occurring at railway level crossings (ŽCPs), this paper will attempt to analyze the state of security at railway level crossings in the Western Region, as well as the impact of human factors on road and railway traffic safety, i.e., to determine the responsibility of level crossing users for the occurrence of extraordinary events at them.

Then, the working hypothesis "Fatal accidents occur at level crossings with low railway and road traffic on county, local, and unclassified roads in settlements or near settlements because drivers do not comply with regulations" will be attempted to be supported.

2. Theoretical framework and research problem

In the following text, methods of securing level crossings (ŽCPs), legal framework, and definitions of terms categorizing extraordinary events will be described, along with the actual state of level crossing security in the Western Region.

Level crossings (ŽCPs) can be secured in two ways: passively and actively. The passive method involves securing ŽCPs with a traffic sign (St. Andrew's cross and STOP sign along with the prescribed visibility triangle). The active method of securing is executed by physically preventing road vehicles from crossing the railway track using barriers/gates and light-sound signaling, barriers/gates alone, or only light-sound signaling, accompanied by appropriate road traffic signs. (cf. Scheme 1.)



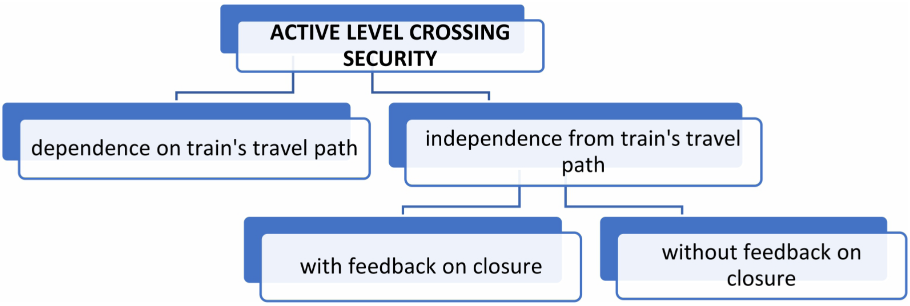
Scheme 1. Types of level crossing (ŽCP) security
Source: Authors

The installation of half-barriers/full barriers, i.e., their operation and control, can be achieved through mechanical, electromechanical, or electronic devices. In addition to mechanical protection, flashing lights and audible signals are commonly used as supplements.

Activation and deactivation occur automatically upon the train's approach to certain contacts, activation by workers from the official site electronically or mechanically, or through an on-site level crossing attendant manually operating the barrier.

Technical supervision of level crossings secured by a signaling and safety device (SS-device) can be achieved in two ways, found in most countries. One method involves integrating level crossings with the train's travel path. These are typically located within the station area or near the station and are dependent on main signals, ensuring that a train cannot enter, exit, or pass through the crossing without it being secured or protected beforehand.

The other method involves autonomous level crossings that are monitored independently of the train's travel path. These are commonly found on open tracks and are activated automatically by the train's approach to specific contacts on the track. (cf. Scheme 2.)



Scheme 2. Classification of active level crossings based on supervision type
Source: Authors

Regarding level crossings where the method of security is a crossing attendant (BR+ČV) who operates the barrier manually, lifting and lowering it on-site, the situation is somewhat different as the entire safety level relies on the individual. Consequently, there is a greater possibility of error.

In the following text, legal frameworks and definitions related to extraordinary events are described. Extraordinary events in railway traffic are defined by the Law on Safety and Interoperability of the Railway System and the Regulation on Procedures in Case of Extraordinary Events. The classification of extraordinary events depends on their consequences. Therefore, extraordinary events considered as serious accidents are those that result in the death of at least one person, serious injuries to five or more people, or material damage in the monetary equivalent of two (2) million euros or more. Accidents are classified as extraordinary events if they result in serious injuries to one to four people or material damage up to two (2) million euros. A safety recommendation from the Agency for Investigation of Air, Maritime, and Railway Accidents has been accepted, stating that every collision between a train and a road vehicle at a level crossing is considered an accident, regardless of whether there was minimal material damage, which was previously classified as an incident. An incident is any event, except for an accident or serious accident, related to railway traffic that affects its safety. An incident at a level crossing is considered if there has been a barrier/gate breakage, untimely securing of the level crossing, or passage of a train over the level crossing where traffic is secured by SS-devices if the traffic is not secured by those devices [21].

After a brief overview of level crossing security methods, legal frameworks, and definitions of terms categorizing extraordinary events, the following text will analyze the actual situation at level crossings in the EU, Croatia, and the Western Region.

In the European Union, there are a total of 108,196 level crossings at grade. On average, there are slightly under 5 level crossings with active protection measures for every 10 kilometers of railway, representing a percentage of 53% of actively secured crossings compared to all crossings in the EU [26-27]. Therefore, the situation regarding the number of level crossings per kilometer of railway is slightly lower in the EU than in Croatia, albeit with a higher prevalence of actively secured level crossings in the EU, contributing to greater safety in both road and rail traffic.

Railway traffic management in Croatia is organized so that HŽ Infrastructure Ltd. is the manager of the railway infrastructure, and the area is divided into five regional working units, or regions: North (Koprivnica), Central (Zagreb), East (Vinkovci), West (Rijeka), and South (Split).

HŽ Infrastructure Ltd. manages a total of 2,617 kilometers of railway, of which 37% are electrified and 10% are double-track. They oversee 558 official sites, 549 bridges, 109 tunnels, and handle 20.4 million train kilometers. With over 5000 employees, they manage 1402 level crossings. Among these, 812 are secured only by traffic signs (passive protection), while 586 are secured by SS-devices (active protection). This means that 42% of level crossings are actively secured compared to 58% passively secured. On average, there are 1.86 level crossings per kilometer of railway [10].

The Western Region, in railway terms, comprises the railway lines passing through the geographical areas of Karlovac County, Lika-Senj County, Primorje-Gorski Kotar County, and Istria County. In this area, the railway network is significant for international, regional, and local traffic. The railway lines significant for international traffic include the main corridor lines M202 Zagreb Main Station-Rijeka from Zvečaj station to Rijeka station, the M203 line from Rijeka to Šapjane-DG, and the corridor lines M602 Škrljevo-Bakar, M603 Sušak Pećine-Rijeka Brajdica, and M604 Oštarije-Knin-Split from Oštarije station to Lovinac station. Additionally, the regional line R101 from DG-Buzet-Pula and the local line L212 from Rijeka Brajdica to Rijeka are also significant for international traffic. The Western Region encompasses a total of 90 official sites (52 stations, 1 junction, 1 dispatching point, and 36 stops), 450 kilometers of railway lines, and 176 level crossings (excluding pedestrian crossings) with various security measures in place. (cf. Figure 1.)

Figure 1. Map of the railway network in Croatia
Source: [11]

Regarding the level crossing (ŽCP) security methods in the Western Region compared to the rest of Croatia, the fact that the density of level crossings is such that there is one level crossing for every 2.56 kilometers of railway favors the region. This density is slightly lower than the average for Croatia. The security method is such that passive protection is more prevalent, accounting for approximately 53% (93) compared to active protection at 47% (83), which is a similar case to the rest of Croatia. This predominantly passive approach contributes to decreased traffic safety because there are still many level crossings per kilometer of railway, and passive protection methods are still prevalent. (cf. Table 1.)

Table 1. Comparison of Types of Level Crossing Security in EU, Croatia, and Western Region

Level Crossing Security Type	Active (%)	Passive (%)
European Union	53	47
Republic of Croatia	42	58
Western Region	47	53

Source: [7 i 26]

In most cases, the highest proportion of passive level crossing security is found on lower-ranked railway lines, such as those in Istria County. Therefore, on main corridor lines, active level crossing security measures are more prevalent.

Analyses indicate that extraordinary events with the most severe consequences (fatalities, serious injuries, and significant material damage) occur at level crossings secured by passive methods, as well as at crossings with lower levels of active protection, such as those equipped only with light and sound signaling.

Therefore, if we consider the area of the Western Region, it is a specific and challenging area to analyze due to its affiliation with multiple counties. It is not geographically or territorially bounded by railway lines but rather traversed by several railway lines of different ranks and various methods of traffic regulation for trains. The area of the Western Region is highly demanding due to its density of roads, totaling approximately 5000 kilometers in length, of various ranks that intersect railway lines at the same level. This results in a large number of level crossings with different security methods.

The number of accidents largely depends on the number of users of level crossings, so potential users of level crossings must also be mentioned. According to the results of the 2021 Census, the area is home to approximately 500,000 inhabitants, accounting for 12% of the population in Croatia (4,284,889).

3. Analysis and Research Results

In order to analyze the impact of the human factor on safety at level crossings (ŽCPs) in the Western Region, a summary of the number of extraordinary events at level crossings on the railway network of Croatia is provided (cf. Table 2.) and on the railway network managed by the Western Region for the period from 2014 to 2023 (cf. Table 3.). Furthermore, extraordinary events at level crossings are graphically depicted based on their security method and responsibility for the occurrences in the total amount from 2014 to 2023 (cf. Graph 1.). Additionally, graphical and tabular representations are provided for the consequences of extraordinary events, including fatalities and serious injuries, based on the level crossing security method. Furthermore, responsibility for fatalities and serious injuries at level crossings in the Western Region is shown (cf. Graph 2. and Table 4.). So, a graphical representation of the trend in barrier breakages over the years for the observed period in the Western Region is provided (cf. Graph 3.).

During the analyzed period of 10 years (2014-2023), a total of 8987 extraordinary events occurred on railway lines in Croatia, out of which 54.6% (4909) occurred at level crossings (ŽCPs), resulting in 60 fatalities and 58 serious injuries. Out of the 4909 extraordinary events that occurred at level crossings in Croatia, 94.8% (4654) of them were caused by level crossing users, i.e., drivers of road vehicles. This is slightly less prominent in the Western Region (cf. Table 2 and 3).

Table 2. Extraordinary Events at Level Crossings by Categories in Croatia from 2014 to 2023.

IZVANREDNI DOGAĐAJI na ŽCP-u	2014.	2015.	2016.	2017.	2018.	2019.	2020.	2021.	2022.	2023.	UKUPNO
OZBILJNE NESREĆE	4	6	2	6	7	6	4	6	8	2	**49**
NESREĆE	33	24	25	31	30	25	26	29	14	28	**237**
INCIDENTI	488	513	459	531	462	446	383	406	449	456	**4137**
UKUPNO:	**525**	**543**	**486**	**568**	**499**	**477**	**413**	**441**	**471**	**486**	**4909**
Teže ozlijeđeno korisnika ŽCP-a	6	11	5	5	5	6	6	7	2	5	**58**
Usmrćeno korisnika ŽCP-a	7	8	2	7	8	6	4	6	10	2	**60**
Odgovoran korisnik ŽCP-a	487	499	466	523	485	469	380	433	469	443	**4654**
OZBILJNE NESREĆE na ŽCP-u	**2014.**	**2015.**	**2016.**	**2017.**	**2018.**	**2019.**	**2020.**	**2021.**	**2022.**	**2023.**	**UKUPNO**
a) promet osiguran SS uređajem	1	4	0	5	5	3	2	3	3	1	**27**
b) promet osiguran prometnim znacima	2	2	2	1	2	2	2	2	4	1	**20**
c) pješački prijelaz	1	0	0	0	0	1	0	1	1	0	**4**
UKUPNO:	**4**	**6**	**2**	**6**	**7**	**6**	**4**	**6**	**8**	**2**	**51**
NESREĆE NA ŽCP-u	**2014.**	**2015.**	**2016.**	**2017.**	**2018.**	**2019.**	**2020.**	**2021.**	**2022.**	**2023.**	**UKUPNO**
a) promet osiguran SS uređajem	11	9	8	9	5	9	7	10	5	10	**83**
b) promet osiguran prometnim znacima	22	14	17	22	24	15	19	19	9	18	**179**
c) pješački prijelaz	0	1	0	0	1	1	0	0	0	0	**3**
UKUPNO:	**33**	**24**	**25**	**31**	**30**	**25**	**26**	**29**	**14**	**28**	**265**
INCIDENTI NA ŽCP-u	**2014.**	**2015.**	**2016.**	**2017.**	**2018.**	**2019.**	**2020.**	**2021.**	**2022.**	**2023.**	**UKUPNO**
Prolazak želj. vozila preko ŽCP-a gdje je promet osiguran SS uređajima ako promet nije osiguran tim uređajem	2	2	3	0	6	8	3	1	4	3	**32**
Nepravovremeno zaštićivanje ŽCP-a	5	4	1	3	3	2	1	1	1	3	**24**
Izvanredni događaj na ŽCP-u	11	6	8	4	1	1	1	2	2	5	**41**
Lom polubranika/branika	470	501	447	524	452	435	378	402	442	445	**4496**
UKUPNO:	**488**	**513**	**459**	**531**	**462**	**446**	**383**	**406**	**449**	**456**	**4593**

Source: HŽ Infrastructure Ltd., internal reports

A slightly lower trend in extraordinary events at level crossings is noticeable on the railway network of the Western Region compared to the total number, where a total of 1580 extraordinary events occurred, mostly incidents, totaling 1456, along with 108 accidents and 16 serious accidents. Out of the total number of extraordinary events (1580), 36% (576) occurred at level crossings, including 551 incidents, primarily barrier breakages (539), 22 accidents, and 3 serious accidents (cf. Table 3.).

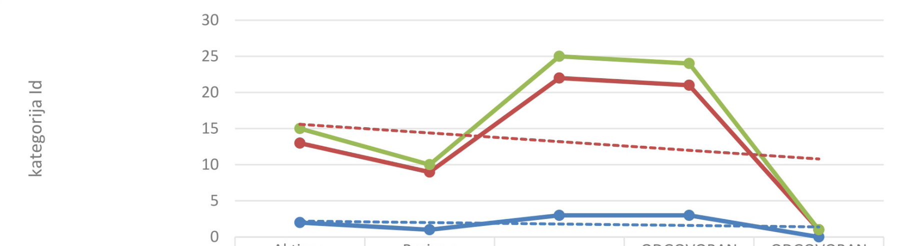
Table 3. Extraordinary Events at Level Crossings by Categories in the Western Region from 2014 to 2023.

IZVANREDNI DOGAĐAJI na ŽCP-u	2014.	2015.	2016.	2017.	2018.	2019.	2020.	2021.	2022.	2023.	UKUPNO
OZBILJNE NESREĆE	0	1	0	0	2	0	0	0	0	0	3
NESREĆE	2	0	2	3	5	3	2	2	1	2	22
INCIDENTI	53	77	42	71	58	53	55	45	55	42	**551**
UKUPNO:	**55**	**78**	**44**	**74**	**65**	**56**	**57**	**47**	**56**	**44**	**576**
Teže ozlijeđeno korisnika ŽCP-a	0	1	0	0	0	0	1	1	0	0	**3**
Usmrćeno korisnika ŽCP-a	0	1	0	0	3	0	0	0	0	0	**4**
ODGOVORAN korisnik ŽCP-a	48	61	42	60	51	55	50	45	53	42	**507**
OZBILJNE NESREĆE na ŽCP-u	**2014.**	**2015.**	**2016.**	**2017.**	**2018.**	**2019.**	**2020.**	**2021.**	**2022.**	**2023.**	**UKUPNO**
a) promet osiguran SS uređajem	0	1	0	0	2	0	0	0	0	0	**3**
b) promet osiguran prometnim znacima	0	0	0	0	0	0	0	0	0	0	**0**
c) pješački prijelaz	0	0	0	0	0	0	0	0	0	0	**0**
UKUPNO:	**0**	**1**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**3**
ODGOVORAN korisnik ŽCP-a	0	1	0	0	2	0	0	0	0	0	**3**
NESREĆE NA ŽCP-u	**2014.**	**2015.**	**2016.**	**2017.**	**2018.**	**2019.**	**2020.**	**2021.**	**2022.**	**2023.**	**UKUPNO**
a) promet osiguran SS uređajem	1	0	2	1	1	2	1	2	1	2	**13**
b) promet osiguran prometnim znacima	1	0	0	2	4	1	1	0	0	0	**9**
c) pješački prijelaz	0	0	0	0	0	0	0	0	0	0	**0**
UKUPNO:	**2**	**0**	**2**	**3**	**5**	**3**	**2**	**2**	**1**	**2**	**22**
ODGOVORAN korisnik ŽCP-a	2	0	2	3	5	3	2	2	0	2	**21**
INCIDENTI NA ŽCP-u	**2014.**	**2015.**	**2016.**	**2017.**	**2018.**	**2019.**	**2020.**	**2021.**	**2022.**	**2023.**	**UKUPNO**
Prolazak želj. vozila preko ŽCP-a gdje je promet osiguran SS uređajima ako promet nije osiguran tim uređajem	1	1	0	0	2	1	2	1	1	1	**10**
Nepravovremeno zaštićivanje ŽCP-a	0	0	0	0	0	0	0	0	1	0	**1**
Izvanredni događaj na ŽCP-u	1	0	0	0	0	0	0	0	0	0	**1**
Lom polubranika/branika	51	76	42	71	56	52	53	44	53	41	**539**
UKUPNO:	**53**	**77**	**42**	**71**	**58**	**53**	**55**	**45**	**55**	**42**	**551**
ODGOVORAN korisnik ŽCP-a	46	60	40	57	44	52	48	43	53	40	**483**

Source: HŽ Infrastructure Ltd., internal reports

So, during the observed period, out of the total number of all extraordinary events that occurred at level crossings in the Western Region (576), human factor responsibility is over 90% (519). The responsibility of level crossing users accounts for 88% (507), while the responsibility of executive workers of HŽ Infrastructure Ltd. is approximately 2% (12).

Regarding serious accidents in the Western Region during the observed period, there were 2 serious accidents at level crossings with active protection and 1 serious accident at a level crossing with passive protection, with 100% responsibility attributed to drivers of road vehicles. Also, during the observed period, a total of 22 accidents occurred, with 13 accidents at level crossings secured by active protection and 9 accidents at level crossings secured by passive protection. Out of the total of 22 accidents, drivers of road vehicles were responsible for 21 accidents, while responsibility for 1 accident lies with an executive worker of HŽ Infrastructure Ltd. Analyzing the causes of extraordinary events at level crossings in the Western Region, it is evident that the majority of extraordinary events occurred due to the negligence of level crossing users or disregard for traffic signals, i.e., due to the influence of the human factor (cf. Graph 1.).



	Aktivno osiguranje	Pasivno osiguranje	UKUPNO:	ODGOVORAN korisnik ŽCP-a	ODGOVORAN izvršni radnik
Ozbiljna nesreća	2	1	3	3	0
Nesreća	13	9	22	21	1
UKUPNO 2014.-2023.	15	10	25	24	1

Graph 1. Extraordinary Events at Level Crossings by their Security Method and Responsibility for the Western Region from 2014 to 2023.
Source: HŽ Infrastructure Ltd., internal reports

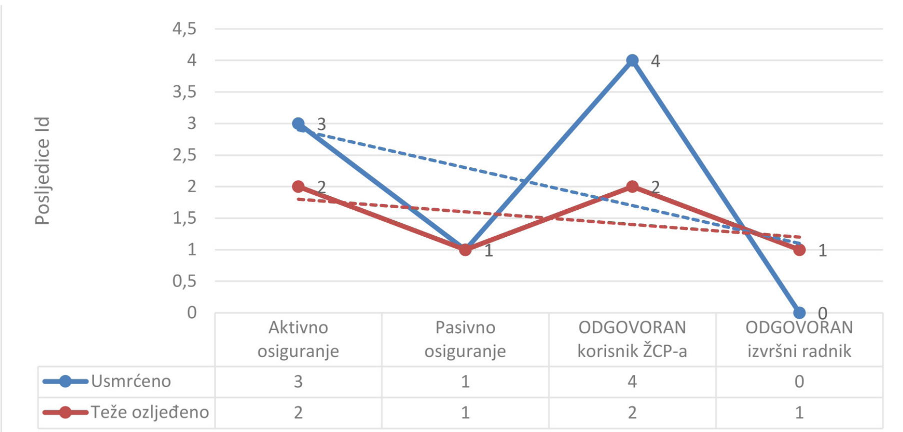
In the observed period from 2014 to 2023, four (4) people were fatally injured at level crossings, and three (3) people sustained serious injuries. Two fatalities occurred at the intersection of railway lines with unclassified roads with active protection (lights and sound signals). One (1) fatality occurred at the intersection of railway lines with unclassified roads with passive protection (passive barriers). Additionally, two (2) individuals sustained serious injuries at the intersection of railway lines with unclassified roads with active protection, while one (1) person sustained serious injuries at the intersection of railway lines and unclassified roads at a level crossing secured by passive protection (cf. Table 3.).

Table 4. Fatalities and severely injured persons at level crossings in the West Region from 2014 to 2023.

Railway line designation	Railway track name	Kilometer position of the level crossing	Road rank	County	City or municipality	Existing insurance	Fatalities	Seriously injured persons
M202	Zagreb Gk Rijeka	495+929	N.C.	Karlovačka	Duga Resa	SV+ZV active	2	0
M202	Zagreb Gk Rijeka	592+700	N.C.	Primorsko-goranska	Delnice	SV+ZV active	0	1
M604	Oštarije-Knin Split	25+207	N.C.	Karlovačka	Plaški	SV+ZV active	1	0
R101	DG - Buzet Pula	81+866	Ž.C.	Istarska	Sv. Petar u Šumi	BR IZ ST active	0	1
R101	DG - Buzet Pula	87+875	N.C.	Istarska	Žminj	PZ pasive	1	1
TOTAL:							**4**	**3**

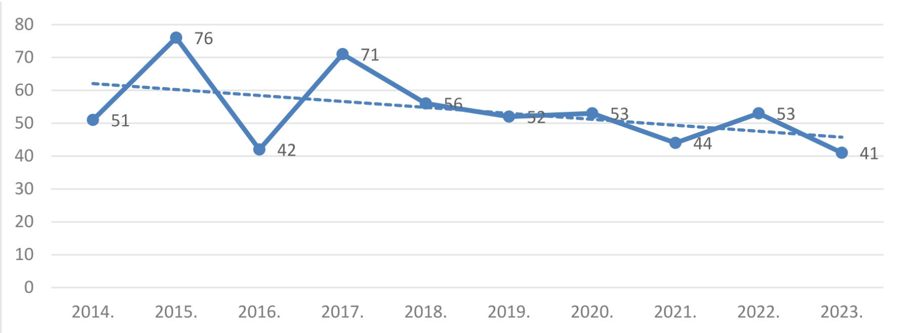
Source: HŽ Infrastructure Ltd., internal reports

Regarding responsibility, all fatalities were level crossing users with 100% responsibility attributed to the level crossing users, i.e., the human factor (cf. Graph 2.). It's evident that the influence of the human factor is the primary, almost sole cause of extraordinary events at level crossings, especially when accidents and serious accidents occur. Therefore, serious accidents happen at both active and passive level crossings where railway lines intersect unclassified roads, which is a similar case in Croatia as well.



Graph 2. Consequences of Extraordinary Events at Level Crossings by their Security Method and Responsibility for the Western Region from 2014 to 2023. Source: HŽ Infrastructure Ltd., internal reports

It's concerning that there's a very high trend of vehicles colliding with lowered half-barriers/full barriers, with a total of 539 breakages during the observed period, and 90% of the responsibility lies with the level crossing users, while the remaining incidents are attributed to adverse weather conditions (cf. Graph 3.).



Graph 3. Breakage of Half-Barriers/Full Barriers at Level Crossings in the Western Region from 2014 to 2023. Source: HŽ Infrastructure Ltd., internal reports

Based on the data from Graph 3, the trend line shows a consistent decline from 2015 to 2023, which is a positive indicator. Therefore, each breakage of a half-barrier/full barrier by level crossing users contributes to the increase in traffic accidents, and thus, each breakage of a half-barrier/full barrier can be viewed as a potential accident.

4. Measures to Increase Safety at Level Crossings

By analyzing the extraordinary events, it has been determined that level crossings have a significant impact on the safety of both railway and road traffic, especially those crossings secured by passive means, where drivers of road vehicles and their passengers are most often fatally injured. From this perspective, efforts are being made to abolish level crossings entirely in the future. From a financial perspective, abolishing level crossings entirely is currently difficult to achieve. Instead, efforts are being made to find cheaper technical and organizational solutions to reduce the number of level crossings. The first step in eliminating a level crossing is to find an alternative solution, such as constructing connecting roads, underpasses, and similar structures to separate road traffic from railway traffic. However, for railways with speeds exceeding 160 km/h, road and railway crossings must be constructed at two different levels [32].

Reducing the number of level crossings can be achieved through various methods, some of which include [32]:

a. consolidating two or more level crossings into one (closure with consolidation),

b. closing a level crossing (closure without consolidation),
c. replacing a level crossing with overpasses or underpasses.

Furthermore, addressing the safety issues of level crossings was identified in the Transport Development Strategy of the Republic of Croatia 2017-2030 as one of the measures to increase the safety of railway and road traffic.

Therefore, some of the mentioned options for reducing the number of level crossings are costly. However, one of the most expensive options is the construction of underpasses or overpasses. Nevertheless, a more cost-effective solution would be efficient, such as upgrading existing level crossings with modernized equipment. This could involve replacing current passive level crossing protection with active devices that automatically activate and deactivate upon the approach of a train. This would help avoid human errors, specifically mistakes made by operators managing level crossing protection devices. On the other hand, physically, it would greatly influence level crossing users through barriers, as well as visual and auditory signals. Additionally, there are various traffic calming solutions, such as preventing bypassing of barriers by installing fences between lanes, constructing islands, and installing speed bumps. There are also additional, much cheaper solutions, such as additional warning signs on the road surface or double lines between lanes, etc. Additionally, there are modern technical solutions used only in the Republic of Austria within the EU. It's a modern system that represents an innovative way of alerting drivers of road vehicles when a train approaches. The operation of the mentioned system is based on the installation of LED markers, luminous signals embedded in the road surface, which illuminate when a train is approaching within a radius of 800 meters from the railway-road crossing.

In addition to the above, it is necessary to educate users of railway-road crossings to better acquaint them with the dangers at those locations. According to a conducted survey [6] among drivers of motor vehicles regarding their knowledge of road traffic signs at railway-road crossings, 46% of respondents did not know the name of the road traffic sign "Andrijin križ" (Andrej's cross), and 57% of respondents did not know its meaning. Similarly, for road traffic signs "Crossing of the road over the railway without barriers or half-barriers" and "Crossing of the road over the railway with barriers or half-barriers," 72% of drivers did not know the names of these road traffic signs, while 82% of drivers were not familiar with what these signs meant. HŽ Infrastructure, in collaboration with the Faculty of Transport and Traffic Sciences, implements various awareness-raising campaigns for users of railway-road crossings. Some of the measures on which the Faculty of Transport and Traffic Sciences and HŽ Infrastructure jointly participate include "Safety Starts with You," "Your Opinion Matters," "Book Month," "Traveling Exhibition," "Conscientious Driver," "Social Media," and "Media." Furthermore, future drivers should be better educated about railway-road crossings during their training in driving schools, as few drivers are familiar with the meaning of road signs at such crossings. Mere knowledge of signs and regulations alone is not sufficient for safety if awareness of the dangers at railway-road intersections is not raised. Additionally, traffic safety education should be introduced as a subject in lower grades of elementary school to teach children about traffic hazards and how to behave in traffic.

5. Conclusion

By analyzing the causes of extraordinary events at level crossings (ŽCP) in the West Region, it is evident that the majority of these events occur due to negligence and disregard of traffic signals by level crossing users. Human factors play a significant role in these incidents, making them the primary reasons across the entire territory of Croatia as well.

When it comes to the method of securing level crossings (ŽCP) in the West Region compared to the rest of Croatia, the fact that there is one level crossing approximately every 2.56 kilometers of railway favors the argument. This density is slightly lower compared to the rest of Croatia, where there is one crossing every 1.86 kilometers of railway. Additionally, the method of securing these crossings leans more towards passive measures at 53%, as opposed to active security at 47%. Mentioned factors contribute to decreased traffic safety because there are still a significant number of level crossings per kilometer of railway, and passive security measures are prevalent. Analyses indicate that significant incidents also occur at level crossings secured by active measures, which is the case in the Western Region. This is logical considering that level crossings are actively secured on higher-ranked railways and roads due to the higher frequency of railway and road traffic, increasing the likelihood of incidents resulting from user error due to their abundance.

Serious accidents and incidents resulting in fatalities and severe injuries primarily occur at level crossings with active protection, specifically those with only light and sound signals, due to minimal railway and road traffic on county, local, and unclassified roads in or near settlements. This is often a result of drivers not adhering to traffic regulations. Based on the above, the working hypothesis that accidents resulting in fatalities occur at level crossings with low railway and road traffic on county, local, and unclassified roads in or near settlements due to drivers not adhering to traffic regulations has been proven.

The authors recognize the significance of this study in highlighting that level crossing incidents constitute more than 52% of all railway incidents in Croatia, and their occurrence is not decreasing. Moreover, the high impact of human factors, accounting for approximately 90% of these incidents, is similar in both the overall analysis and in the West Region.

Furthermore, it is noted that a significant number of level crossing users are not sufficiently familiar with road traffic signs at railway crossings and are unaware of the dangers of crossing railway and road traffic at the same level.

Given the aforementioned factors, it is supported by the fact that all new railways being designed and constructed do not allow for the crossing of two types of traffic at the same level. Additionally, on existing railways, the number of level crossings is being reduced, some are being eliminated, and there is a growing effort to actively secure priority level crossings in the future in order to meet EU standards, where approximately 53% of level crossings are actively secured.

Therefore, some of the recommendations that would be effective and have shown results in increasing safety at level crossings, and are easily achievable and not expensive, include additional warnings through road signs on the roadway about crossing railway tracks. Additionally, there is a need to improve awareness among level crossing users through marketing activities and promotions. Furthermore, it is proposed to better educate future drivers in driving schools about traffic behavior at level crossings. Similarly, in lower grades of elementary school, it is proposed to introduce a subject called Traffic Education, through which children would acquire knowledge about the dangers in traffic, as mere knowledge of signs and regulations is not the key to safety unless awareness of the dangers of land transport is raised.

Literature

1. Ambrosio, J.; Pombo, J.; Pereira, M.; Antunes, P.; Mosca, A. A computational procedure for the dynamic analysis of the catenary-pantograph interaction in high-speed trains, *J. Theor. Appl. Mech.,* 2012.
2. Analiza izvanrednih događaja u 2017. godini, broj: 526/18, HŽ Infrastruktura, Zagreb, 2018.
3. Analiza izvanrednih događaja u 2023. godini, broj: 548/24, HŽ Infrastruktura, Zagreb, 2024.
4. Barić, D., Starčević, M., Pilko, H. (2016). Analiza ponašanja sudionika u prometu na željezničko - cestovnim prijelazima, Željeznice 21, Stručni časopis Hrvatskog društva željezničkih inženjera, God. 16, Br. 3., p.7-17
5. Bruni, S.; Bucca, G.; Carnevale, M.; Collina, A.; Facchinetti, A. Pantograph-catenary interaction: recent achievements and future research challenges, *Int. J. Rail Transp,* 2017, *6*, 57-82.
6. Đambo, A. i dr., (2018.), Identifikacija uzroka rizičnog ponašanja korisnika željezničko-cestovnih prijelaza i primjena VR tehnologije u edukaciji i prevenciji, Sveučilište u Zagrebu: Fakultet prometnih znanosti.
7. Državni zavod za statistiku, Statistički ljetopisi Republike Hrvatske, različita godišta.
8. Facchinetti, A.; Bruni, S. Special issue on the pantograph-catenary interaction benchmark. *Veh. Syst. Dyn.* 2015, *53*, 303-304.
9. HŽ Infrastruktura d.o.o., Priručnik o željezničkim prugama
10. HŽ Infrastruktura d.o.o., Plan poslovanja 2023.
11. HŽ Infrastruktura d.o.o., Izvješće o mreži 2024.
12. European Railway Agency, dostupno na: www.era.europa.eu, pristupljeno: 28.02.2023.
13. Fonverne, I.: Safety at level crossings: A worldwide issue, *Global Railway Review*, Vol 24, 2018., No 3, p. 60-64.
14. Kaužljar, D. (2009). Analiza učestalosti ljudskog čimbenika kao uzroka izvanrednih događaja u željezničkom prometu, Željeznice 21, Stručni časopis Hrvatskog društva željezničkih inženjera, God. 8. Br. 3, p. 50-56.
15. Knežević, J., Belančić, M. (2018). Analiza stanja sigurnosti na željezničko - cestovnim prijelazima u Primorsko - goranskoj županiji, Željeznice 21, Stručni časopis Hrvatskog društva željezničkih inženjera, God. 17, Br. 2., p.27-34.
16. Marques, F.; Magalhães, H.; Pombo, J.; Ambrósio, J.; Flores, P. A three-dimensional approach for contact detection between realistic wheel and rail surfaces for improved railway dynamic analysis, *Mech. Mach. Theory,* 2020, *149*.
17. Mikuš, Lj., Bošnjak, M., Amanović, S.(1999). Analiza izvanrednih događaja na HŽ-ovim prugama te njihovih posljedica i učestalosti u funkciji sigurnosti željezničkog prometa, Željeznica u teoriji

i praksi, Časopis Hrvatskih željeznica, Vol 23, No 1., p. 159-172.
18. Mikuš, Lj., Bošnjak, M. (1999). Ljudske pogreške kao uzrok nesrećama u željezničkom prometu, Željeznica u teoriji i praksi, Časopis Hrvatskih željeznica, Vol 23, No 2., p.139-152.
19. Nåvik, P.; Rønnquist, A.; Stichel, S. Identification of system damping in railway catenary wire systems from full-scale measurements, *Eng. Struct.,* 2016, *113*, 71-78.
20. Pojam sigurnosti u željezničkom prometu, dostupno na: www.fpz.unizg.hr, pristup: 15.02.2023.
21. Pravilnik o postupanju u slučaju izvanrednih događaja (HŽI Sl.vj. br. 02/21, 03/23 i 15/23)
22. Pupavac, D., Knežević, J. (2021). Analiza izvanrednih događaja u željezničkom prometu. *Sigurnost, 63* (2), 155-164.
23. Pupavac, Drago; Knežević, Josip; Polovina, Žarko (2021). Analiza utjecaja ljudskog čimbenika na nastanak izvanrednih događaja u željezničkom prometu // Željeznice 21 : stručni časopis inženjera i tehničara Hrvatskih željeznica, 20 (2021), 3; 7-13
24. Projekt Istraživanje mjera povećanja sigurnosti na željezničko-cestovnim prijelazima Fakultet prometnih znanosti, Zagreb, 2015.
25. Railway Safety in the European Union Safety overview 2017, European Union Agency for Railways, Luxembourg, dostupno na: https://www.era.europa.eu/library/corporate-publications/safety-and-interoperability-progress-reports_en, pristup: 25.02.2023.
26. Railway safety statistics in the EU, dostupno na: https://ec.europa.eu/eurostat/statistics-explained/index.php/Rail_accident_fatalities_in_the_EU. (pristupljeno:12.03.2023.)
27. Song, Y.; Zhang, M.; Øiseth, O.; Rønnquist, A. Wind deflection analysis of railway catenary under crosswind based on nonlinear finite element model and wind tunnel test, *Mech. Mach. Theory,* 2021, *168.*
28. Song, Y.; Liu, Z.; Wang, H.; Lu, X.; Zhang, J. Nonlinear analysis of wind-induced vibration of high-speed railway catenary and its influence on pantograph-catenary interaction, *Veh. Syst. Dyn.,* 2016, *54.*
29. Song, Y.Z.; Liu, H.; Wang, J.; Zhang, X.L.; Duan, F. Analysis of the galloping behaviour of an electrified railway overhead contact line using the non-linear finite element method, *Proc. Inst. Mech. Eng. Part F J., Rail Rapid Transit,* 2018, *232*.
30. Stary, D. (1998). Ljudski čimbenici u zaštiti. Zagreb : IPROZ: Visoka škola za sigurnost na radu.
31. Strategija prometnog razvoja Republike Hrvatske (2017.-2030.), kolovoz 2017.
32. Toš Z., Signalizacija u željezničkom prometu, Sveučilište u Zagrebu, Zagreb, 2013.
33. Urda, P.; Aceituno, J.F; Muñoz, S.; Escalona, J.L. Artificial neural networks applied to the measurement of lateral wheel-rail contact force: A comparison with a harmonic cancellation method, *Mech. Mach. Theory,* 2020, *153*.
34. Zakon o sigurnosti i interoperabilnosti željezničkog sustava (NN br. 63/20)
35. http://www.era.europa.eu/Document Register/Documents/Safety%20Interim%20Report%202017.pdf, pristupljeno 28. veljače 2023
36. Wu, T.X.; Brennan, M.J. Dynamic stiffness of a railway overhead wire system and its effect on pantograph-catenary system dynamics, *J. Sound Vib.,* 1999, *219*, 483-502.
37. Xie, Q.; Zhi, X. Wind tunnel test of an aeroelastic model of a catenary system for a high-speed railway in China, *J. Wind. Eng. Ind. Aerodyn.,* 2019, *184*, 23-33.