

# IDENTIFICATION OF FACTORS INCREASING THE RISK OF PEDESTRIAN DEATH IN ROAD ACCIDENTS INVOLVING A PEDESTRIAN WITH A MOTOR VEHICLE

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## Abstract:

Walking is a basic form of activity for every human being and has many advantages, including health, economic and environmental benefits. Every journey made using various means of transport begins and ends on foot. As is well known, the group of road users particularly exposed to the risk of serious injury in road accidents, apart from cyclists, also includes pedestrians. These are the so-called vulnerable road users. Pedestrians are a group of road users that is often deprecated by many drivers of motor vehicles, but very important in road traffic. Pedestrian injuries and pedestrian fatalities have enormous social and economic consequences. The problem of high pedestrian risk on Polish roads is well known and has been widely described in the scientific literature last few years. However, the reasons for this state of affairs have not been fully explained, as evidenced by the statistics of road traffic incidents. Despite many studies in this area, the causes indicated in the research often differ depending on the area of analysis, the environment in which the incident took place, location, participants of the incident, environmental conditions, behaviorism and many other features. Therefore, the main goal of the article was to determine the factors influencing the formation of fatalities in road traffic accidents among pedestrians in accidents involving pedestrians and motor vehicles in the Silesian Voivodeship (Poland) in 2016-2021. The logit model presented in the article allowed for the conclusion that the main attributes influencing the increasing the risk of pedestrian death in road accidents involving a pedestrian with a motor vehicle include such features as driving under the influence of alcohol by the driver, exceeding the speed limit by the vehicle driver, when the road incident involves a heavy vehicle (truck, bus), a pedestrian is a male, pedestrian is over 60 years old, is under the influence of alcohol, the incident took place outside built-up area, at night, i.e. from 10:00 p.m. up to 6:00 a.m, in other than good weather conditions. The obtained results can be used in various activities, campaigns aimed at improving the safety of pedestrian traffic in the area of the analysis.

**Keywords:** pedestrian, pedestrian safety, road traffic safety, road crashes, road transport, road traffic engineering

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## 1. Introduction

Walking is the basic form of activity of every human and has many advantages, including among others health, economic benefits and a positive impact on the natural environment. As it is commonly known, the group of road users particularly exposed to the risk of serious injuries in road accidents are unprotected road users, i.e. pedestrians and cyclists. Pedestrians are a group of road users that is often deprecated by many drivers of motor vehicles, but very important in road traffic. Pedestrian injuries and pedestrian fatalities have enormous social and economic consequences.

According to the recommendations of the European Commission, the basic way to reduce the risk of dangers of the health and life of pedestrians is to create safer road infrastructure and solutions as well as vehicle construction in order to minimize the effects of deductions. Various programs aimed at improving road traffic safety, carried out in recent years, have also proved effective. In connection with the activities carried out in Poland for years, aimed at improving road traffic safety, the total number of fatalities in road accidents is decreasing. The number of serious injured pedestrians is also decreasing (Fig. 1). However, the proportion of fatalities among pedestrians compared to the total number of road fatalities is still high, and depending on the year accounts for 23.65% to 33.99% of total fatalities.

The problem of high pedestrian risk on Polish roads is widely known and has been described many times in the scientific literature (Budzyński et al., 2017; Jacyna et al., 2017; Mackun et al., 2017; Cieśla et al., 2020). Moreover, the current methods for assessing pedestrian risk and proposed pedestrian safety measures have been presented in the Polish manual for pedestrian traffic designers titled "Pedes-

trian Safety - Guidelines for pedestrian traffic organizers" (Jamroz et al., 2014). However, the reasons for low level of traffic safety have not been fully explained yet. Despite many research studies in this area, the causes indicated in the research often differ depending on the environment in which the incident took place, location, participants of the incident, environmental conditions, behaviorism and many other features. The mathematical tool used in modeling process is also important. Moreover, many times in the research on the causes of road incidents involving pedestrians and in the studies of the severity of pedestrian injuries in road incidents, major problems with obtaining reliable, homogeneous, and not missing data are emphasized. A reliable database of road incidents is the basis for identifying the main problems related to road traffic safety. It is a starting point for planning preventive actions as well as a source of information in the process of assessing implemented road projects. The accuracy of the decisions made, and thus the improvement of road traffic safety, depends to a large extent on the scope and quality of the collected data and their analyzes. The problem is also the impact of those factors that cannot be measured or obtained data on them, as well as factors that are not recorded during the inspection of the accident site e.g. the actual vehicle speed at the time of the incident, change in speed of the vehicle due to the collision, status of the use/operation of exterior lights, brake lights, direction indicators, horn, actions performed by the driver (steering style, use of the brake, degree of throttle opening), monitor of the operation of airbags, belt tensioners, support systems monitor, and many others factors. Such heterogeneity of the collected data set may result in erroneous estimation of model parameters, which translates into incorrect conclusions based on the estimated models.

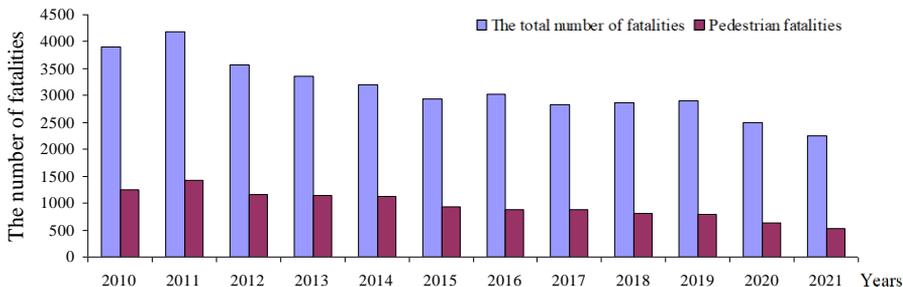


Fig. 1. Fatalities in road accidents in Poland in 2010-2021

In order to ensure the desired conditions for pedestrian traffic in terms of safety, comfort, environmental conditions, etc., it is important to know the relationship between the pedestrian and the motor vehicle and the main factors contributing to the occurrence of such incidents. Hence, the main goal of the research was to determine the factors influencing the formation of road fatalities among pedestrians in accidents involving pedestrians and motor vehicles. These analyzes were carried out for the area of the Silesian Voivodeship (Poland) for the period from 2016-2021. In turn, the results of these analyzes may be useful not only in the scientific aspect aimed at understanding the main attributes influencing the occurrence of fatal injuries among pedestrians, but also for decision makers and practitioners involved in implementing solutions on city transport networks aimed at pedestrian protection.

The article consists of six parts. After the introduction, section two presents a scientific literature review related to the analysis of attributes determining the occurrence of pedestrian injuries in road traffic accidents. The next two sections present the characteristics of the area of analysis and the descriptive statistics of the number of pedestrian incidents for the area of analysis, respectively. The fifth section presents a case study for the selected area and the collected data set, and on the basis of the constructed logit model, attributes determining the occurrence and severity of injuries to pedestrian in road accidents in the Silesian Voivodeship (Poland) were determined. In the last, section, sixth section, a discussion on the obtained results is included, together with a summary and conclusions.

## 2. Literature review

In the contemporary scientific literature, one can find research works in the field of road traffic safety analyzes with the participation of pedestrians. Many studies to date indicate that human behavior (both vehicle driver and pedestrian) plays a significant role in the occurrence of road traffic accidents and the resulting injuries (Cieśla et al., 2022; Macioszek et al., 2022). In general, the attributes that have the potential to influence the severity of pedestrian injuries, and that have been studied by various authors, can be grouped into several groups, such as pedestrian-related attributes, attributes of vehicle drivers, attributes of motor vehicles, attributes of the scene of the incident, and attributes of the environment in

which the incident took place. Table 1 presents a synthesis of the research work to date related to the analysis of the attributes determining the occurrence of pedestrian injuries in road accidents carried out in recent years. More detailed research in this area concerned the division of pedestrians according to various characteristic attributes (such as young children, young adults, male pedestrians, elderly, intoxicated or distracted pedestrians, disabled pedestrians, pedestrians in low-income countries), and assigning them individual attributes determining the occurrence of injuries in road traffic accidents (Stoker et al., 2015).

According to (Billah et al., 2021), attributes such as right-of-way failure and driver inattention were the main factors that contributed to the occurrence of pedestrian and vehicle accidents. In addition, the risk of pedestrians serious and fatal injuries increases significantly when the pedestrian was the culprit of the accident (Makarova et al., 2018), (Okraszewska et al., 2017), Macioszek, E. (2022). The strongest attributes of serious pedestrian injuries included the lighting condition, road class, speed limit, type of traffic control, type of incident, age and sex of the pedestrian. Undoubtedly, a factor that also increases the likelihood of a pedestrian being seriously injured is the influence of alcohol (this applies to both the pedestrian and the driver of the vehicle) (Qiu & Fan, 2022). Some studies indicate that a pedestrian is more likely to suffer severe and fatal injuries at weekends (Nasri et al., 2022).

On the other hand, the results of the analyzes presented in the research work (Yoon & Lee, 2021) indicate that the number of killed or seriously injured pedestrians decreases after the implementation of projects to improve the pedestrian environment and after implementation of safe infrastructure to improve pedestrian safety. The analysis also reveals the need to pay more attention to pedestrian safety in areas with a high proportion of elderly people in the population. This work recommends strengthening pedestrian safety measures in areas of concentrated wholesale and retail businesses. The study also indicates that illegal parking poses a risk to pedestrian safety. Finally, this study confirms some positive impact of rebuilt or newly designed areas and projects to improve the pedestrian environment on pedestrian safety.

Some studies clearly indicate that older pedestrians are at a much greater risk of serious or fatal injury

compared to other age groups (Guo et al., 2021; Febres et al., 2021; Peng & Bongard, 1999). In turn, the research work (Obinguar & Iryo-Asano, 2021) showed that accidents involving older pedestrians,

heavy vehicles, occurring late at night, on good pavement conditions and in open spaces, were associated with an increased probability of pedestrian death.

Table 1. A synthesis of the research work to date related to the analysis of the attributes determining the occurrence of pedestrian injuries in road traffic accidents

Research Author(s)	Year of research	Research place	Data	Research description	Factors increasing the probability of pedestrian's death
Pljakić et al., 2022	2022	Serbia	Accident data from Novi Sad (Serbia)	A geographically weighted regression used in order to identify and localize all factors that contribute to the occurrence of pedestrian accidents	Length of national roads, length of streets, number of bus stops, number of parking spaces and number of objects in the area of analysis
Wang et al., 2022	2022	Shenzhen, China	Accident and collision data from Shenzhen from 2014-2016	Random parameter logit models	Road type, road pavement condition, visibility, presence of roadside protection, and road alignment
Nasri et al., 2022	2022	United Kingdom	Accident and collisions data from 2010- 2019	Unordered multinomial logit model, and an ordered logit model	Crashes on weekends, on dark streets, in areas with a speed limit above 50 km/h, in the period from 10 a.m. to 10 p.m., at intersections, and on medians or footpaths
Olszewski et al., 2015	2015	Poland	Accident and collision data from 2001-2013 for crosswalks	Logistic regression method	At unsignalized zebra crosswalks: darkness, especially with no street lighting, divided road, two-way road, non built-up area, mid-block crosswalk location, and summer time period. Speed limit is a crucial factor: probability of death increases by 37% with every 10 km/h rise in the speed limit. Fatality risk increases also with victim's age and is higher for male pedestrians
Chong et al., 2018	2018	USA	Accident and collision data from USA from 2006-2015	Multivariable logistic regression	Male, age more than 65 years, incident participants were under the influence of alcohol, incident occurred after midnight, with no intersections, and with heavy vehicles and buses
Casado-Sanz et al., 2019	2019	Spain	The accidents that involve a single vehicle, and a single pedestrian on Spanish crosstown roads from 2006-2016	K-means cluster analysis, and multinomial logit model	Visibility restricted by weather conditions or glare, infractions committed by the pedestrian (not using crossings, crossing unlawfully, or walking on the road), infractions committed by the driver (distracted driving, and not respecting a light or a crossing), and, speed infractions committed by drivers (i.e. inadequate speed)
Wang et al., 2019	2019	Hong Kong	Accident and collision data from Hong Kong from 2010-2012	Random parameter probit models	Children younger than age 11 years, crashes that occur between 10:00 p.m. and 06:59 a.m., crashes occurring in rainy weather, crashes involving pedestrians older than age 46 years, bus crashes
Sobrinho-Junior et al., 2022	2022	Brazil	Laboratory studies on humans	Multivariate analysis of variance tests	Using a smartphone or iphone in road traffic can be risky for pedestrians

Research Author(s)	Year of research	Research place	Data	Research description	Factors increasing the probability of pedestrian's death
Mukherjee & Mitra, 2019	2019	India	Accident and collision data from 2011-2016	Binary logistic regression models	The absence of designated bus stop facility, average daily vehicles and pedestrian traffic volume, inadequate sight distance, pedestrian-vehicular interaction
Besharati et al., 2018	2018	Iran	Accident and collision from Iran from 2009-2012	The combined use of clustering analysis and association rules mining technique	The pedestrian is over 60 years old, waiting or walking beside the road on poorly illuminated locations of those segments of rural roads that pass through agricultural or residential districts, inattention to yield sign
Zafri et al., 2020	2020	Bangladesh	Accident and collision data from 2010-2015	A binary logistic regression model	Crashes during adverse weather, dawn/dusk period, night period (where street light was absent), off-peak period, crashes where road divider was unavailable, road geometry was straight and flat, and crashes those were occurred by heavier vehicles
Martinez-Ruiz et al., 2019	2019	Spain	Accident and collision data from 1993-2013	Poisson regression models	Pedestrian attributes: male sex, age, having a physical defect, committing an infraction. Vehicle drivers attributes: exceeding the speed limit, the presence of passengers in the car, visual defects, heavy vehicles (trucks, vans, buses), rural areas with fewer than 5000 inhabitants
Malin et al., 2020	2020	Finland	Accident and collision data from 2014-2017	Indicator method, calculating the pedestrian killed or seriously injured rate and comparing it according to demographic, spatial and temporal variables	Pedestrians aged over 75 years, rural areas
Chen et al., 2019	2019	Beijing, China	Accident and collision data from 2015	Binary logit model	At mid-blocks: two-way divided road, darkness (especially for no street lighting), normal weather, crossing elsewhere in carriageway, rural area, light vehicle, large vehicle and male pedestrian
Mukherjee & Mitra, 2020	2020	India	Accident and collision data from 2011-2016	Binary logit model	Approaching speed of the vehicles, the presence of specific land-use type (i.e., commercial hubs), vehicular traffic and pedestrian volume of the intersection and their interaction, disorderly movement of traffic (i.e., overtaking tendency of the vehicles), inefficient planning and design (i.e., inaccessibility of the pedestrian crosswalk, the absence of pedestrian signal head, etc.), the presence of wider carriageway, the encroachment of the footpath, restricted visibility (i.e., inadequate sight distance)
Congiu et al., 2019	2019	Italy	Accident and collision data for Alghero city for 2015	Logistic regression analysis	On-street parking was found to increase the risk of pedestrian accidents by about two times
Li & Fan, 2022	2020	USA	Accident and collision data for North Carolina for 2007-2014	Mixed logit model	Pedestrians under the influence of alcohol, pedestrian accident with vehicles such as: van, pickup truck, female pedestrian, two-way road, without a dividing lane

Research Author(s)	Year of research	Research place	Data	Research description	Factors increasing the probability of pedestrian's death
Casado-Sanz et al., 2020	2020	Spain	Accident and collision data for North Carolina for 2006-2016	Multinomial logit model	Low traffic volumes, wider lanes, lateral crosstown roads, higher percentages of heavy vehicles, lack of road markings, infractions
Das et al., 2019	2019	USA	Accident and collision data for 2014-2016	Empirical Bayes data mining	Backing vehicle-related crashes for female pedestrians (especially those aged 79 and above), segment-related crashes at night for 65 to 69 year-old male pedestrians, crossing an expressway at night for male pedestrians, especially the 65 to 69 year group, failure to yield while crossing at intersections, and crashes occurring in the dark with poor street lighting
Pour-Rouholamin & Zhou, 2016	2016	USA	Accident and collision data for Illinois for 2010-2013	Ordered-response models	Older pedestrians (more than 65 years old), pedestrians not wearing contrasting clothing, adult drivers (16-24), drunk drivers, time of day (from 10:00 p.m. to 05:00 a.m.), divided highways, multilane highways, darkness, heavy vehicles
Olowosegun et al., 2022	2022	Scotland	Accident and collision data for 2010-2018	Ordered probit models	Roadway, location, weather, vehicle, and driver characteristics as well as temporal attributes (including time and day of the accident)
Lalika et al., 2022	2022	USA	Data from pedestrian crashes involving older pedestrians at signalized intersections in Florida from 2016-2018	A bayesian logistic regression model	Driving straight ahead, road type, and shoulder type, lighting conditions were directly related to the fatalities and serious injuries of older pedestrians. The maneuver of the vehicle (driving straight ahead) was the most important factor influencing the severity of accidents involving older pedestrians. The correlation between a vehicle running straight, in night conditions and a two-way divided road with limited shoulders was associated with the highest probability of fatal accidents and serious injuries involving older pedestrians

Interesting research results were presented by Sivasankaran and Balasubramanian (Sivasankaran & Balasubramanian, 2022), who investigated the attributes influencing the fact that a driver of a motor vehicle who committed an accident with a pedestrian will run away from the scene of the accident, as this type of behavior often contributes to the death of a pedestrian who was left without quick help. The results of their research showed that the tendency of the perpetrator to leave the scene of the accident increases in dark and unlit conditions. Increased likelihood of driving accidents occurring in the summer, winter and urban areas. Among the characteristics of pedestrians, drunk pedestrians, pedestrian areas such

as the sidewalk, road crossing and the roadside contribute significantly to these types of accidents. It was also found that factors such as the day of the week, road category, accident cause, vehicle type, weather conditions, driver alcoholism, type of pedestrian residence, and road traffic were statistically insignificant with a 90% confidence interval. Based on an extensive review of the scientific literature on the subject, it can also be concluded that various econometric modeling approaches such as binary logistic regression (Sze and Wong, 2007; Sarkar et al., 2011), logit models (Li & Fan, 2019), mixed logit models (Ricardi et al., 2022; Qiu & Fan, 2021), multinomial logit models (Tay et al., 2011),

and probit models (Lee & Abdel-Aty, 2005) are most often used in order to develop statistical models to determine the severity of injuries of road users. Summarizing the review of the scientific literature on the subject in the field of research related to the assessment of road traffic safety among pedestrians and determining the potential attributes influencing pedestrian injuries, including fatal injuries as a result of accidents involving a pedestrian and a motor vehicle, it can be stated that the scientific literature on the subject has already devoted a lot to work on this issue. However, due to the available, often highly differentiated set of data to be analyzed, the mathematical apparatus used in modeling and, above all, the area for which the analyzes were performed, it can be concluded that specific attributes contributing to fatal injuries among pedestrians differ in individual cases, which causes that the results for given areas do not have to be consistent with the results obtained for other areas.

### 3. Characteristics of the area of analysis

The area of analysis was the Silesian Voivodeship (Fig. 2) located in the southern part of Poland, which is one of the smallest voivodeship in Poland and, at the same time, after the Mazowieckie Voivodeship, it is the most populous region of Poland. Silesian Voivodeship is characterized by the highest population density index in Poland (there are 368 people per 1 km<sup>2</sup> (for the country the indicator is equal 123 people per km<sup>2</sup>)) (Silesian Voivodeship, 2020). This area is characterized by far the highest density of paved roads in the country, including motorways and expressways, moreover, the road infrastructure in the voivodship is constantly developed. Silesian Voivodeship is characterized by a very large number of registered motor vehicles. According to the Central Register of Vehicles and Drivers in Poland (in Polish CEPIK database), at the beginning of 2022 year, over 181,000 vehicles were registered in the Silesian Voivodeship (CEPIK, 2022). The high population density, high density of roads and infrastructure are a potential contributing factor to the occurrence of incidents on the region's transport network. Hence, in accordance with the assumptions of the Development Strategy of the Silesian Voivodeship until 2030 (Silesian Voivodeship, 2020), in the area of transport, apart from measures such as improving transport connections through their restoration, expansion, modernization and management of

infrastructure enhancing the accessibility and cohesion of the region, one of the strategic goals is also the improvement of the safety of road users.

### 4. Statistics characterizing the number of pedestrian incidents in the area of analysis

Pedestrian traffic is concentrated mainly in urban areas, as this is where pedestrian traffic generators such as work, study, public buildings, health facilities, and entertainment venues are located. According to the public available System of Records of Accidents and Collisions Database in Poland (in Polish SEWIK database) for the analyzed area, as much as 94.97% of incidents involving pedestrians and motor vehicles took place in a built-up area (5.03% outside of built-up area) (SEWIK 2022). Therefore, the efforts should be made to redesign this space in a pedestrian-friendly manner as much as possible.

In the analyzed area in 2016-2021, 7,970 road incidents involving pedestrians took place. In these incidents, 2,436 people (30.56%) were slightly injured, 1,584 (19.87%) were seriously injured and 350 people (4.39%) were fatally injured. In the vast majority of incidents (98.97%), there was a road incident involving a pedestrian and a motor vehicle (then there were pedestrian incidents involving a truck with a total weight up to 3.5 tons (0.39%), with a truck with a maximum permissible weight of up to 3.5 tons (0.39%), total weight over 3.5 tons (0.11%), and with the participation of a bicycle (0.11%)). In the case of other groups of vehicle types, the share of road incidents involving pedestrians was negligible and did not exceed 0.10%.

By analyzing the temporal variability of incidents in the analyzed area, it can be concluded that most incidents took place in the winter months from September to March (Fig. 3a). This phenomenon is fully explainable, because in the climatic conditions that prevail in Poland in the period from September to March, autumn and winter lasts, i.e. periods of time when darkness falls quickly, precipitation, fog and other unfavorable weather conditions often occur. The rapid increase in fatalities among pedestrians in the late afternoon hours was also confirmed in the studies presented in the research work of Olszewski and Zielińska (Olszewski & Zielińska, 2012). Under unfavorable weather conditions, less than 46% of all incidents involving pedestrians and motor vehicles took place (Fig. 3b). These conditions contribute to poorer visibility of pedestrians and increase the

probability of road incidents involving pedestrians. On the other hand, when analyzing the number of incidents involving pedestrians on individual days of the week (Fig. 4a), a decrease in incidents during the weekend is noticeable, with the fewest incidents taking place on Sundays. The result of this analysis is also logical and explainable, because Saturday and Sunday are days off for most people in Poland, which is related to a smaller number of obligatory trips on the road transport network. It should be noted that virtually every person who is able to walk is a pedestrian in the road traffic, the length and purpose of the journey being on foot remain a question. The distance that a road user has to travel is the basic factor influencing the choice of the form of travel.

In many cases, people who travel by public transport or passenger cars must additionally cover significant sections of the route on foot, reaching parking lots or public transport stops. Thus, it can be concluded that if anyone want to make any journey, it is an indispensable part of it on foot.

On the other hand, taking into account the daily variability of the number of road incidents involving pedestrians (Fig. 4b), it can be concluded that most incidents took place in the afternoon from 4:00 p.m. to 7:00 p.m. corresponding to the afternoon communication rush-hour. The period of increased number of incidents is probably associated with returns from work, school, university, shopping and other activities performed during afternoon free time and duties.

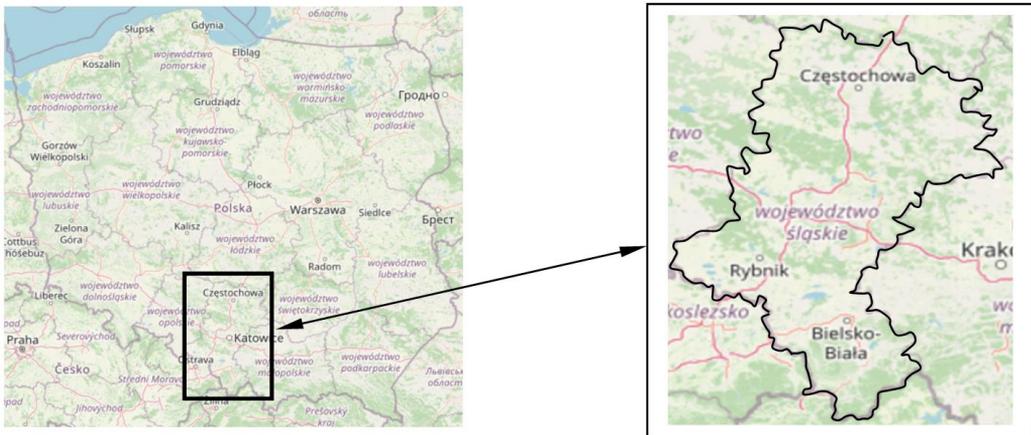


Fig. 2. Location of the analyzed area (Silesian Voivodeship) in comparison to Poland (Source: Own elaboration based on Open Street Maps 2022)

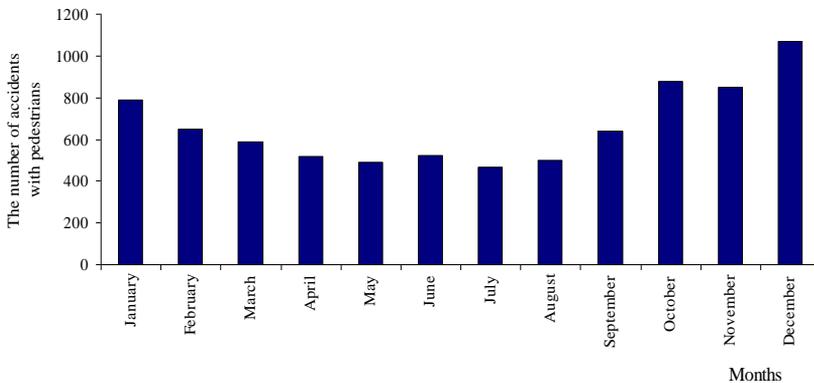


Fig. 3a. Variability of the number of road incidents involving pedestrians and motor vehicles in individual months of the year

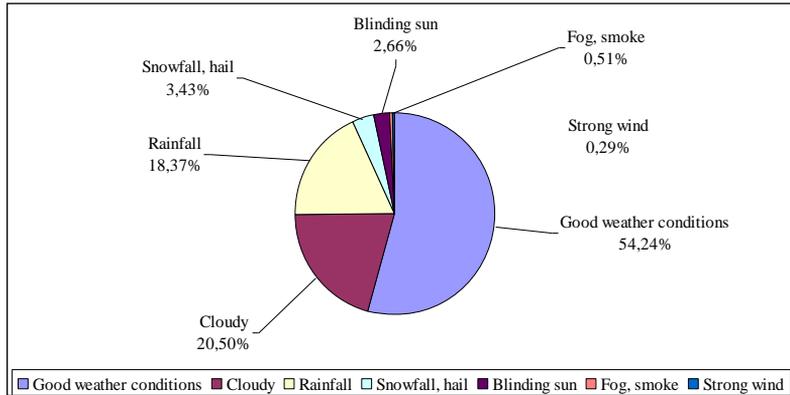


Fig. 3b. Variability of the number of road incidents involving pedestrians and motor vehicles in various weather conditions

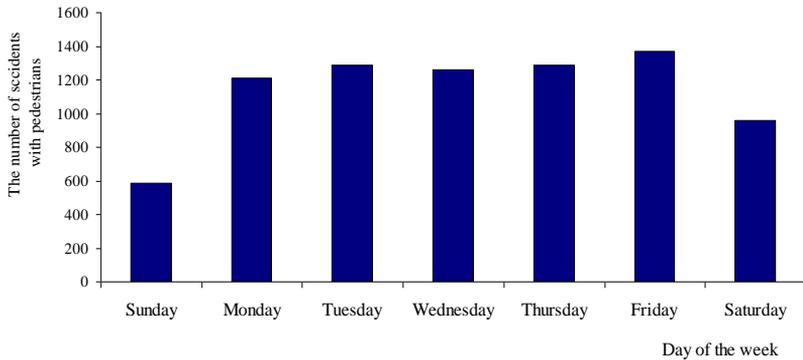


Fig. 4a. Variability of the number of road incidents involving pedestrians and motor vehicles a). on individual days of the week

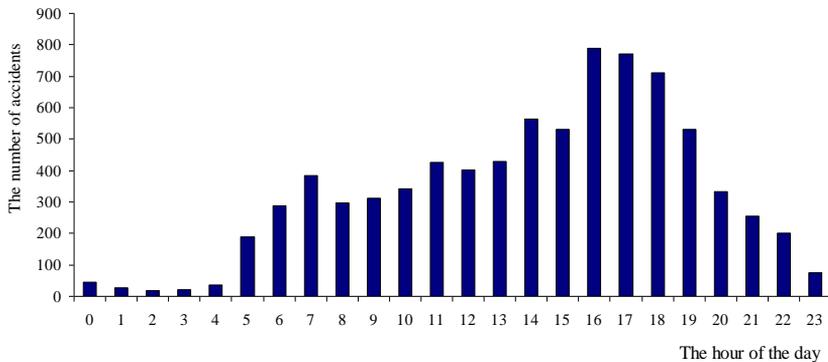


Fig. 4b. Variability of the number of road incidents involving pedestrians and motor vehicles at particular hours of the day

When analyzing the locations of pedestrian incidents with motor vehicles (Fig. 5), it can be concluded that most incidents took place at pedestrian crossings (as much as 47.83% of all incidents), and then in the area of the road (42.40%). This result is quite absurd, as the pedestrian crossing is by definition a place for safe passage through the traffic lane or traffic lanes intended for use by motor vehicles. There can be many reasons for this. On the one hand, it may be incorrect driving over of pedestrian crossings by vehicle drivers, dangerous behavior of drivers towards pedestrians, but also it may be dangerous behavior of pedestrians themselves in road traffic, such as crossing the road in forbidden places or careless entering or running onto the road, etc. Some of the incidents were recorded in the area of the pavement, pedestrian paths (4.27%), the parking lot and the square (3.16%). The share of other places of road incidents with pedestrians is less than 1%. Analyzing the collected data, it can also be stated that a significant part of the incidents occur on straight sections of roads (93.61% of all incidents), and then on horizontal curves (3.50%). In addition, many incidents were recorded in the absence of traffic lights (90, 82%).

In the next stage of the work, the causes of incidents involving pedestrians and motor vehicles due to the fault of vehicle drivers (Fig. 6), the fault of pedestrians (Fig. 7), and for reasons other than the fault of drivers and pedestrians (Fig. 8) were analyzed. The vast majority of perpetrators of the accidents with pedestrians are drivers of passenger cars. The most common reasons in these accidents were failure to give way to pedestrians at a pedestrian crossing (which accounted for as much as 60.75% of all incidents caused by vehicle drivers), failure to give way to pedestrians in other circumstances (9.17%), incorrect reversing (8.17%). The share of other causes of incidents due to the fault of vehicle drivers was less than 5%. On the other hand, the main reasons for the occurrence of incidents caused by pedestrians include: careless entering on the road in front of a moving vehicle (which accounted for as much as 50.73% of all incidents caused by pedestrians), careless entering on the road from behind a vehicle or obstacle (14.95%), crossing the road in a prohibited place (12.51%), other, undetermined reasons (10.27%), entering the road at a red light (6.44%). The share of other causes of incidents caused by pedestrians was less than 5%.

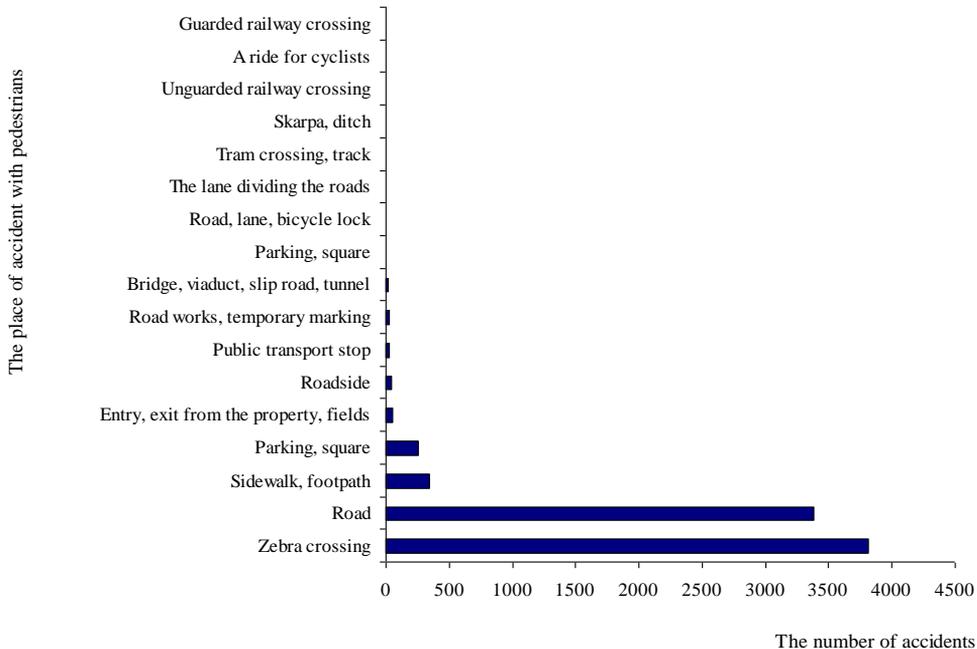


Fig. 5. Places of incidents involving pedestrians and motor vehicles in the Silesian Voivodeship in 2016-2021

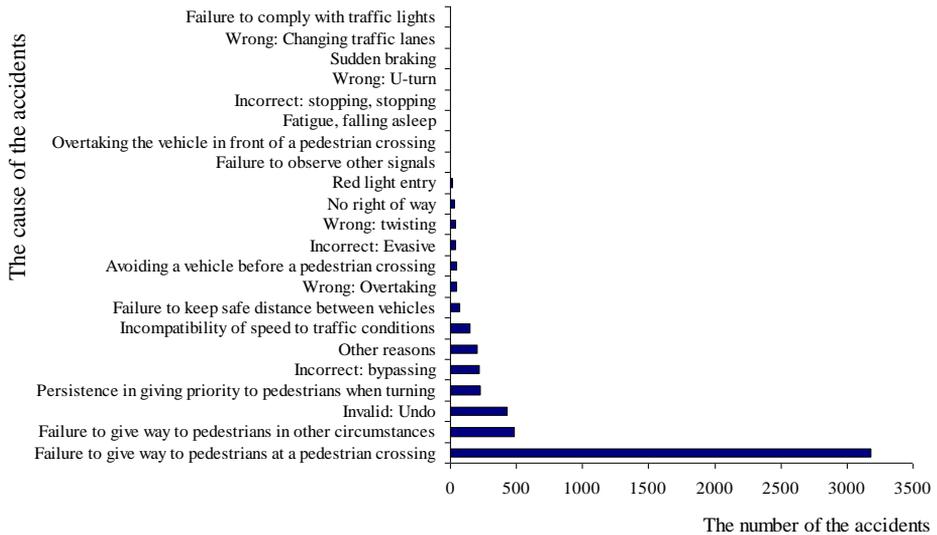


Fig. 6. The reasons for the occurrence of incidents involving pedestrians and motor vehicles due to the fault of vehicle drivers in the Silesian Voivodeship in 2016-2021

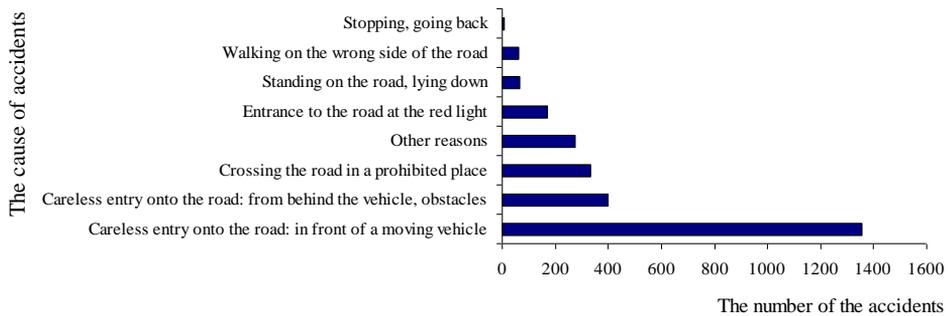


Fig. 7. The causes of incidents involving pedestrians and motor vehicles caused by pedestrians in the Silesian Voivodeship in 2016-2021

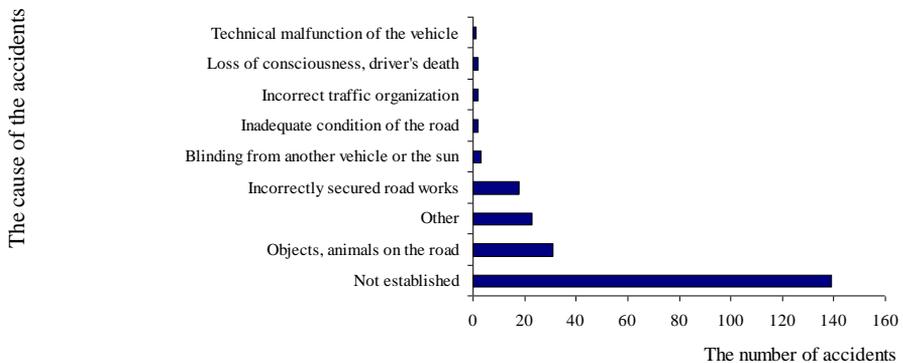


Fig. 8. The causes of incidents involving pedestrians and motor vehicles for reasons other than the fault of vehicle drivers and the fault of pedestrians in the Silesian Voivodeship in 2016-2021

While, the causes of incidents involving pedestrians and motor vehicles for reasons other than the fault of vehicle drivers, and the fault of pedestrians include the presence of objects, animals on the road (14.03%), improperly secured road works (8.14%), and others reasons.

In the Silesian Voivodeship, pedestrians over 60 years of age constitute the largest share of fatalities (52.75%) (Fig. 9).

##### 5. Attributes determining the occurrence and severity of injuries to pedestrian in road accidents in the Silesian Voivodeship (Poland)

The data for the analysis was obtained from the SEWiK database (SEWiK, 2022). The data concerned the Silesian Voivodeship (Poland) in 2016-2021. The logit model was used in order to identify of attributes increasing the risk of pedestrian death in road accidents involving a pedestrian with a motor vehicle. The variable in the binary model is dichotomous and takes two values 0 and 1, and is coded as follows: 1 when pedestrian has fatal injuries, and 0 when pedestrian is slightly injured. The majority of attributes that can be extracted from the SEWiK database were adopted as independent variables in the model. These are:

- gender of the vehicle driver (1 when vehicle driver is a woman, 0 when the vehicle driver is a men) - (X1),
- age of the vehicle driver (1 when vehicle driver is up to 60 years old, 0 when vehicle driver is older than 60 years old) - (X2),
- consumption of alcohol by the vehicle driver (1 when the vehicle driver is under the influence of alcohol, 0 when the vehicle driver is not under the influence of alcohol) - (X3),
- the number of years of possession of a driving license by the vehicle driver (1 when the vehicle driver has a short driving license, i.e. up to 5 years, 0 when the vehicle driver has a driving license for more than 5 years) - (X4),
- having the vehicle driver's license to drive a vehicle (1 when the vehicle driver has the driving license, 0 when the vehicle driver does not have the driving license) - (X5),
- exceeding the speed limit by the vehicle driver (1 when the vehicle driver exceeded the speed limit, 0 when the vehicle driver did not exceed the speed limit) - (X6),

- vehicle type (1 when the vehicle type is a heavy vehicle, 0 when the vehicle type is a passenger car) - (X7),
- sex of the pedestrian (1 when the pedestrian is man, 0 when the pedestrian is woman) - (X8),
- pedestrian age (1 when pedestrian is up to 60 years old, 0 when the pedestrian is older than 60 years old) - (X9),
- consumption of alcohol by the pedestrian (1 when the pedestrian is intoxicated, 0 when pedestrian is sober) - (X10),
- incident in the right-of-way intersection area (1 when the incident took place in the right-of-way intersection area, 0 when incident took place at other types of intersections) - (X11),
- incident took place in the pedestrian crossing area (1 when the incident took place in the pedestrian crossing area, 0 when the incident took place elsewhere) - (X12),
- vehicle speed limit in the incident place (1 when the speed limit was 50 km/h or more, 0 when the speed limit was less than 50 km/h) - (X13),
- road geometry (1 when the incident occurred on a straight section, 0 when the incident took place on other geometrical elements of the road) - (X14),
- type of area where the incident took place (1 when the incident took place in a built-up area, 0 when the incident took place outside built-up area) - (X15),
- time when the incident took place (1 when the incident took place in the night hours, i.e. from 10:00 p.m. up to 6:00 a.m.) - (X16),
- weather conditions (1 when the incident took place in good weather conditions, 0 in other cases) - (X17),
- causes of the incident due to the fault of vehicle drivers (1 when the cause of the incident was the failure to give way to pedestrians at a pedestrian crossing, 0 in other cases) - (X18),
- causes of the incident caused by pedestrians (1 when the cause of the incident was careless entry onto the road in front of a moving vehicle; 0 in other cases) - (X19),
- causes of the incident other than the fault of vehicle drivers and pedestrians (1 when the cause of the incident was objects on the road or animals on the road) - (X20).

The results are presented in Table 2.

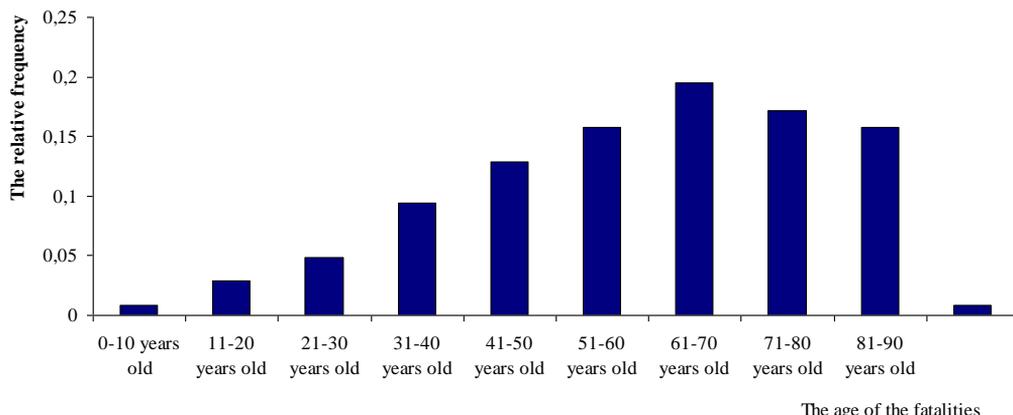


Fig. 9. Relative age frequency of fatalities among pedestrians in road accidents in the Silesian Voivodeship in 2016-2021

Table 2. Estimation model parameters and fit statistics

Independent variables $X_i$	$\alpha_k$	Wald's Statistics	Level of significance $p$ -Value	Exp ( $\alpha_k$ )	Standard error
The vehicle driver is under the influence of alcohol (X3)	0,107	3,297	0,103	1,113	0,202
The vehicle driver exceeds the speed limit (X6)	0,291	4,291	0,074	1,338	0,189
Vehicle type (X7)	0,573	8,062	0,182	1,774	0,16
Pedestrian's gender (X8)	0,408	6,127	0,179	1,504	0,171
Pedestrian's age (X9)	-0,596	8,196	0,002	0,551	0,196
Pedestrian under the influence of alcohol (X10)	0,325	4,381	0,000*	1,384	0,223
Type of area where the incident took place (X15)	-0,547	7,908	0,000*	0,579	0,257
Time when the incident took place (X16)	0,689	9,578	0,101	1,992	0,158
Weather conditions (X17)	-0,945	21,349	0,000*	0,389	0,244
$\alpha_0$	-3,472	35,92	0,027		
Log Likelihood			-49,821028		
-2 Log Likelihood			99,642056		
Log Likelihood (for $\alpha_0$ )			93,719302		
2 Log Likelihood (for $\alpha_0$ )			187,438604		
Chi-square statistics			836,0		
$p$ -value			<0,00001		
Pseudo $R^2$			0,326854		
$R^2$ Nagelkerke			0,583256		
$R^2$ Cox-Snell			0,473632		
Hosmer-Lemeshow test results:					
Chi-square statistics			10,0		
$p$ -value			0,1208		

\*  $p < 0.001$ .

On the basis of the obtained results it can be concluded that the main attributes determining the occurrence and severity of injuries to pedestrian in road accidents in the Silesian Voivodeship (Poland) are like follows: driving under the influence of alcohol by the driver, exceeding the speed limit by the

vehicle driver, when the road incident involves a heavy vehicle (truck, bus), a pedestrian is a male, pedestrian is over 60 years old, is under the influence of alcohol, the incident took place outside built-up area, at night, i.e. from 10:00 p.m. up to 6:00 a.m, in other than good weather conditions.

The constructed model was assessed using the Pseudo R<sup>2</sup> (equal 0.33), R<sup>2</sup> Nagelkerke (equal 0.58), and R<sup>2</sup> Cox-Snell coefficients (equal 0.47), which confirm a good fit of the model to real data. The Hosmer and Lemeshow test ( $p = 0.12$ ) was also performed, which also confirmed a good fit of the model. R<sup>2</sup> Nagelkerke equal 0.58 means that the variance in the number of pedestrian fatalities was explained in 58%. Summarizing, it can be concluded that the model is statistically significant, which is also confirmed by the likelihood ratio test ( $<0.00001$ ).

## 6. Discussion and conclusions

On the basis of the presented model, it can be concluded that the main attributes influencing the increasing the risk of pedestrian death in road accidents involving a pedestrian and a motor vehicle include such attributes as vehicle driver under the influence of alcohol, exceeding the speed limit by the vehicle driver, when a heavy vehicle (truck, bus) is involved in the road incident, the pedestrian is a male, is over 60 years old, is under the influence of alcohol, the incident took place outside build-up area, at night, i.e. from 10:00 p.m. up to 6:00 a.m., in other than good weather conditions.

Changing the value of independent variables by one unit affects the odds ratio of  $\text{Exp}(\alpha_i)$  [ $(\text{Exp}(\alpha_i) - 1) \cdot 100\%$ ] with other independent variables unchanged. Hence the probability of increasing the risk of pedestrian death in road accidents involving a pedestrian with a motor vehicle:

- increases by 11.29% if the vehicle driver is under the influence of alcohol, and other variables remain unchanged,
- increases by 33.78% in case the driver exceeds the speed limit (*cetis paribus*),
- increases by as much as 77.36% in the case when the pedestrian has been involved in a road accident with a truck or bus (*cetis paribus*),
- increases by as much as 50.38% in a situation when the pedestrian was male (*cetis paribus*),
- increases by 44.90% in a situation when the pedestrian was older than 60 years old (*cetis paribus*),
- increases by 38.40% when the pedestrian was under the influence of alcohol (*cetis paribus*),
- increases by 42.13% in a situation when the incident took place outside build-up area (*cetis paribus*),

- increases by 99.17% if the incident took place at night, i.e. from 10:00 p.m. up to 6 a.m. (*cetis paribus*).

When analyzing the obtained results, it can be concluded that they are mostly consistent with the results obtained in the research of other authors, which were presented in the review of the literature on the subject. Taking into account the increasing the risk of pedestrian death in road accidents, when the vehicle driver was under the influence of alcohol, it should be stated that this is an obvious result and has already been confirmed in many other previous studies, e.g. (Xue & Wen, 2022; Rampinelli et al., 2022). Alcohol is a psychoactive substance that has a very strong effect on the human body, it slows down the functioning of the nervous system, as a result a person under the influence of alcohol loses the ability to properly perceive external stimuli. The perception of the surrounding world is disturbed, situational assessment, overestimation of one's own abilities occurs. Driving under the influence of alcohol or a similar substance prevents safe participation in road traffic, and is prohibited by law. The phenomenon of driving while intoxicated or under the influence of alcohol has long been noticed and condemned. However, the problem still exists. The influence of alcohol always seriously increases the risk of dangerous situations on the road, hence the elimination of drivers who are under the influence of alcohol from road traffic is undoubtedly right. Hence, conducting permanent educational campaigns on television, in the press, on the Internet and radio, aimed at making the society aware of the negative effects of functioning in road traffic under the influence of alcohol, is very important, especially among young people, among whom the lack of experience in driving or bravado in behavior may lead to dangerous behavior on the road. Not only drunk drivers of vehicles are the perpetrators of road accidents, but also pedestrians who are under the influence of alcohol. The research also confirmed the increased risk of death in a pedestrian accident when the pedestrian was under the influence of alcohol. The unpredictable behavior of a drunk pedestrian is as dangerous as a drunk driver. One of the main causes of accidents caused by drunk pedestrians is careless access to the road in front of a moving vehicle. In such situations, vehicle drivers often have no chance of avoiding a collision. The problem of alcohol abuse by pedestrians, and the related dangers in road traffic have been described in

detail, among others, in the works (Ye et al., 2023; Koh et al., 2021).

Among all the analyzed factors, the night hours turned out to be the most important, i.e. from 10:00 p.m. up to 6 a.m. The probability of increasing the risk of pedestrian death in road accidents at night rises by almost 100%. The night hours are associated with the occurrence of darkness, sometimes lack of lighting or illumination of the road with artificial light. The negative impact of darkness on the occurrence of more serious injuries than during daylight hours, including fatal accidents among pedestrians, has already been confirmed in domestic (Olszewski et al., 2015) and foreign studies, which stated that the relative risk of pedestrian death in a road accident at night it was 1.3 times higher than during the day (Ackaah et al., 2020). Some studies indicate that the risk of pedestrian accidents, including fatal accidents at night, increases in the area where retail outlets are located (Gu & Peng, 2021). At night, visibility conditions are usually poor, which may be aggravated by the visual impairment of road users as well as poor-quality (worn) road and street markings, and in some places the lack of street lighting. Hence, preventive actions in this area should be focused on ensuring efficient street lighting and ensuring good quality road and street markings.

Another attribute that increased pedestrians fatal injuries in an accident was the occurrence of an accident outside build-up area. Earlier research work in this area has indicated that the pedestrian fatality rate is higher in rural areas than in urban areas, although built-up areas experience a greater number of both pedestrian and pedestrian crashes (Kuskapan et al., 2019). This fact is probably related to the higher speeds of vehicles moving outside build-up areas as well as to the lack of street lighting. Interesting research in this regard is presented in the paper (Malin et al., 2020), which adopted a very detailed categorization of places where incidents with pedestrians took place, and was associated with the severity of injuries suffered by pedestrians. The conclusions of this study indicate the need to adapt the planned measures to improve road traffic safety to different local conditions, and the constant need to change the measures applied to take into account both fatalities and serious injuries to pedestrians.

The obtained results allow the conclusion that increasing the risk of pedestrian death in road accidents increases when a driver exceeds the speed

limit. Speed is the basic parameter that determines the proper level of road traffic safety. Speeding is one of the main causes of road accidents. A pedestrian's likelihood of dying increases with increasing vehicle speed. Earlier research works indicate that with road speed limit increasing by 10 km/h, the probability of pedestrian death increases by 46% (Chen et al., 2019; Sugiyanto & Malkhamah, 2018). The likelihood of a pedestrian dying in a road accident also increases if the pedestrian has been involved in a road accident with a truck or bus. Other studies also confirm this regularity, e.g. in the research work (Wiratama et al., 2022) it was found that pedestrians in road accidents with heavy vehicles were 39.3% more at risk of death or seriously injured than victims of accident with passenger cars. Moreover, pedestrians had an 82.3% higher risk of serious or fatal injuries than cyclists.

In addition, studies have shown that the likelihood of a pedestrian dying in a road accident increases when the pedestrian is male and when the pedestrian is older than 60 years old. With age, the human body ages, the psycho-technical functions and the motor efficiency of the body deteriorate, the person reacts slower to external stimuli, which translates into slower reactions and less efficient participation in road traffic. On the other hand, the increase in the risk of death in an accident among men compared to women is puzzling. Such a result was obtained in several previous studies. In the research work (Olszewski et al., 2015) it was explained by the fact that men are prone to more risky behaviors, such as walking on the road in the dark or crossing the road in forbidden places.

The studies presented in the article are pilot studies because they were conducted for data from one voivodeship in Poland. In the future, it is planned to extend the area of analyzes to new voivodeships as well as to the period of the analysis.

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