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Effects of Road Infrastructure on Pedestrian Safety

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Effects of Road Infrastructure on Pedestrian Safety

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Abstract. Pedestrians represent more than 30% of all of Poland's road traffic fatalities. This is much higher than the EU average (about 20%). Pedestrian accidents are usually the result of a complex situation and a number of contributing factors involving road users, the road and roadside and the vehicle. Pedestrian accidents are caused by road user error (drivers and pedestrians) and wrong planning and design. Poorly maintained road infrastructure is also a very frequent cause. The objective of the work was to identify risks for pedestrians that involve road infrastructure and roadside and to define how selected elements of geometry and traffic layout affect driver behaviour (speed on approaching pedestrian crossings). The results have helped to formulate recommendations on pedestrian crossing design. The research included an analysis of 2013-2017 statistics to identify the circumstances and causes of pedestrian accidents. Field work at about 2,000 unsignalized pedestrian crossings was the basis for assessing the safety of these crossings. Assessment criteria were selected and a safety classification was made with specific recommendations made for possible treatments. More field work was designed to measure speeds near pedestrian crossings in three cases: no pedestrians in the crossing area, a pedestrian is approaching a crossing, a pedestrian is waiting to cross the road. The study was conducted in different areas (city, transit roads passing through small towns, non-built-up areas) for different cross-sections (one carriageway and two lanes – 1x2, two carriageways with two or three lanes each – 2x2, 2x3, one carriageway and four lanes – 1x4). The study also looked at speed limits – 50 and 70 km/h. The share of drivers giving way to pedestrians waiting to cross was also assessed. Pedestrians were surveyed and asked about how safe they feel crossing the road. The survey also asked drivers about driver behaviour and use of speed management measures. Statistical analyses show the circumstances and causes of pedestrian accidents. These include driving across a pedestrian crossing illegally, pedestrians stepping onto the road abruptly, night-time, excessive speed and others. Pedestrian crossings are the site of more than 30% pedestrian fatalities which shows the need for treatments. By assessing the hazards caused by road infrastructure near and at pedestrian crossings, the following hazards could be identified: limited sight-distance, poor illumination, excessive speed and no means of speed management, wrong geometry (length of crossing, number of traffic lanes), technical condition of the road and signage. Speed tests near pedestrian crossings show that some 40% of drivers do not observe the speed limits in built-up areas (especially on sections of transit roads passing through small towns and on dual carriageways in urban areas) and 30% do not observe the speed limits on rural roads.

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1. Introduction

Walking plays a crucial role in the transport system. This is true of small towns and villages with very little public transport and of big cities where walking is often used to get around the city. Walking is also part of many people's everyday lives (especially children, school youth, older people, people who do not have a car). Walking helps to stay fit and reduces the share of cars in road traffic benefitting the environment and keeping congestion lower, especially in major urban areas. In many cases people who use public transport or cars still have to walk substantial distances to get to car parks or public transport stops. This is why it is safe to say that all trips will always involve walking. While pedestrians are also road users, they are often depreciated by motorists. In addition, road infrastructure fails on basic functional and pedestrian safety standards.

With no comprehensible or clear rules for giving priority (in Poland as an example) driver behaviour may be dangerous towards pedestrians, for example when they drive over a pedestrian crossing carelessly. Pedestrians using road traffic are also negligent when they step onto the road suddenly, cross the road where it is illegal or cross on a red light, etc. Another problem is that pedestrian infrastructure is insufficient: across the road (asylum islands, proper marking, pedestrian crossings are not extended) and along the road (pavements). These deficits are especially evident in areas outside cities, on sections of transit roads and road sections in rural areas where pedestrian traffic may be substantial. In addition, some of the existing pedestrian traffic devices do not meet traffic or safety standards (such as poor technical condition, poor visibility of pedestrian crossings and public transport stops, discontinued pavements).

Pedestrians expect to be able to walk safely, comfortably, efficiently and in a walking-friendly environment. Pedestrians put safety first and expect that the streets they use will be free from fast moving vehicles, fairly quiet, with vehicles not occupying their space or poorly lit spaces [1]. The relations between pedestrians and motorists and pedestrian hazards created by road traffic must be studied to ensure adequate conditions for walking.

2. Literature study

Each year around 1.4 million people die in road accidents which puts the risk factor at 18 fatalities per 100,000 populations. Pedestrians worldwide account for 23% of all road accident fatalities [2]. In 2016 in the EU there were 5,320 pedestrians killed in road accidents which represents 21% of all road deaths. Over the decade of 2007-2016 across the European Union pedestrian fatalities went down by 36% compared to a reduction of 41% of all fatalities. Of all pedestrian fatalities 69% are killed in urban areas [3]. In recent years pedestrian fatalities have remained practically the same [4].

To assess pedestrian safety a detailed analysis must be conducted looking at road incidents and the related factors. This includes the role of drivers, pedestrians, vehicles, road infrastructure and the environment. For the purposes of this article a pedestrian is anyone walking, running, sitting or lying who is involved in motor vehicle road accidents. Pedestrians are a group of vulnerable road users which leads to serious consequences when an accident happens (serious injury and death). They are unable to keep themselves safe from the speed and weight of the other side [5]. Collisions between pedestrians and cyclists or motor vehicles are a major problem in countries which experience a surge in motorisation while pedestrian trips continue to represent a very big share [6]. Pedestrian safety is a challenge because the infrastructure is usually designed for motor vehicles with little attention paid to pedestrians, especially in non-built-up areas [7]. Research shows that there is a relation between pedestrian accidents and the type of road infrastructure and solutions used [8]. Safety perception may be a strong factor in whether communities will choose to walk in their local environment or in the neighborhood [9] [10]. Designated pedestrian crossings may significantly reduce the perception of being involved in an accident [11], [12].

Polish studies have focused on studying pedestrian behavior by analyzing digital footage from test cameras. This method is used in the MOBIS programme, for example, whose main objective is to develop a method for assessing pedestrian safety using video footage [13]. Polish studies have also examined luminance on pedestrian crossings at night time depending on road lighting. Pedestrian visibility on a pedestrian crossing was found to be the decisive factor of their safety. This suggests the need for properly selecting and designing lighting [14]. Work on the textbook “Pedestrian Safety” [15] included pilot in-the-field tests to collect more reliable data. Research into pedestrian and driver behavior in the area of unsignalised pedestrian crossings shows that a large percentage of drivers do not go at the required speed [16], [17]. Other research results show that pedestrians are at a high risk on sections of rural and transit roads passing through small towns [18].

In the United States pedestrian traffic is usually studied using surveys. The analysis looked at the probability of an accident on pedestrian crossings for different parameters such as driver speed, width, a marked or unmarked pedestrian crossing, signalised or unsignalised crossing, with barriers or without them [19], [20]. In Australia a survey was conducted to establish how familiar road users are with traffic regulations on the priority of road users in different situations [21]. In another study surveys were used to collect the basic parameters such as the respondent’s age, gender and education. The analysis also looked at the destination and knowledge of the regulations by asking questions about road users’ priorities in different situations [22]. A study in France aimed to analyze the behavior and mutual pedestrian-driver relations. When the results were analyzed it was found that when a pedestrian looks at an approaching vehicle, the vehicle is more likely to stop by more than 10% [23]. A survey in the United Kingdom checked three potentially dangerous behaviors: crossing a dual carriageway, crossing on red on a Pelican light controlled crossing and crossing a very busy road between parked cars [24]. In Germany behavior in road traffic at signalised junctions was studied recording the duration of signal phases, time for a pedestrian to cross the whole crossing or part of it (when the road was divided by a dividing lane or refuge), waiting time, pedestrian speed, “type of pedestrian behaviour” and driver-pedestrian conflicts [25]. In the Netherlands studies showed that excessive vehicle speed is the biggest problem for pedestrians, especially for people aged >65 [26].

3. Assessing pedestrian safety

3.1. EU countries

In 2016, 5,500 pedestrians were killed in road accidents in the EU, which is 20% of all road fatalities. During the decade 2007-2016, in the European Union, pedestrian fatalities were reduced by 36%, while the total number of fatalities was reduced by almost 41%. Latvia and Poland experienced the most significant reductions in pedestrian fatalities between 2007 and 2016 (65% and 56% respectively). In the Netherlands and Ireland, pedestrian fatalities almost halved, while in France and Italy the reduction in pedestrian fatalities was lower than 10%. The percentage of pedestrian fatalities per total road fatalities in each EU country is shown in figure 1. In 2016, the percentage is the lowest in the Netherlands (8%), Finland (11%) and Belgium (12%) compared to Romania (37%), Estonia (36%) and Latvia (35%). The EU average was 21%. To compare pedestrian fatality numbers of different countries, figure 2 takes account of the respective population size. The pedestrian fatality rates vary from 2.6 pedestrian fatalities per one million populations in the Netherlands to 36.3 pedestrian fatalities per one million populations in Romania. The elderly form the largest group in pedestrian fatalities. The number of elderly (aged >64) pedestrian fatalities decreased by 25% in the EU between 2007 and 2016, from 3.459 to 2.595, while the total number of pedestrian fatalities decreased by 36% [3].

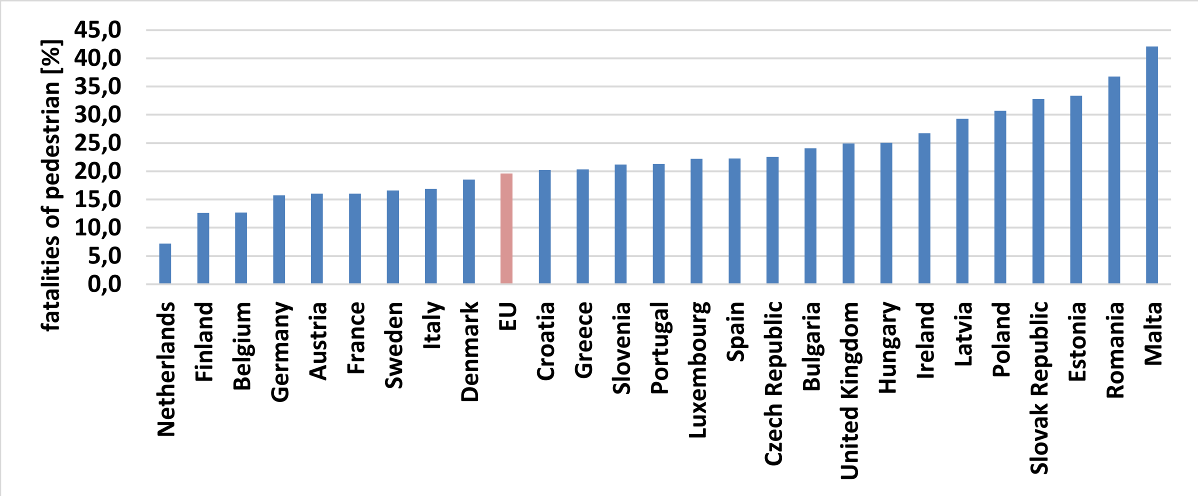

Figure 1. The percentage of pedestrian fatalities per total road fatalities in EU countries

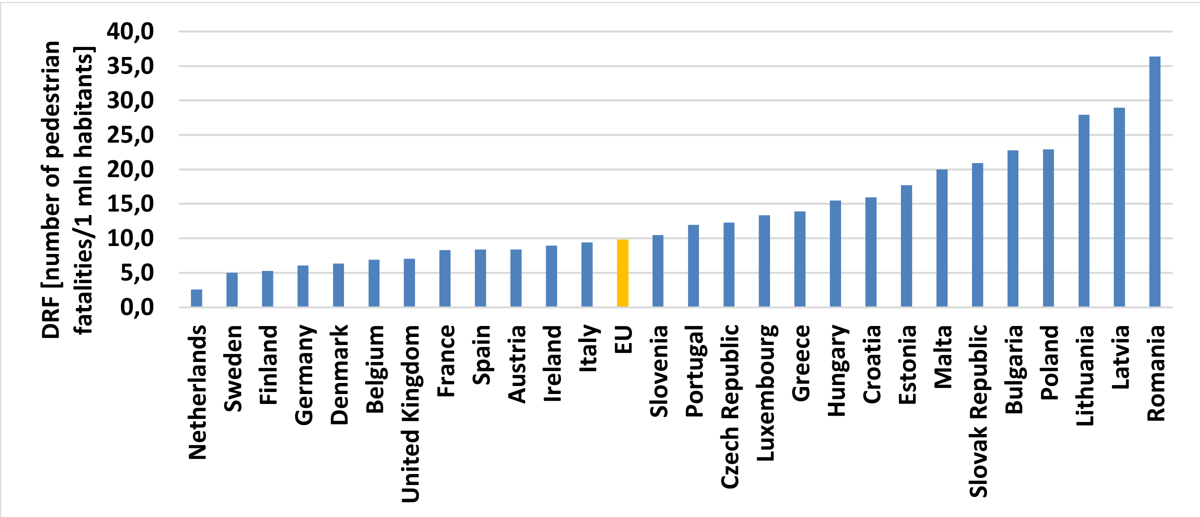

Figure 2. The pedestrian fatality rates - pedestrian fatalities per one million populations in EU countries

3.2. Poland

Over the recent decade (2009 – 2018) in Poland there were nearly 94,500 pedestrian accidents with more than 89,000 injuries and 11,000 people killed. Over the analyzed period pedestrian accidents dropped by 42%, with injuries decreasing by 43% and fatalities by 46% (figure 3). Analysis of 2018 data shows that pedestrian crossings recorded 285 fatalities which represents 10% of all people killed in road accidents in Poland. The distribution of injuries and fatalities by area (built-up and non-built-up area) is 90% for injuries and 65% for fatalities in built-up areas.

While in theory designated and marked places for pedestrians to cross the road should keep them safe, they are in fact the scene of numerous fatal accidents. Steps must be taken to improve pedestrian crossing safety. To achieve this, pedestrian and driver behavior in the area of pedestrian crossings should be studied as well as the relations between pedestrians and drivers (such as drivers giving priority to pedestrians).

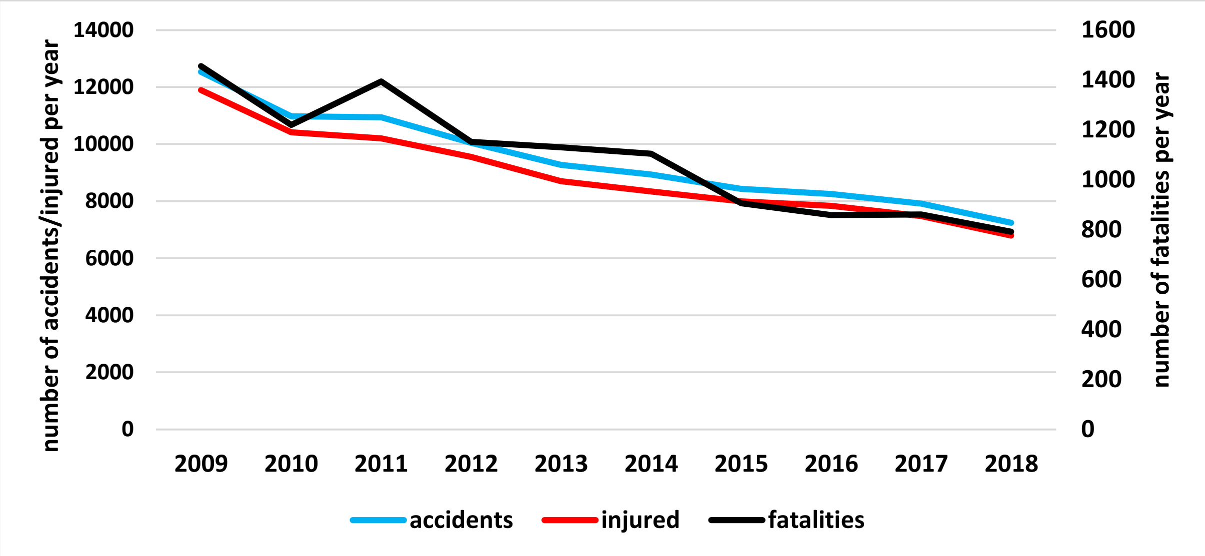

Figure 3. Pedestrian accident and victims in Poland (2009 – 2018)

4. Methodology

Speed at and around pedestrian crossings was studied building on a study carried out in the regions of Pomorskie – with an average level of pedestrian risk (the second region with the lowest societal risk in relation to the number of fatal and serious injury accidents vs. the population) and Malopolskie – with a very high level of pedestrian risk (the worst region for societal risk in relation to the number of fatal and serious injury accidents vs. the population).

The study of pedestrian behavior and the "pedestrian– driver" relations included work on-site in (figure 4):

- major cities,
- small towns and villages (less than 10,000 population),
- rural areas – outside built-up areas designated with D-42 signs.

The study covered two categories of roads and streets:

- with 50km/h speed limit,
- with 70 km/h speed limit.

In each of the areas the study was conducted for:

- signalised pedestrian crossings between junctions – with up to 30m from the crossing to the junction (further defined as signalised crossing within a junction),
- signalised pedestrian crossings between junctions – more than 100 m (further defined as signalised crossing outside the junction),
- unsignalised pedestrian crossings between junctions – with up to 30m from the crossing to the junction (further defined as unsignalised crossing within a junction),
- unsignalised pedestrian crossings between junctions – more than 100 m from the junction (further defined as unsignalised crossing outside the junction).

Measurement points took account of different road cross-sections:

- single carriageways (1x2, 1x4 single carriageway, with 1 and 2 lanes in each direction),
- dual carriageways (2x2 or 2x3 two carriageways, with 2 and 3 lanes in each direction).

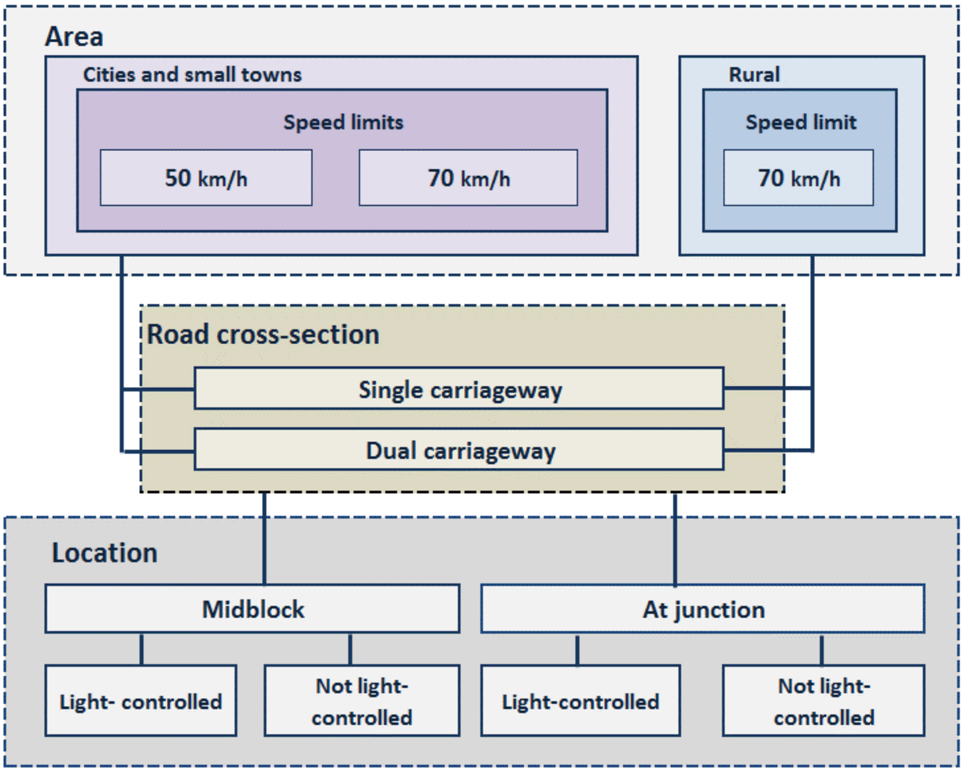

Figure 4. Diagram of how measurement points are selected

The study of pedestrian crossings also included lighting assessment. Hazards were identified which involved geometric parameters, traffic layout, roadway and pavement technical condition and visibility. The assessment covered about 2,000 unsignalised pedestrian crossings and followed the principles of road safety audit and inspection. A simplified methodology has been developed, which still contains elements needed in an audit. Firstly, the audit was carried out by certified, highly experienced road safety auditors. Vehicle speeds were assumed on the basis of speed samples for particular road cross-sections, as typical for the city of Warsaw. The volume and age structure of pedestrians were calculated on the basis of half-hour measurements during morning and afternoon rush hours, and calibrated for rush hour with the use of 6 hour measurements on selected pedestrian crossings. The most important element of the audit, however, is the on-site visit by the auditor, when user observation is carried out and hazards are identified. The basic risk factors for pedestrians on pedestrian crossings are vehicle speed, length of pedestrian crossing and driver-pedestrian visibility. The auditor collects information on-site about the geometric parameters, and in particular measures the available sight distance which could be limited by solid obstacles, such as buildings, posts, road barriers, road signs, but also temporary obstacles, such as greenery or parked vehicles. In addition to the basic elements indicated above, the auditor fills in a pre-defined form including: pedestrian crossing location details, pedestrian crossing characteristics (near crossroads, between crossroads, other), any measurable geometric parameters (width, length, distance from crossroads), speed limits, type and condition of road surface, the presence and the geometric parameters of traffic islands, the type of horizontal and vertical road markings and their condition, the distance of parked vehicles and whether parked legally or illegally, correctness of drainage systems, devices for the blind and visually impaired, pavement-roadway ramps and condition of pavements. Collecting the above data will allow the road authority to analyse irregularities by exploring the new database.

One of the preventive actions which could improve safety on pedestrian crossings is to assess the condition of the lighting installations located in the area of the pedestrian crossing. The field studies and the work of a team of experts will result in creating tools for assessing the level of hazard due to the lighting conditions measured at night. The newly developed and applied assessment method and the newly acquired experience should constitute a valuable contribution to the development of a comprehensive assessment of hazards in the area of pedestrian crossings. The authors attempted to systematize the description of the method of assessing the condition of lighting installations fitted in the area of pedestrian crossings. The lighting of pedestrian crossings in urban areas is often provided by the street lighting installation or by special, dedicated fixtures. The lighting systems installed on pedestrian crossings should provide:

- the driver – with the right conditions to judge the traffic situation and to observe the silhouette of a pedestrian within the driver's sight;
- the pedestrian – with the right conditions to observe the surrounding of the pedestrian crossing and any approaching vehicles.

5. Selected study results

5.1. Speed

Where the speed limit is 50 km/h, the results show:

Type of area:

- urban areas feature lower speeds when vehicles approach a pedestrian crossing compared to small towns, if there are no pedestrians by 2.5 km/h at 10 m from the crossing and by 10 km/h less at 50 m from the crossing,
- in both types of areas recorded vehicle speeds were similar at 10 m from the crossing when a pedestrian is waiting to cross,
- urban areas feature higher speeds when vehicles approach a pedestrian crossing compared to small towns, when a pedestrian is crossing the road, 2 km/h more at 10 m from the crossing and 1 km/h at 50 m from the crossing,
- in both areas vehicle speeds went slightly down at 10 m from the crossing when a pedestrian is waiting to cross compared to no pedestrians waiting and a significant speed reduction when pedestrians are crossing the road.

Type of street cross-section:

- the lowest speed on approaching a crossing with no pedestrians, at 10 m from the crossing and a 1x2 cross-section with a refuge island (30 km/h less than for a 1x4 cross-section and 23.5 km/h less than on dual carriageways),
- the lowest speed on approaching a crossing with a pedestrian waiting to cross was recorded on a 1x2 cross-section without a refuge island (16 km/h less than for a 1x4 cross-section and 1x2 with a refuge island and 22 km/h less than for dual carriageways),
- the lowest speed on approaching a crossing with a pedestrian crossing the road was recorded for a 1x2 cross-section with a refuge island, but the differences between cross-sections are minor.

For all types of cross-sections vehicle speed when a pedestrian is waiting to cross is lower than when there are no pedestrians waiting (by 16 km/h for 1x2, by 16 km/h for 1x4, by 2 km/h for 2x2 and 2x3).

Where the speed limit is 70 km/h, the results show:
Type of area:

- small towns feature lower vehicle speeds on approaching a crossing than rural areas, with no pedestrian waiting by 35 km/h at 10 m from the crossing and by 18 km/h at 50 m from the crossing,
- small towns feature lower vehicle speeds on approaching a crossing than rural areas with a pedestrian waiting by 25 km/h at 10 m from the crossing and by 20 km/h at 50 m from the crossing,
- small towns recorded higher speeds when pedestrians were waiting to cross as opposed to no pedestrians waiting - by 5 km/h, in rural areas lower speeds were recorded when pedestrians were waiting to cross than when no pedestrians were waiting - by 1 km/h (applies to 10 m from the crossing).

Type of cross-section:

- The highest speed on approaching a crossing with no pedestrians waiting, at 10 m from the crossing was recorded for cross-sections of 2x2 and 2x3 (29 km/h more than for a 1x2 cross-section),
- The highest speed on approaching a crossing with pedestrians waiting was recorded for cross-sections of 2x2 and 2x3 (27 km/h more than for a 1x2 cross-section),
- The lowest speed on approaching a crossing with a pedestrian crossing the road was recorded for a cross-section of 1x2, i.e. 4 km/h less than for 2x2 and 2x3 cross-sections,
- For both types of cross-sections, the lowest speed was recorded when a pedestrian was waiting to cross compared to no pedestrian waiting (by 5-6 km/h).

5.2. Driver behaviour
On-site studies of driver behaviour showed that:

- 3.1% of drivers do not comply with the obligation to stop on a red light,
- in areas where the speed limit is equal to 50 km/h, i.e. areas in cities and small towns, app. 40% of drivers exceed the speed limit,
- in rural areas with a 70 km/h speed limit, 30% of drivers exceed the speed limit

5.3. Pedestrian behaviour
During the field work selected parameters were analyzed such as speed, time lost at crossings, distance between a pedestrian waiting and the road and pedestrian age. It was found that:

- average speeds at crossings with a refuge island are lower than on cross-sections with no refuge island,
- there are no major differences between crossing speeds for different cross-sections and types of areas with values ranging from 1.0 to 1.6 m/s,
- there are differences in time lost depending on the area – urban areas, pedestrians need on average 17 s to cross the road and 25 s in small towns with 48 s in rural areas; this shows that crossings are a major problem in how they operate and that they may generate dangerous behaviour,
- of the registered dangerous pedestrian behaviours, a clear majority involve failure to check the road before crossing – 84% (app. 10% of all registered pedestrians), crossing the road on a red light – 8% (app. 1% of all registered pedestrians) and crossing where it is illegal – 8% (app. 1% of all registered pedestrians).

5.4. Identification of hazards
In order to create material that would be easy to analyse and economically valuable, the methodology attempted to define types of hazards and problems. Six groups of hazard types have been predefined

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(lack of facilities for special needs persons, limited visibility, errors in marking, hazards related to the geometry of the pedestrian crossing and the street in front of it, errors in drainage and other unclassified factors.) The methodology covered hazards resulting from the following elements:

- insufficient facilities for disabled persons and persons with impairments: lack/insufficient facilities for the visually impaired, lack/insufficient ramps on the edge of the crossing,
- insufficient driver – pedestrian sight distance due to limited visibility caused by: parked vehicles, fences, posts, billboards, municipal transport stops, greenery, other,
- errors in marking, both horizontal and vertical, due to incompleteness or poor technical condition,
- hazards related to the geometry of the pedestrian crossing and the road in its area related to: pedestrian crossing too long, pedestrian crossing cutting across at least three lanes, pedestrian crossing cutting cross lanes that are too wide, the use of "painted" surface which does not protect the pedestrian, insufficient width of traffic islands, very high / high speed of vehicles,
- hazards resulting from insufficient drainage of pedestrian crossings: lack of drains in the area of pedestrian crossing, lowest point of vertical alignment/catchment resulting in the formation of puddles,
- hazards resulting from other factors: poor technical condition of the road surface, the pedestrian crossing or the pavement, pedestrian crossing susceptible to being blocked by parked vehicles, unnecessary pedestrian crossing, e.g. doubling a neighbouring crossing, no room for vehicles before the crossing,
- other not categorised above.

6. Summary

Walking plays a crucial role in the transport system. This is true of small towns and villages with very little public transport and of big cities where walking is often used to move around the city. Walking is also part of many people's everyday lives (especially children, school youth, older people, people who do not have a car). Having said this, pedestrians are the most vulnerable road users and most at risk of death in road accidents, representing more than 30% of all road accident fatalities in Poland and more than 20% in the EU. The relations between walking and driving and the hazards generated should be further researched to ensure that pedestrians can use roads safely. The pedestrian-driver relation and the behavior must be monitored on an on-going basis and pedestrian crossings must be inspected for safety. This will help improve pedestrian safety effectively. The authors will work to develop a consistent database of measurements and expert assessments and pedestrian incidents. It could serve as the start of a model that will quantify the share of the elements in overall pedestrian hazards.

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