

Analysis of pedestrian road safety in the Republic of Croatia

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Abstract: Pedestrians are a special category of road traffic participants. The special feature of pedestrian traffic is that it is accessible to everyone, regardless of age or knowledge of traffic. Pedestrians do not usually wear protective clothing and have a low and vulnerable position on the road compared to other road users. In road accidents involving pedestrians, 96% of those involved were injured due to inadequate pedestrian protection. Pedestrians are responsible for about 20% of all road traffic fatalities, although the proportion of road accidents involving pedestrians is only 4%. This shows that pedestrians are an extremely vulnerable group of participants. Therefore, this paper presents an analysis of all traffic accidents involving pedestrians in a five-year period in the Republic of Croatia. It is analysed in which locations and for what reasons traffic accidents occur in which pedestrians suffer fatal consequences. The analysis is conducted so that the micro-locations where pedestrian accidents occur can be further investigated.

Keywords: PEDESTRIAN COLLISION, TREFFIC ACCIDENTS, CRASH TEST, PC CRASH, PEDESTRIAN

1. Introduction

Traffic accidents are one of the leading causes of death in the world. If we analyse the number of fatalities in traffic accidents, 20% of them are pedestrians. As pedestrians are the most vulnerable traffic users, a significant portion of pedestrian accidents results in injury or death.

Pedestrian travel is the most accessible form of transportation because there are no age restrictions or acquired knowledge and skills.

The paper contains statistical data on road traffic accidents in the Republic of Croatia for the observed period of five years. Data on pedestrian injuries in the countries of the European Union and data on pedestrian injuries in the Republic of Croatia are also presented.

2. Pedestrian road safety in European Union countries

One of the most vulnerable groups on the road are pedestrians. From 2010 to 2018, there were 280,000 seriously injured pedestrians in the European Union, while 51,000 pedestrians were killed. From 2010 to 2018, the number of pedestrian fatalities decreased by about 2.6% each year. In 2019, 4,628 pedestrians died in road accidents on the territory of the European Union, representing 20% of all persons killed in road accidents. In 2020, 3,608 pedestrians died in traffic accidents in the European Union, representing approximately 19% of all those killed in traffic accidents. (1) Among the European Union countries, the number of pedestrians killed in traffic accidents is highest in Romania. In countries such as Romania, Latvia and Lithuania, the number of pedestrians killed in traffic accidents is twice the average of the other countries of the European Union. Romania has 34.4 pedestrians killed per million inhabitants, the Republic of Croatia is above average with 13.4 pedestrians killed per million inhabitants, and the Netherlands has the lowest number with 2.6 pedestrians killed per million inhabitants. Looking at European Union countries, the average number of pedestrians killed on the roads in 2018-2020 is 9.7 pedestrians per million inhabitants. The trend in pedestrian fatalities in the EU is currently downward. From 2011 to 2020, the number of pedestrian fatalities decreased from 5,986 to 3,608, a relative decrease of about 40%. The decrease for pedestrians is more significant than the decrease for all other road users, which is about 34% over the same period. (2) All European Union countries have seen a decrease in pedestrian fatalities except Cyprus, which has seen an increase of about 10%. In Hungary and Bulgaria, the number of fatal pedestrian accidents decreased the least during the observation period, while Estonia recorded the largest decrease of 53%. In the Republic of Croatia, the trend in pedestrian fatalities between 2011 and 2013 is 23% compared to 2018-2020. Looking at the gender of traffic fatalities in EU countries, 78% are men and 22% are women. For pedestrian fatalities, the ratio is slightly different: 64% of pedestrian fatalities are men and 36% are women. In the Republic of Croatia, in the period from 2012 to 2020, 79% of

persons killed in traffic accidents were men, and in pedestrian accidents, 59% of pedestrians killed were men. 48% of pedestrians killed are over 65 years old, of all road users killed, 28% are over 65 years old, while the largest proportion of those killed, 56%, are between 25 and 64 years old. Most pedestrians killed are over 65 years old, and 21% of the population in EU countries is over 65 years old. Most traffic accidents in which pedestrians are killed occur during the day on weekdays 64%, weekends during the day 18%, weekends at night 10% and weekdays at night 8%. If the above data is correlated with the participants killed in traffic accidents, the ratios are different, but the distribution is the same. 53% of participants killed in traffic accidents were killed on non-urban roads, 40% on urban roads, and 8% on expressways and highways. Fatal pedestrian crashes occurred 5% on expressways and highways, 24% on nonurban roads, and most fatal pedestrian accidents occurred on urban roads 71% of all fatal pedestrian fatalities. In 2020, most pedestrians 77% in EU countries died on straight road sections and the fewest pedestrians 1% died on traffic circles. In 74% of road accidents involving pedestrian fatalities, the road surface was dry and without precipitation, in 24% of road accidents the road surface was wet or dirty, and in only 1% was the road surface slippery or covered with snow and ice. (2,3)

3. Road safety in Republic of Croatia

In the Republic of Croatia, in the observation period from 2018 to 2022. 154,895 traffic accidents recorded by the police occurred, which corresponds to an average of 30,979 traffic accidents per year. The following table shows that the number of traffic accidents at the beginning of the observed five-year period was at a maximum of 33,440. There was a significant decrease in the number of traffic accidents in 2020, which was due to the Covid pandemic; the number of traffic accidents in that year was about 17% lower than the year before and after.

Table 1. The number of traffic accidents in the Republic of Croatia in terms of consequences

	2018	2019	2020	2021	2022
Traffic accidents	33 440	31 367	26 074	31 453	32 561
Traffic accidents (damage)	22 990	21 672	18 364	22 307	22 122
Traffic accidents (injured)	10 153	9 416	7 496	8 883	9 762
Killd	317	297	214	292	275

Traffic accidents can be divided into several different categories, one of the categories is regarding the consequences, in the consequences of traffic accidents a distinction is made between road accidents in which only property damage occurred, then in traffic accidents with injured participants and as traffic accidents with deceased participants. Traffic accidents with material damage

account for the largest proportion of all road traffic accidents with approximately 69%, followed by traffic accidents with injured participants with 30% and 1% of traffic accidents with fatalities. Based on the previously presented statistical data, the Republic of Croatia is above the average of European countries with 71.2 road traffic fatalities per million inhabitants. In the Republic of Croatia, road accidents are divided into different types depending on the characteristics of the traffic accident. The following table shows all types of road accidents and the number of road accidents with material damage, injured, and killed in each type of road accident. (4)

Table 2. Number of traffic accidents by types

Type of accident	Material damage	Injured	Fatal consequences
Side collision	20470	8584	100
Frontal collision	9413	5547	259
Bicycle collision	409	1737	58
Pedestrian collision	266	5733	234
Collision with animal	3415	157	1
Vehicle landing from the road	12333	9610	426
Vehicle collision with motorcycles	151	539	9
Collision with train	69	53	21
Collision with object near/on the road	13575	1941	80
Collision with parked vehicle	23547	512	7
Comparison driving	3523	907	9
Rear end collision	11325	7015	67
Other	4122	3114	24
Driving backwards	4712	225	0

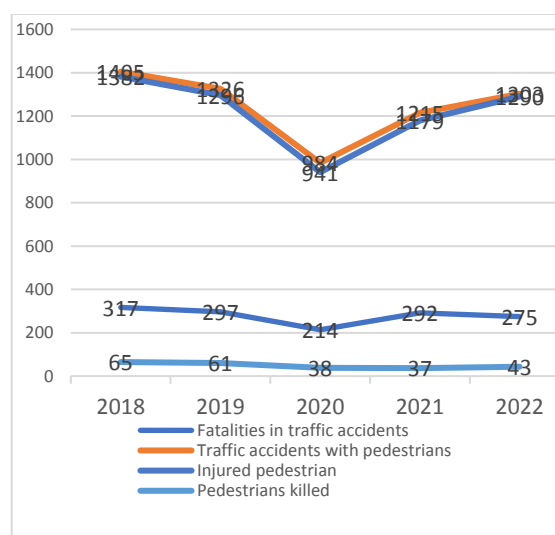
The above table shows that the most common type of traffic accidents is a side collision 19%, a collision of a vehicle with a parked vehicle 16% and a departure from the roadway 14%, the least common traffic accidents are collisions with a rail vehicle, collisions between a vehicle and a motorcycle, and collisions with a bicycle. The number of people killed in relation to the number of traffic accidents by type of traffic accident is not reciprocal, so the most common type of traffic accident in the observed period of five years is a side collision, and the highest number of people killed, when looking at the cumulative number, is when a vehicle leaves the road, also the highest number of people injured is when the vehicle leaves the road. In the annual report on the state of safety in the Republic of Croatia, nowhere is the cause of traffic accidents mentioned, but the circumstances in which the traffic accident occurred. Thus, the most common circumstance that preceded the traffic accidents is a speed not adapted to the conditions, followed by disregarding the right of way and improper movement of vehicles on the road. In traffic accidents characterised by these three circumstances, there are more than 70% dead participants and about 60% injured. If we consider the traffic accidents in relation to the road geometry, we find that most traffic accidents occur on a straight road, about 40%, then at an intersection with a share of about 26% and in a curve with about 16%. Comparing the number of accidents on straight road sections, curves, and intersections with the number of fatalities, it can be seen that the number of fatalities is not reciprocal to the number of accidents. The proportion of accidents on a straight road section is 40%, the number of fatalities is 42%, and the proportion of accidents on a curve is only 16%, while the number of fatalities in the same accidents is 37%. Considering the above data, it can be concluded that the consequences of traffic accidents that occur in a curve are much more "dangerous". The specific cause of the traffic accidents is not known, as no detailed analysis of all accidents has been performed but given the significant number of people killed in curves in relation to the

number of accidents, this is an indication that additional research on traffic accidents in curves is needed.

4. Pedestrian safety in Republic of Croatia

Along with motorcyclists and bicyclists, pedestrians are the most vulnerable group of road users, and pedestrian traffic is the most accessible form of traffic. In the Republic of Croatia, in the period from 2018 to 2022, 154,895 traffic accidents occurred, 45,679 traffic accidents with injured persons, including 6,233 traffic accidents with collisions with pedestrians, in the observed period, 1,395 people died, including 244 pedestrians. The proportion of traffic accidents marked as a collision with a pedestrian is 6,233, which is about 4% of the total number of traffic accidents, if we consider the number of injured pedestrians, which for a five-year period is 6,088 pedestrians, about 13%, and 244 pedestrians died, which is about 17% of all fatalities. Between 1,300 and 1,405 traffic accidents involving pedestrians occurred annually. The exception was 2020, when the number of traffic accidents involving pedestrians was less than 1,000, but the year indicated is not entirely relevant due to lower traffic volumes during the Covid pandemic.

Graph 1. Number of traffic accident in period of five years



Graph 1 shows the relationship between traffic accidents involving pedestrians, the number of pedestrians injured, the number of pedestrians killed, and the total number of people killed in traffic for the observed period. In 2019, compared to 2018, there was a 6% decrease in the total number of persons killed in traffic, the number of traffic accidents involving pedestrians, the number of pedestrians injured and the number of pedestrians killed also decreased by 6%. In 2020, there was a positive trend of 28% fewer traffic fatalities compared to the previous year, the number of traffic accidents recorded a smaller decrease of 26%, the number of pedestrians injured decreased by 27%, while the number of pedestrians killed decreased by 38%. The year in question cannot be considered relevant because in 2020 there was a pandemic in the Republic of Croatia and the traffic of road users was significantly restricted, so the number of traffic accidents and the number of fatalities was lower. In 2021, a significant increase in the number of fatalities was recorded compared to the pandemic year 2020, the number of fatalities increased by 36%, the number of traffic accidents involving pedestrians increased by 23%, the number of injured pedestrians increased by 25%, and the number of pedestrians killed decreased by 3%. The total number of people killed and the number of pedestrian accidents increased significantly, while the number of pedestrians killed did not increase for an unknown reason, i.e., one less pedestrian

died than in 2020. In 2022, the total number of people killed was 275, the number of fatalities decreased by 6%, the number of traffic accidents involving pedestrians increased by 7%, the number of pedestrians injured increased by 9%, and the number of pedestrians killed increased by 16%. To determine the relationship between variables such as the number of traffic accidents, the number of fatalities, and the number of pedestrian accidents, the correlation coefficient between the above variables is calculated using the analysis presented previously. Since the data is not linear and a period of five years is considered, Spearman's correlation coefficient is applied according to the following formula:

$$r_s = 1 - \frac{6 \cdot \sum d^2}{n^3 - n}$$

Year	Traffic accidents	Pedestrian deaths	Rx	Ry	di	di ²
2018.	33440	65	1	1	0	0,00
2019.	31367	59	3	2	1	1,00
2020.	26074	36	3	5	-2	4,00
2021.	31453	37	2	4	-2	4,00
2022.	32561	40	1	3	-2	4,00
						13,00

Table 3. Calculation of Spearman coefficient

Table 3 shows the construction table for the calculation of the Spearman correlation coefficient between the variable of traffic accidents and the total number of pedestrians killed for a period of five years. The Spearman correlation coefficient is 0.35, which means that the correlation between the total number of traffic accidents and the number of pedestrians killed is relatively weak.(5)

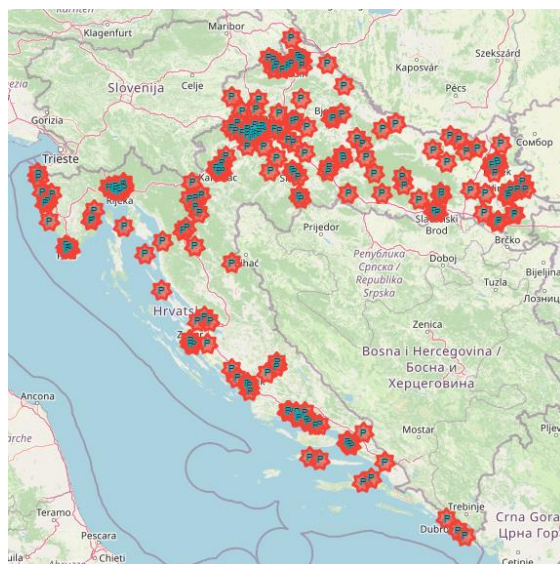


Figure 1. Location of pedestrian accidents with fatal consequences

Figure 1 shows all locations in the Republic of Croatia with traffic accidents in which pedestrians died. Visual inspection of the attached map clearly shows that traffic accidents involving pedestrian fatalities are concentrated in cities or urban areas. About 90% of traffic accidents involving pedestrians occur on county, township, and city roads, followed by 10% on national highways and less than 1% on freeways. Fatalities are similar, with 70% of pedestrian fatalities also occurring on county, local and city roads, 27% on state highways, and 3% on freeways. Looking at road conditions, most traffic accidents occurred on dry road 79%, followed by 21% on

slippery road and a very small percentage on macadam. No pedestrian died in traffic accidents on macadam, 26% of pedestrian fatalities occurred on slippery roads, while the remaining 74% of fatalities occurred on dry roads.

A very significant analysis of pedestrian traffic accidents refers to the geometric elements of the road. At the Republic of Croatia, the road elements on which a traffic accident can occur are divided into 17 elements, which are listed in the following table.

Table 4. Number of traffic accidents with pedestrian and number of pedestrian deaths

Geometric elements on the road	Traffic accidents with pedestrians	Pedestrian deaths
Bicycle path	27	1
Four-way intersection	888	20
A multi-level intersection	5	0
Y-intersection	116	5
T- intersection	910	23
Roundabout	72	3
Bridge	6	0
Overpass	1	0
Other	236	8
Parking	316	3
Pedestrian zone	250	1
Pedestrian crossing	787	26
Underpass	0	0
Crossing over the railroad	x	x
Straight road stretch	2318	114
Tunnel	0	0
Curve	291	30

Table 4 shows that not a single accident involving pedestrians at the railroad crossing was recorded, as according to the Road Traffic Safety Act of the Republic of Croatia, the collision of a train with a pedestrian is not considered a traffic accident and such events are therefore not recorded as traffic. The above table also shows that most accidents occurred on a straight stretch of road 37%, then at intersections 32% and at pedestrian crossings 13%. The number of traffic accidents involving pedestrian fatalities is also highest on a straight stretch of road at 49%, followed by 22% at junctions and 13% at a curve, 11% of pedestrians are killed at a pedestrian crossing. Looking at each geometric element separately, the geometric element curve has the highest percentage of people killed with 10%, followed by straight road sections with 5% and pedestrian crossings with 3%. From the previously analysed data, it can be concluded that it is necessary to subject four geometric elements to additional analysis: a straight road section, a curve, a pedestrian crossing and intersections, where traffic accidents involving pedestrians occur most frequently. When only intersections are considered, most traffic accidents and pedestrian fatalities occur at T-intersections. The calculation of the Spearman correlation coefficient between the geometric elements of the road and the number of pedestrians killed at these elements of 0.88 suggests that the correlation between the number of traffic accidents at the geometric elements and the number of fatalities at the same locations is significant. Increased attention should be paid to the curve, because about 16% of the recorded traffic accidents occur on the curve, and 37% of the fatalities occur on the curve. Looking at traffic accidents involving pedestrians on a curve, about 5% of traffic accidents involve pedestrians, but the number of pedestrians killed on a curve is about 13%.

It is not possible to determine the cause of a traffic accident without a detailed analysis and expert investigation of each accident. Therefore, the report on traffic safety in the Republic of Croatia does not indicate the cause of the traffic accident, but the circumstances that preceded the traffic accident. The circumstances of the traffic accident may also be the cause, but this cannot be determined without a detailed analysis of each individual accident. The circumstances of a traffic accident are divided into 21 types. The circumstances in which most traffic accidents involving pedestrians were recorded

were "other driver' error" 25%, inappropriate speed 16% and improper reversing 11%. traffic pedestrian fatalities, the order is slightly different: most pedestrian fatalities were due to inappropriate speed at 38%, followed by other driver error at 15% and other pedestrian error at 10%. This shows that the number of traffic accidents and fatalities is not linear in all circumstances. It can be concluded that inappropriate speed is the circumstance in which most pedestrians are killed. The Spearman coefficient for the number of traffic accidents involving pedestrians that occurred under certain circumstances and the number of pedestrians killed under the given circumstances is a high 0.94, which means that the circumstances of traffic accidents are correlated with the number of pedestrians killed under the same circumstances.(6)

5. Conclusion

Road traffic accidents are one of the leading causes of death in the world. Every year, an average of 1,240,000 road users are killed on the roads, of which about 20% are pedestrians. Considering the relatively low number of traffic accidents involving pedestrians, but the high percentage of pedestrians injured and killed, it can be clearly concluded that pedestrians are among the most vulnerable road users.

When writing the article, it was found that the number of pedestrians killed is not linear with the total number of traffic accidents, i.e. the correlation between the variables mentioned is negligible. This means that if the total number of traffic accidents is prevented and reduced, it does not mean that the number of pedestrians killed will also decrease. The number of pedestrians killed is also related to the geometric elements of the road and the circumstances in which the traffic accident occurred.

In order to take quality measures to reduce the number of injured and killed pedestrians, the exact cause of the traffic accident must be determined. The circumstances of the traffic accident cannot be considered as the cause, because to determine the cause of traffic accidents, a detailed expert opinion would have to be prepared for each individual accident.

The highest percentage of injured and fatally injured pedestrians occurred precisely under circumstances such as inappropriate speed and other driving errors, as well as with the geometric element "curve".

With the aim of reducing the number of pedestrians killed, it is necessary to make a more detailed analysis of the traffic accidents that occurred in the curve, traffic the circumstance of inappropriate speed due to the high correlation and the highest number of fatalities in the mentioned conditions.

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