TRANSPORT PROBLEMS 2020 Volume 15 Issue 4 Part 1
PROBLEMY TRANSPORTU DOI: 10.21307/tp-2020-048

Keywords: rail-road crossings; road safety; transport

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OVERVIEW OF SAFETY AT RAIL-ROAD CROSSINGS IN POLAND IN 2008-2018

Summary. The intersection of a public road with a railway line in one level, called a rail-road crossing, is a particularly dangerous place due to the traffic flows crossing it. The regulations give absolute priority to a rail vehicle over a public road user; in addition, significant differences in the masses and speeds of moving vehicles require traffic regulation consisting of adequate passage protection. To this end, the road on which motor vehicles is equipped with road signs informing drivers that they are approaching an intersection with a railway line. The rail-road crossing, depending on the category, is equipped with signaling devices warning of an oncoming train and barriers closing the entire width of the road or part of it, operated or operating automatically. In Poland, the category of rail-road crossing, the associated method and type of security used at the crossing, is determined on the basis of relevant acts and internal regulations of the railway line manager. The paper presents an overview of the state of safety at rail-road crossings in Poland in the years 2008-2018, presents applicable regulations regarding traffic safety at rail-road crossings, and presents methods of protection of rail-road crossings. In addition, a map of concentration of events on rail-road crossings was presented for the area of the Silesian Voivodeship. The effect of the case study for the Silesian Voivodeship is to identify sensitive rail-road crossings with the highest number of events during the analysis period.

1. INTRODUCTION

Rail-road crossings on the transport network of a given area are usually critical elements and their spatial location and functioning are of great importance for transport safety, which results from the consequences of potential events at crossings, which are usually catastrophic and have serious consequences in the form of seriously injured and fatal victims. The most common participants of these events are vehicles, pedestrians, and cyclists [1]. On the contrary, the probability of an event increases with the increase in traffic volume of road users [2-5]. When analyzing the research works on events at rail-road crossings available in the literature on the subject, it should be stated that many of them focus on statistical analyses of the frequency of accidents or the problem of predicting the occurrence of events at rail-road crossings [6-8]. As indicated in the research works [9, 10], owing to limited information from historical accidents statistics, these analyses are often carried out with the use of the forecasted number of events, in many cases using the empirical Bayesian method, whose goal is improving precision by combining accident history with accident prediction.

When analyzing the risk factors of the occurrence of an event and the causes of events on rail-road crossings, it can be concluded that vehicle drivers who do not comply with the applicable rules of vehicle priority at rail-road crossings have a significant share. Hence, the literature on the subject includes a significant number of research works devoted to an attempt to identify risk factors for the occurrence of an event [11], as well as the influence of vehicle drivers' behavior while driving, often aggressive, on the severity of drivers' injuries [12]. Analyses of this type are often conducted with the use of geographic information systems (GIS) in the management of territorial information [13].

In the available literature on the subject, we can also find research works that present innovative systems for securing rail-road crossings, the use of which is aimed at reducing the number of events at rail-road crossings. Some research work proposes to establish secure two-way communication between technology VANETS (technology for vehicles on a highway to share road condition, traffic and weather information) and Positive Train Control System (PTC) [14]. Thanks to the establishment of this type of communication, it will be possible to integrate information on train traffic within an Intelligent Transportation System (ITS) in order to eliminate traffic congestion as well as avoid accidents on rail-road crossings. In turn, R. Jain et al. [15] propose to secure the rail-road crossings with the use of a laser alarm system.

The main purpose of the research was to overview the state of safety at rail-road crossings in Poland in the years 2008-2018, presents applicable regulations regarding traffic safety at rail-road crossings, and presents methods of protection of rail-road crossings. Moreover, a case study resulted as a map of concentration of events and victims on rail-road crossings was presented for the area of the Silesian Voivodeship. The effect of the case study for the Silesian Voivodeship is to identify sensitive rail-road crossings with the largest number of events and fatalities during the analysis period.

2. STATISTICS DATA AND TYPES OF EVENTS AT RAIL-ROAD CROSSINGS

The Fig. 1a shows the number of active rail-road crossings on lines in Poland in the years 2008-2018 by crossing category. The most frequent group is rail-road crossings of category D (6,580 crossings), which represents 56% of all rail-road crossings. Over the years 2008-2017, their number decreased by 2019 items (24%). In 2018, the number of crossings of category D increased by 4% compared with 2017, which results from the creation of crossings in this category for the purposes of modernization works carried out within stations and rail-road crossings. Currently, the second category of rail-road crossings is rail-road crossings of category A, which constitute 21% of all rail-road crossings. Since 2008, their number has been steadily decreasing, and in 2017, it reached the value of 2,392, which is a 13.7% decrease in this category compared with 2008. Similar to category D, in 2018, a slight increase in the number of rail-road crossings of category A was recorded relative to 2017 (by 23 rail-road crossings). In 2018, rail-road crossings of category C numbered 1,431 (11% of all crossings). In the analyzed period, their number systematically increased. Rail-road crossings of category B in 2018 accounted for 12% of the number of crossings all categories. Their number is also systematically increasing, and in 2018, it reached a value of 625 compared with 2008.

In 2018, the number of rail-road crossings or crossings located on internal roads classified in category F was 616 units. In turn, the number of pedestrian crossings marked with category E was 489. In the further part of the paper, the events on rail-road crossings that took place on the publicly accessible railway line were analyzed, hence the events on the levels E and F rail-road crossings will not be taken further into consideration. Despite the use of various kinds of security solutions on rail-road crossings occur on them adverse events. The Rail Transport Act [18] classifies and defines the following types of adverse events that may occur on rail-road crossings:

- serious accident - any accident caused by a collision, derailment, or other event having an obvious effect on railway safety regulations or safety management: with at least one fatality or at least five seriously injured persons (seriously injured - a person who as a result of a serious accident or the accident suffered a violation of bodily functions or health disorder and as a result of being in hospital for more than 24 hours), or causing significant damage to a railway vehicle, railway infrastructure, or

the environment, which can be immediately estimated by the commission investigating the accident for at least 2 million euro,
- accident - an unintentional, sudden event or a series of events involving a railway vehicle with negative consequences for human health, property, or the environment; accidents include in particular collisions, derailments, level crossing events, events involving people caused by a moving railway vehicle, or a fire from a railway vehicle,
- incident - any event other than an accident or serious accident related to railway traffic and affecting its safety.

a). b).

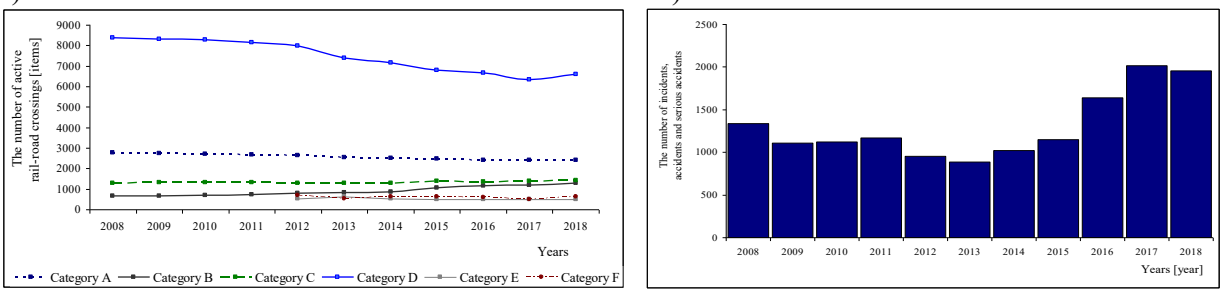

Fig. 1. a) The number of active rail-road crossings by crossing category; b) The number of incidents, accidents and serious accidents in the years 2008-2018 in Poland. Source: Own research based on [16, 17]

In turn, the following terms are used in road traffic:
- road accident - an incident in road traffic where one or more road users take part in the event as a result of which a road participant has been injured or has died, and
- collision - a traffic incident as a result of which the people involved do not suffer death or injury and only property is damaged.

It can be stated that the terminology specified in the rail and road regulations is slightly different.

Based on the data presented in the Annual Reports on the Activities of the State Commission for the Investigation of Railway Accidents, in the years 2008-2018, almost 14,300 events occurred in Poland within the railway network. The smallest number of events was serious accidents (3% of all events), followed by incidents (41% of all events). In turn, the most accidents were recorded (56% of all events). In recent years, i.e. in 2016, 2017, and 2018, an increase in the total number of events on the railway network has been observed (Fig. 1b).

3. POLISH LEGAL FRAMEWORK FOR THE METHOD OF SECURING TRAFFIC ON THE RAIL-ROAD CROSSINGS

To ensure the safe operation of railway lines, and in particular the safe railway vehicles traffic, railway lines should be equipped with devices protecting, among others, against collision of a railway vehicle with a road vehicle at the intersection of a railway line with a road at one level. One of the documents defining the rules for securing traffic on rail-road crossings is the Regulation of the Minister of Infrastructure and Development of 20 October 2015 on technical conditions to be met by junctions of rail lines and railway sidings with roads and their location [19]. This regulation contains recommendations regarding the division of level crossings into categories resulting from railway line parameters (i.e. number of tracks, type and traffic volume, and speed) and road. This regulation assumes the existence of six categories of rail-road crossings on railway lines on which the maximum train speed is not higher than 160 km/h. Pursuant to this regulation, rail-road crossings and level crossings are divided into the following categories [19]:
- category A - rail-road crossings on which road traffic is directed by authorized employees of the railway manager or railway company or by means of manual signals or systems or crossing devices equipped with barriers closing the entire width of the road;

- category B - rail-road crossings where traffic is directed by means of automatic crossing systems, equipped with traffic lights and traffic barriers closing the road in the direction of entry to the crossing or/and exit from the crossing; the product of traffic should be equal to or greater than the number 150,000 or the railway line or railway siding crosses the national road;
- category C - rail-road crossings where traffic is directed by means of automatic crossing systems equipped with traffic lights only; the product of traffic should be equal to or greater than the number 150,000 or the railway line or railway siding crosses the national road;
- category D - rail-road crossings that are not equipped with traffic safety systems and devices; the product of traffic should be less than 60,000, and the railway traffic on a given section of the railway line or siding is carried out at a maximum speed of not more than 120 km/h and visibility conditions are met;
- category E - passages equipped with a semi-automatic or automatic crossing system or reels, barriers, or labyrinths; and
- category F - rail-road crossings or crossings located on internal roads.

Single-level intersections do not apply when the maximum speed specified on the railway line is greater than 160 km/h. The selection of the rail-road crossing category results from several important conditions, among others, based on the devices used at a given crossing, but the daily number of road and rail vehicles passing through them is of fundamental importance.

The indicator (daily traffic volume), on the basis of which the category of rail-road crossing is determined, is the product of the average daily traffic volume of road and rail. The method of calculating the product of traffic at level crossings is set out in Annex 2 to the Regulation of the Minister of Infrastructure and Development of 20 October 2015 on Technical Conditions to be met by the Junction of Railway Lines and Railway Sidings with Roads and their Location [19]. The calculations are carried out by the appropriate road board not less frequently than every 5 years and the railway board in the same periods for all rail-road crossings. According to the recommendations, traffic measurements should be carried out in September or October, within two days (Tuesday, Wednesday), from 6:00 a.m. to 6:00 p.m. and include all vehicles crossing the rail-road crossing. When calculating the rail traffic volume, the traffic volume of traffic for all rail vehicles that have traveled over the rail-road crossing during the day should be taken into account. The rail-road crossing category also defines the type of devices used to secure traffic at the crossing. The crossing may be equipped with local service or with automatic crossing signaling, whose requirements and technical conditions regarding the construction of barriers and traffic lights are also specified in the regulation [19], legal act, and E4 instruction dedicated to the construction, inspection, and maintenance of traffic safety devices at rail-road crossings.

In turn, the behavior of motor vehicle drivers at rail-road crossings is regulated by the Act of 20 June 1997 Road Traffic Law as amended according to which motor vehicle drivers are obliged to follow the instructions given by the rail-road crossing service, road signs, and signals displayed on the signaling devices. The vehicle driver when approaching and passing through the rail-road crossing is obliged to exercise extreme caution. Before entering the track, the vehicle driver must ensure that the train is not approaching and take appropriate precautions when visibility is restricted. The vehicle driver speed should be such that the driver can stop the vehicle in a safe place when a train arrives or when signals prohibiting entry are displayed. It is forbidden to drive around abandoned dams or half-dams and enter a crossing when raising or lowering dams. It is also dangerous to enter the crossing if there is not space to continue driving on the other side of the crossing. These are dangerous situations in which an incident with a rail vehicle can occur.

4. OVERVIEW OF SAFETY AT RAIL-ROAD CROSSINGS IN POLAND IN 2008-2018

4.1. The number of accidents at rail-road crossings guarded and unguarded

Depending on the traffic conditions prevailing at the rail-road crossing and in relation to the basic principles of operation of security devices, rail-road crossings protected by technical devices called guarded crossings and rail-road crossings without technical devices referred to as unguarded crossings can be distinguish. Unguarded rail-road crossings are secured only by road signs. The number of

accidents and serious accidents at guarded and unguarded rail-road crossings in Poland in 2008-2018 is shown in Fig. 2a.

a) b)

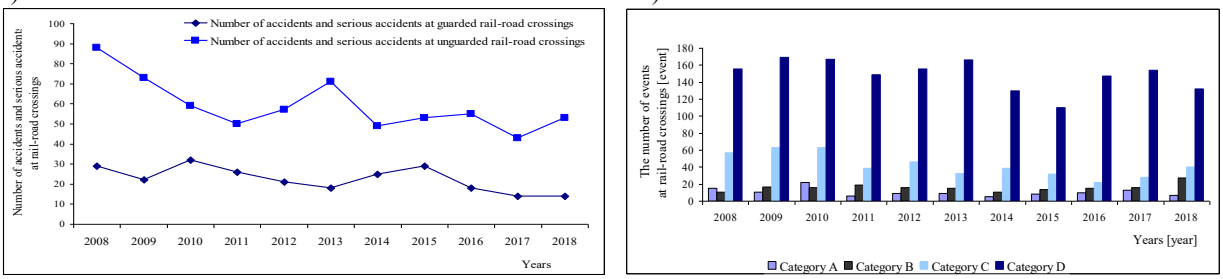

Fig. 2. a) The number of accidents and serious accidents at guarded and unguarded rail-road crossings; b) The variability of the number of events on the rail-road crossings categories A-D in the 2008-2018 in Poland. Source: Own research based on [16]

Over the years 2008-2018, numerous accidents occurred on guarded and unguarded rail-road crossings. Based on the data presented in Fig. 2a, it can be stated that more accidents occurred on unguarded rail-road crossings than on guarded ones. The number of accidents in individual years fluctuated but generally showed a downward trend. In the last year of the analysis, the number of accidents at unguarded rail-road crossings slightly increased.

4.2. Events at rail-road crossings of individual categories

Fig. 2b shows the number of events on rail-road crossings of individual categories. In the years 2008-2018, events at rail-road crossings category A accounted for 5% of all events occurred at crossings of categories A-D. On rail-road crossings category A, a total of 115 events occurred, representing an average of 11 events per year. Owing to the built investments in recent years, there are many rail-road crossings of category B. In 2008-2018, 177 events occurred on rail-road crossings of category B (representing 7% of all events in 2008-2018), which on average accounts for 18 events per year. The smallest number of events was recorded in 2008 and in 2014. The most number of events occurred in 2018, which is an increase over a year 2017 by 69% of events on this type of crossings. A total of 461 events occurred on rail-road crossings of category C (19% of all events in 2008-2018), which is 46 events per year. From the data presented in Fig. 2b, it can be stated that the highest number of accidents on rail-road crossings of category C took place in 2009, whereas 2016 was the year in which the number of events was almost three times lower, despite the number of such crossings was 4% higher than in 2009. The most sensitive in the structure of rail-road crossings is crossings of category D, because they are characterized by the largest number of events per year. In total, in the years 2008-2018, as many as 1636 events were recorded within them (representing as much as 69% of all events), which indicates the occurrence of an average of 164 events per year. The smallest number of events was recorded in 2015, whereas the most occurred in 2009.

Analyzing the total number of events on rail-road crossings of category A-D, it can be stated that in 2008-2018, there were 2,390 events. Most events occurred in 2010 and the least in 2015 (a decrease in the number of events by 39% compared with 2010). In the analyzed period, initially there was an upward trend in the number of events. Then, in 2011, there was a decrease in the total number of events by 21% compared with 2010. In the years 2013-2015, a downward trend in the number of events can be seen, which, however, did not persist, because in the last three years, there has been an upward trend in the number of events at rail-road crossings of categories A-D. In 2018, there was a slight decrease in the total number of accidents at rail-road crossings of categories A-D by 4.8% compared with 2017. According to the State Commission for the Investigation of Railway Accidents [16], in 2018, the most common events at rail-road crossings were the result of failure to comply with the provisions of ignoring the "Stop" sign and other road signs and signals, not adapting speed to road conditions, passing vehicle drivers under closing turnpikes or bypassing closed half barriers, blocking

the passage by entering the tracks without the possibility of exiting, or incompetent behavior in the event of immobilizing the vehicle on rail-road crossing. The analysis of events at rail-road crossings of category A indicated that not only motor vehicle drivers are always to blame but also the reason for such events was the late closing of the turnpikes or not closing them in front of the oncoming train. According to data [16], in 2018, drivers of passenger cars constituted the most numerous group of participants of events on rail-road crossings (they participated in 140 events, which represents 65% of the total number of events). The structure of road traffic participants in accidents at rail-road crossings is shown in Fig. 3a. The observed increase in the number of events at rail-road crossings should be the basis for undertaking appropriate preventive, corrective, and control actions, the visible effect of which should be the improvement of the level of safety in the area of rail-road crossings.

4.3. The safety indicators for rail-road crossings of individual categories

To illustrate the scale of the phenomenon, the safety indicators have been determined. The safety indicators were calculated for serious accidents and accidents at rail-road crossings of individual categories with the participation of road and rail vehicles, as shown Tab. 1, Fig. 3b:

$$w_w = \frac{L_z}{L_p} \tag{1}$$

where w_w - the safety indicator; L_z - the number of events at rail-road crossings of a given category, and L_p - the number of rail-road crossings in a given category.

Table 1

The safety indicators for rail-road crossings of individual categories in 2008-2018

Year	Number of crossings				Number of events				The safety indicators			
	A	B	C	D	A	B	C	D	A	B	C	D
2008	2772	645	1285	8362	15	11	57	156	0.0054	0.017	0.0443	0.0186
2009	2724	665	1313	8314	11	17	63	169	0.0040	0.0255	0.0479	0.0203
2010	2712	684	1311	8270	22	16	63	167	0.0044	0.0233	0.0480	0.0201
2011	2676	728	1304	8155	6	19	39	149	0.0022	0.0260	0.0299	0.0182
2012	2633	789	1302	7967	9	16	46	156	0.0034	0.0260	0.0353	0.0195
2013	2539	812	1289	7386	9	15	33	166	0.0035	0.0184	0.0256	0.0224
2014	2516	856	1283	7158	5	11	39	130	0.0019	0.0128	0.0303	0.0181
2015	2458	1045	1371	6801	8	14	32	110	0.0032	0.0133	0.0233	0.0161
2016	2414	1155	1366	6661	10	15	22	147	0.0041	0.0129	0.0161	0.0220
2017	2392	1192	1386	6343	13	16	28	154	0.0054	0.0134	0.0202	0.0242
2018	2415	1270	1431	6580	7	27	40	132	0.0028	0.0212	0.0279	0.0200
Average value									0.0037	0.0191	0.0317	0.0200

Source: Own research based on data presented in [18].

Analyzing the obtained results, it can be stated that in the years 2008-2018 the lowest safety indicator values were obtained for rail-road crossings of category A (average of 0.0037 per year). In turn, the highest values of the safety indicator were obtained on rail-road crossings of category C (average of 0.0317 per year). In the adopted analysis period, the safety indicator, despite fluctuations, has a decreasing tendency.

4.4. The accidents, serious accidents, and incidents on rail-road crossings

In the next stage, the number of incidents, accidents, and serious accidents that occurred at rail-road crossings of categories A-D was compared with the number of incidents, accidents, and serious accidents on the Polish rail network in 2008-2018 (Tab. 2). The share of incidents, accidents, and serious accidents that occurred on rail-road crossings of categories A-D ranged from 10% in 2017 and 2018 to 25% in 2013. From 2013 to 2018, the downward trend of the share of events at rail-road crossings in the total number of events that occurred on the Polish rail network continued.

a) b)

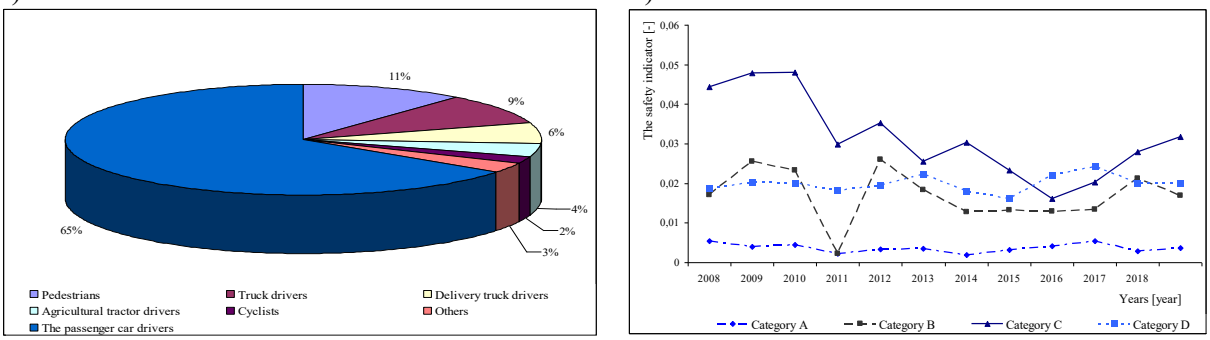

Fig. 3. a) The structure of road traffic participants in accidents at road-rail crossings in 2018; b. The safety indicators for rail-road crossings of individual categories in 2008-2018. Source: Own research based on data presented in *Annual Reports for 2009-2019* [16]

Table 2

The number of incidents, accidents, and serious accidents on the Polish rail network and on A-D rail-road crossings in 2008-2018

Year	The number of incidents, accidents and serious accidents on the Polish rail network	The number of incidents, accidents and serious accidents on the rail-road crossings category A-D	Share of incidents, accidents and serious accidents at A-D rail-road crossings in the total number of events [%]
2008	1339	239	17.8
2009	1110	260	23.4
2010	1120	268	23.9
2011	1171	213	18.1
2012	952	227	23.8
2013	890	223	25.0
2014	1019	185	18.1
2015	1152	164	14.2
2016	1543	194	12.5
2017	2019	211	10.4
2018	1959	205	10.4
The total number of events	14274	2389	16.7

Source: Own research based on data presented in *Annual Reports for 2009-2019* [16].

4.5. Victims of accidents and serious accidents at rail-road crossings

The number of injured and fatalities in accidents and serious accidents that occurred on rail-road crossings of categories A-D was also compared with the number of victims on the Polish rail network (Tab. 3). For both cases, the victim rate was calculated as the ratio of the number of victims on rail-road crossings to the total number of victims in accidents and serious accidents. In the years 2008-2014, there was a downward trend in the number of injured victims. In 2015, the number of victims increased and fluctuated in subsequent years. The average injured rate was 23.41% (52 people).

A total of 550 fatalities in the events at rail-road crossings in 2008-2018 have been recorded, which is 26% of all fatalities in accidents and serious accidents within the rail network over the analyzed period. Most fatalities have been recorded in the rail-road crossings in 2009, whereas in 2014, the number of fatalities was more than twice lower and was the lowest in the analyzed period. On average, in the years 2008-2018, 55 fatalities per year were recorded. In conclusion, it should be stated that in the years 2008-2018, a large number of people were injured in rail-road crossings of categories A-D (1069 victims). Of the victims, injured accounted for 48%, and fatalities for 52%. In total, this number represents 26% of all victims of accidents and serious accidents on the Polish rail network in the years 2008-2018.

Table 3

Injured and fatalities in accidents and serious accidents on the Polish rail network and on A-D rail-road crossings in 2008-2018

Year	The number of injured victims in accidents and serious accidents		Indicator for the injured victims [%]	The number of fatalities in accidents and serious accidents		Indicator for the fatalities [%]
	On the Polish rail network	On the A-D rail-road crossings		On the Polish rail network	On the A-D rail-road crossings	
2008	263	104	39.5	305	39	25.6
2009	260	76	29.2	362	74	20.4
2010	156	59	37.8	303	55	18.1
2011	160	53	33.1	331	62	18.7
2012	179	36	20.1	250	62	24.8
2013	222	34	15.3	129	47	36.4
2014	208	24	11.5	93	35	37.6
2015	227	39	17.1	109	50	45.8
2016	174	37	21.2	92	45	48.9
2017	172	27	15.6	88	37	42.0
2018	196	30	15.3	86	44	51.1
Total number of victims	2217	519	23.41	2148	550	25.6

Source: Own research based on data presented in other articles [16-19].

5. THE SAFETY CONDITION AT RAIL-ROAD CROSSINGS IN THE SILESIAN VOIVODESHIP IN THE YEARS 2008-2018 – CASE STUDY

On the basis of statistics presented by the General Police Headquarters, a map of concentration of events (Fig. 4a) and victims (Fig. 4b) on rail-road crossings in the Silesian Voivodeship in the years 2008-2018 was constructed. In total, 183 events occurred in the analyzed period, in which 52 victims were recorded (10 fatalities, 18 seriously injured, and 24 slightly injured). In the vast majority of cases, one event occurred on a one rail-road crossing. Rail-road crossings where more than one event occurred are listed in Tab. 4. However, rail-road crossings where fatalities were noted include locations like Aleksandrów, Lisowie, Cieszyn, Żywiec, Podlesie, Bełk, Jackowie, Blachownia, and Czerwionka - Leszczyny (Kolejowa Street). Among the aforementioned rail-road crossings, one can also distinguish those on which a greater number of fatalities were recorded, as well as those on which, apart from fatalities, seriously injured (e.g. rail-road crossings in Bełk, in Blachownia) and slightly injured (e.g. rail-road crossing in Molna) were recorded. It is also worth emphasizing that of the rail-road crossings where fatalities were recorded, only the crossing in Czerwionka-Leszczyny is a guarded crossing, whereas all others are unguarded. The variability of the number of victims on rail-road crossings in the Silesian Voivodeship in the years 2008-2018 is shown in Fig. 5a.

As a result of the event-type analysis, it was found that the most common occurrence was of train and motor vehicle side-impact crash (86.70%), followed by a significantly smaller share in the total number of events in the following order: train-vehicle head-on collisions (4.26%), collisions with a stopped vehicle (3.19%), other (3.19%), rear-end collisions of vehicles (1.06%), hitting a pole or sign (0.53%), run into a turnpike (0.53%), and overturning vehicle (0.53%). On the contrary, taking into account the way of protection occurring at rail-road crossings, it can be stated that 90.91% of all events occurred on unguarded rail-road crossings and 9.09% on guarded crossings.

In the next stage, the events' causes were analyzed. Only in 2.19% of cases the event was the train driver's fault, whereas in 97.81% of cases, the cause was the inappropriate behavior of other road users, mainly vehicle drivers (less frequently pedestrians and cyclists).

a) b)

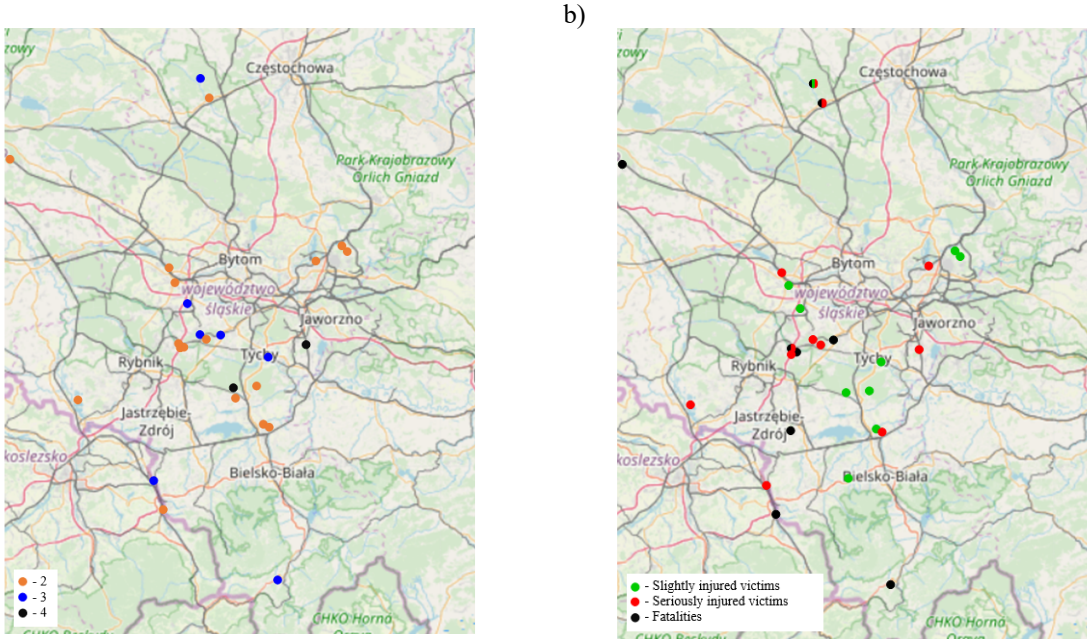

Fig. 4. a) The events concentration map; b) fatalities, slightly and seriously injured victims on rail-road crossings in the Silesian Voivodeship in the years 2008-2018

Table 4

The rail-road crossings in the Silesian Voivodeship in 2008-2018, where more than one event occurred

City	Street / Intersection	Number of events	Rail-road crossing type
Będzin	Kręta	2	Unguarded
Bielsko-Biała	Ciżemki – Spółdzielców	2	Unguarded
Bieruń	Bogusławskiego	4	Unguarded
Blachownia	Częstochowska - Konopnickiej	2	Unguarded
Bycina	Pyskowicka	2	Unguarded
Cieszyn	Frysztacka	3	Unguarded
Czechowice Dziedzice	Górnicza	2	Unguarded
	Nad Białką	2	Unguarded
Czerwionka -Leszczyny	Kolejowa	2	Guarded
	Młyńska – Polna	2	Unguarded
	Rybnicka	2	Unguarded
Dąbrowa Górnicza	J. Piłsudskiego	2	Unguarded
	Laski	2	Unguarded
Gliwice	Okrężna – Pocztowa	2	Unguarded
	Portowa	2	Unguarded
Kaniów	Dankowicka	2	Unguarded
Łaziska Górne	Wyzwolenia – Gostyńska	3	Unguarded
Milówka	Torowa – Kępki	3	Unguarded
Molna	Wiejska	3	Unguarded
Ornontowice	Chudowska – Polna	3	Unguarded
	Kolejowa	2	Unguarded
Piasek	Powstańców Śląskich	4	Unguarded
	Słoneczna	2	Unguarded
Ruda Śląska	Nowy Świat – Halembska	3	Unguarded
Tworków	Dworcowa	2	Unguarded
Tychy	Urbanowicka	3	Unguarded

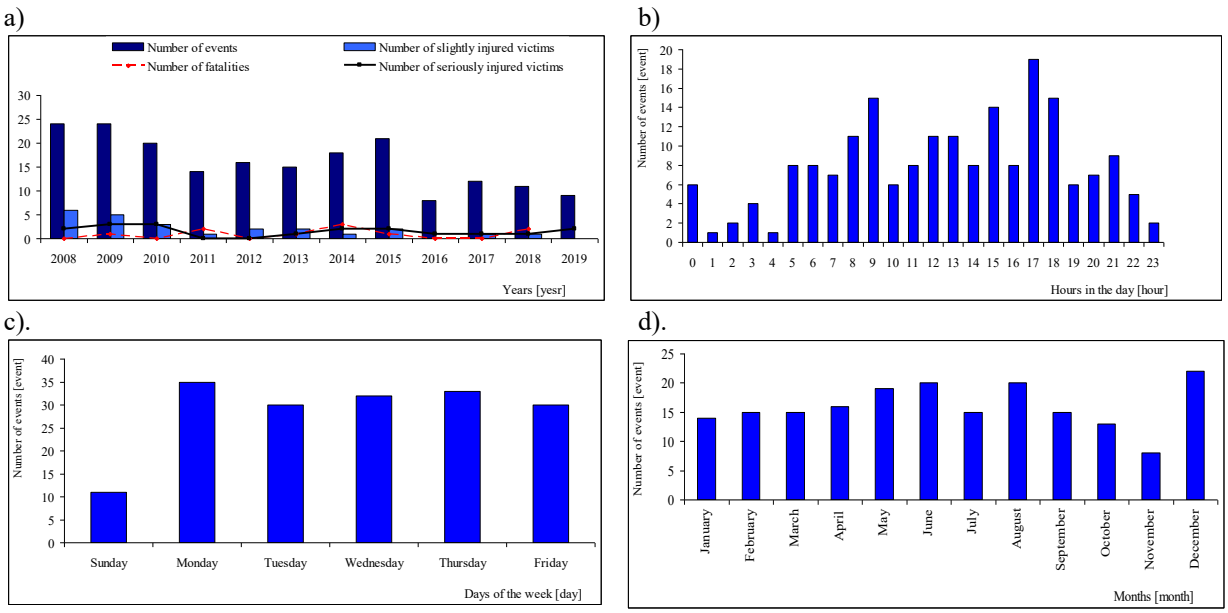

Fig. 5. a) Variability of the number of fatalities, slightly and seriously injured victims against the background of the number of events at rail-road crossings; b) daily; c) weekly; d). monthly variability of events at rail-road crossings in the Silesian Voivodeship in the years 2008-2018

Considering the causes of events in the group of events caused by the fault of other road users, it should be stated that the most frequent events were caused by the motor vehicle driver not giving the right-of-way (78.21%). The detailed structure of the distribution of events' causes is shown in Fig 6. More detailed diagnosis of the causes of events indicates that the main reasons for improper behavior of users on rail-road crossings were distraction (e.g. use of a mobile phone and pet control in vehicle), maneuvering the vehicle, contact with vehicle passengers, weather conditions (e.g. dazzle by the sun or fog), psychophysical condition of the driver (e.g. illness and alcohol or drug abuse), and other difficulties (e.g. stopping a vehicle within a rail-road crossing).

In turn, analyzing the daily (Fig. 5b), weekly (Fig. 5c), and monthly (Fig. 5d) variability of events at rail-road crossings in the Silesian Voivodeship in the years 2008-2018, it can be stated that during the day, the most events occur in the afternoon (17:00-18:00), and the fewest events took place on Sunday; however, the distribution of events in individual months of the year does not show clear trends (except for the decrease in the number of events in November and the increase in December).

6. CONCLUSIONS

The effects of events at rail-road crossings are very dangerous, especially for road users, owing to the powerful kinetic energy of the train, which when released, causes serious damage to vehicles and injuries to drivers and passengers of motor vehicles and pedestrians, and in many cases, results in the loss of life. The paper analyzes the events at rail-road crossings in Poland in 2008-2018. The analysis covered guarded and unguarded rail-road crossings with a distinction between the categories of the crossing. The safety indicators were determined for individual categories of rail-road crossings. Events were also reviewed in terms of their classification into serious accidents, accidents, and incidents, and the number of persons injured in serious accidents and accidents was analyzed.

The conducted analysis allowed to state that in 2008-2018 the numbers of rail-road crossing in Poland had been continuously decreasing (see Fig. 1a). In 2008, there were 13,064 rail-road crossings of all categories on the Polish transport network and 12,801 in 2018. This is in line with activities carried out in many other countries e.g., Czech Republic or Austria, where the continuously limit number of rail-road crossing is also observed.

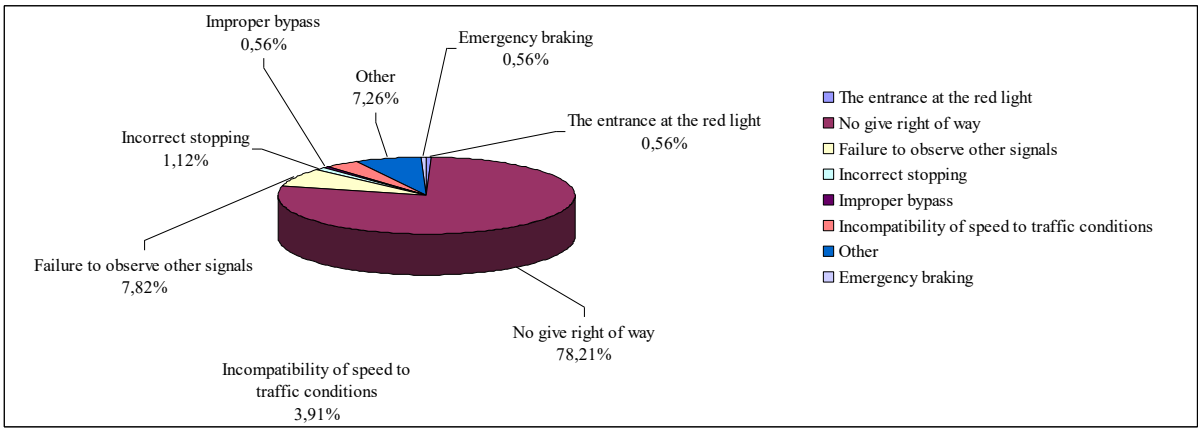

Fig. 6. The detailed structure of the distributions of events' causes on rail-road crossings in the Silesian Voivodeship in the years 2008-2018

To reduce the number of accidents at rail-road crossings, all possible actions should be taken to equip the crossings with modern safety devices, devices for active warning of drivers before approaching a rail-road crossing, vibroacoustic elements restoring the driver's attention before crossing with a railway line, and recording systems in cases of breaking the law by drivers connected to the national system. In justified cases, complete elimination of the rail-road crossings should be achieved through the construction of two-level intersections. When designing activities to improve safety level at rail-road crossings, consideration should be given to issues such as follows:

- educating users of rail-road crossings;
- intensifying actions aimed at imposing penalties for all kinds of offences, from pedestrians, drivers to infrastructure managers responsible for the technical condition; and
- modernization and retrofitting of railway infrastructure, and above all rail-road crossings with appropriate devices.

One clear finding is that safety cannot be reliably assessed without having reliable traffic volumes. Furthermore, according to the statistics, most Polish rail-road crossings are category D, defined based on traffic product, maximum speed, and visibility conditions. Such an approach to definition and classification of rail-road crossing is very limited, and its update and specification should be considered. As traffic product relies on road and rail traffic volumes, they should be reliably known, which is unfortunately often not the case. For example, railway managers, may not always have up-to-date information about road traffic volumes. In addition, road traffic volumes are usually derived from national counts, which take place in relatively long time periods. Moreover, visibility conditions are not stable; they change during the year. Keeping constant visibility conditions all year-round is very unlikely to happen.

Acknowledgements

The article has been presented on *13th International BRD GAMBIT 2020 Conference*.
Co-funded by the Science Excellence programme of the Ministry of Science and Higher Education.

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Received 29.06.2019; accepted in revised form 24.11.2020