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IDENTIFICATION AND ANALYSIS OF POTENTIAL RISK FACTORS INFLUENCING THE ROAD SAFETY LEVEL AT DESIGNATED PEDESTRIAN CROSSINGS

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Abstract. According to the data of the European Road Safety Observatory, around 21% of all road fatalities are suffered by pedestrians in the EU. In 2019 in Hungary, road accidents of pedestrians have had a share of 14,6% in all road accidents with personal injuries, which meant 2535 accidents in which one or more pedestrians were injured. A significant proportion of the accidents occurred at designated pedestrian crossings (43,1% of pedestrian accidents in 2019), and this trend increased over the last 5 years. To account the problem, Institute for Transport Sciences Non-profit Ltd. conducted a research focusing on the identification of potential risk factors which may have a negative impact on the level of traffic safety of designated pedestrian crossings in urban areas. Analysis and ranking of the risk factors have been carried out based on experts' evaluation and scoring, with the use of statistical methods. The results of the work explore the risks that need to be addressed with special attention during the review of existing, and the establishment of new pedestrian crossings.

Keywords: road safety, pedestrian crossing, risk assessment, KIPA analysis, cluster analysis

Introduction

The road safety of vulnerable road users is a key area of recent and future strategic documents. In the framework of the European Union on road safety, actions have been determined in seven focus areas, including vulnerable road users such as pedestrians, cyclists and motorbike riders (EC, 2010). Based on the Working Paper on the EU Road Safety Policy Framework for 2021-2030, the safety of vulnerable road users seems to be highlighted also in the next decade, especially as a wider range of different automated/connected vehicles will appear in a mixed traffic with this group (EC, 2019).

Pedestrians, as part of the vulnerable road users are characterized by high probability of injuries in a road accident (Stutts & Hunter, 1999; Eilert-Petersson & Schelp, 1999). To highlight the importance of the investigations related to the safety level of pedestrians and pedestrian crossings, a short road safety analysis has been provided mainly focusing on to the country of the authors (Hungary).

In the European Union, pedestrians make up 21% of total fatalities in road accidents. If we look only at urban areas, where pedestrians mainly travel, this proportion is as high as almost 40%, accounting for the largest share of victims. The pedestrian fatalities in urban areas fell at a slower pace than the decline in the overall number of road traffic victims (EC, 2020).

In Hungary, between 2014 and 2019 pedestrian accidents accounted for about 15% of the number of total road accidents. In 2019, 2419 accidents happened in which pedestrians were injured. The proportion of pedestrian accidents has not changed significantly in this years (see Figure 1).

Based on the data of 2014-2019, the most frequent type of pedestrian accidents was "traffic accidents with pedestrian at designated pedestrian crossings at intersections". The rate of this type of accident has increased almost continuously over the last 6 years. In 2019, 22,7% of pedestrian accidents were of this type. In addition, the proportion of 3 other types of accidents increased significantly between 2014 and 2019:

- pedestrian crashes outside of intersections (16,9 % of pedestrian crashes in 2019);
- traffic accidents with pedestrians at designated pedestrian crossings outside of intersections (15,5% in 2019);
- other traffic accidents with pedestrians, (16,5% in 2019).

Examining the most common types of pedestrian accidents, we can conclude that a high proportion of pedestrian crashes happened at designated pedestrian crossings.

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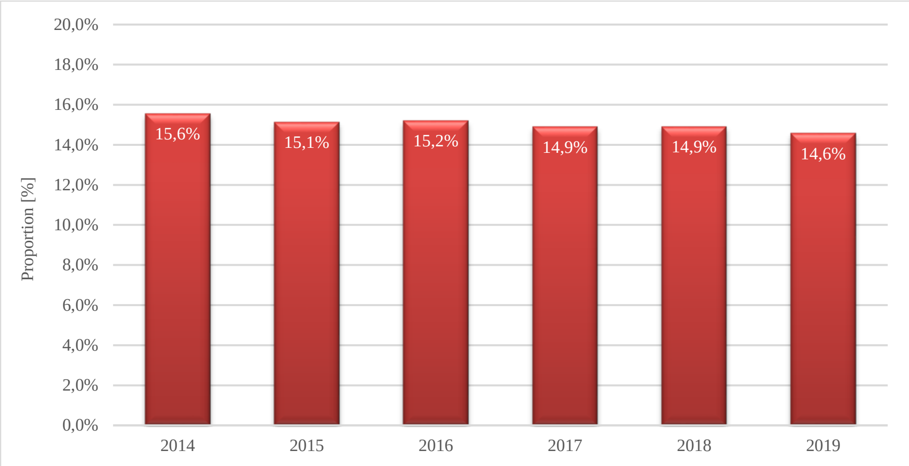

Figure 1. Proportion of pedestrian crashes within all road accidents in Hungary (2014-2019)

The rate of accidents at designated pedestrian crossings are especially high in urban areas. In Hungary in 2019, 43,1% of accidents involving pedestrians (971 accidents) has happened at these kind of locations. As can be seen in Figure 2, the rate of accidents at designated pedestrian crossings has shown an increasing trend urban areas (increasing from 37,7% to 43,1% during the examined years).

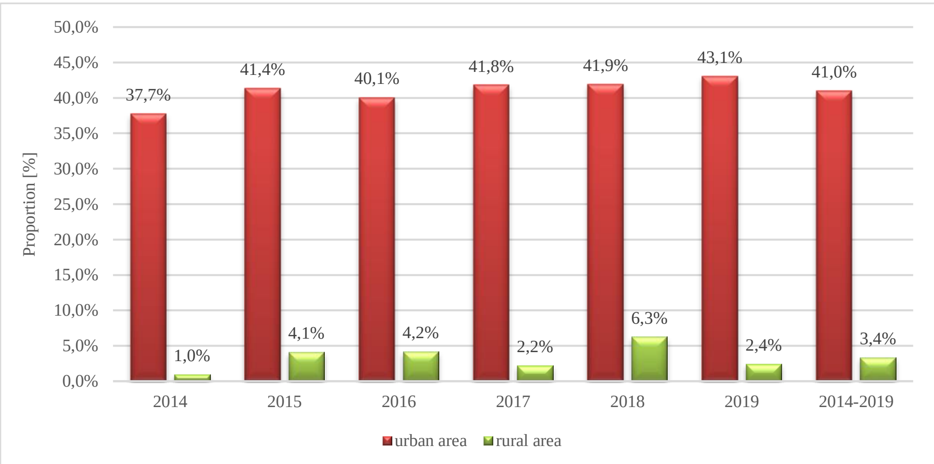

Figure 2. Proportion of pedestrian crashes at designated pedestrian crossings in Hungary (2014-2019)

Accidents at designated pedestrian crossings between 2014 and 2019 resulted in 179 deaths, 1999 serious injuries and 3878 slight injuries in Hungary. In addition to personal tragedies, taking into account the values of road accident losses, all of this caused HUF 194 billion in economic losses to the country in 6 years.

In line with the above presented problems, the purpose of our research was to identify potential risk factors influencing the safety level of uncontrolled (i.e. no traffic lights) pedestrian crossings in a systematic approach. Based on that, factors have been assessed and ranked by statistical methods to identify the most critical risks which have to get the prime focus when the road safety level of pedestrian crossings are to be evaluated or improved.

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1. Identification and assessment of risk factors

The potential risk factors that influence the road safety level of uncontrolled pedestrian crossings have been revealed and categorized into four main groups. The factors have been notated by f_j^i, where the upper index refers to one of the determined four main groups, and lower index identifies the individual factor within the group. The main groups were:

- Factors related to the technical design and control ($i = 1$);
- Factors related to the construction design and close environment ($i = 2$);
- Factors related to the traffic engineering design ($i = 3$)
- Traffic characteristics, distracting situations and objects ($i = 4$).

When determining the individual risk factors (indicated in Table 1), we have relied on the domestic regulation that deals with the principles of road traffic management and the placement of road signs (20/1984. (XII. 21.) Government Decree), the Hungarian Road Technical Specification prescribing the design of transport facilities for pedestrian traffic (ÚT 2-1-211), as well as on the results of international studies (Antov, Rõivas, Antso, & Sürje, 2011; Pashkevich & Nowak, 2017; Pashkevich, Krasilnikova & Antov, 2016) assessing the risks of pedestrian crossings.

Table 1. The list of the identified risk factors influencing the safety level of pedestrian crossings without traffic lights

Notation	Description of risk factor
f_1^1	The need of crossing more than 2 traffic lanes without the possibility to safely interrupt the crossing movement (e.g. by the presence of pedestrian refugee)
f_2^1	Crossing of parallel traffic lanes (with vehicle traffic towards the same direction)
f_3^1	The absence of adequate separation from the road, or not adequate pedestrian waiting areas (e.g. too narrow, not barrier-free)
f_4^1	The uncontrolled pedestrian crossing is within 100m to an intersection/crossing controlled by traffic light, or can be found on a route controlled by coordinated traffic lights
f_5^1	The minimum width of the designated pedestrian crossing is not ensured, or the angle with the road axis is not perpendicular
f_6^1	The absence of public lighting, or the lighting is not adequate
f_1^2	The pedestrian crossing cannot, or can hardly be recognized from a distance of at least 50 metres
f_2^2	Mutual detection of pedestrians and drivers is obstructed due to obscuring elements
f_1^3	Bad condition of road markings and traffic signs designing the pedestrian crossing
f_2^3	The absence of road markings or traffic sign predicting the pedestrian crossing where it would be justified
f_3^3	Bad condition of road markings and traffic signs predicting the pedestrian crossing
f_4^3	The absence of the prohibition of overtaking in front of the pedestrian crossing
f_1^4	The presence of a situation that divides the attention of drivers right in front of to the pedestrian crossing
f_2^4	The presence of a situation that divides the attention of drivers right behind the pedestrian crossing
f_3^4	The presence of an object that divides the attention of drivers in the vicinity of the pedestrian crossing
f_4^4	Generally high traffic volume in the vicinity of the pedestrian crossing
f_5^4	Generally high traffic speed in the vicinity of the pedestrian crossing
f_6^4	The pedestrian traffic is characterized by an increased risk (e.g. low pedestrian traffic, high share of elderly or children)

The identified risk factors may affect the behavior of drivers and pedestrians according to several aspects, and therefore have effects on road safety, on the willingness to give priority for pedestrians as well as on the level of attention.

A questionnaire survey has been carried out among transport and traffic engineering experts assessing the potential effect of the identified risk factors. The experts evaluated the listed factors according to the following criteria, on a scale of 5:

1. C_1: Impact on the risk of accidents due to driver error (1- does not increase at all, 5- increases significantly);
2. C_2: Impact on the risk of accidents due to pedestrian error (1- does not increase at all, 5- increases significantly);
3. C_3: Impact on the rate of giving priority for the pedestrians (1- does not affect at all, 5- affects strongly (whether in a negative or positive direction));
4. C_4: Incidence frequency on the road network (1- does not occur at all, 5- occurs extremely frequently);
5. C_5: Effect on achieving increased attention of drivers (1- does not inhibit at all, 5- strongly inhibits).

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The experts evaluated each influencing factor according to the 5 criteria. During this evaluation, average vehicle and pedestrian traffic have been assumed. For the analysis, the evaluation scores of experts have been averaged and summarized in Table 2. The higher values refer to higher risks, as explained by the scales of the criteria.

Table 2. Average score of risk factors according to the defined evaluation criteria

	C_1	C_2	C_3	C_4	C_5	Relative standard deviation
f_1^1	3,429	3,143	2,857	2,429	3,286	0,159
f_2^1	4,429	2,714	3,571	3,571	3,143	0,136
f_3^1	2,714	3,429	2,286	2,429	2,143	0,226
f_4^1	4,143	3,000	3,429	2,571	3,429	0,203
f_5^1	2,286	2,857	2,429	2,143	2,000	0,250
f_6^1	4,571	2,714	4,286	3,714	4,000	0,196
f_1^2	4,143	2,571	4,143	2,429	4,143	0,178
f_2^2	3,857	3,571	3,571	3,286	3,571	0,082
f_1^3	3,571	1,857	3,143	2,857	3,571	0,163
f_2^3	3,429	1,286	3,000	2,000	3,000	0,126
f_3^3	3,143	1,571	2,857	2,714	2,857	0,149
f_4^3	2,857	1,143	1,857	3,857	2,143	0,133
f_1^4	4,429	2,143	3,857	3,429	4,286	0,133
f_2^4	4,000	1,857	3,571	3,000	3,714	0,104
f_3^4	3,714	2,143	3,571	3,571	3,571	0,098
f_4^4	3,000	3,000	3,000	3,286	3,571	0,085
f_5^4	4,571	3,429	4,143	3,143	3,571	0,174
f_6^4	3,429	3,429	3,286	2,857	1,714	0,140

The highest average scores (4,571) were attributed to deficiencies in public lighting and high traffic speeds in the vicinity of the crossing in terms of the effects on the risk of accidents due to driver error. The lowest average score (1,143) was assigned for the impact of the absence of prohibition of overtaking on the risk of accidents due to pedestrian errors.

Based on the evaluation of experts, the risk factors have been ranked using the KIPA method. The factors have also been classified using cluster analysis, according to different aspects. Our aim was to find the group of factors that can be considered particularly risky according to some criteria.

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2. Ranking of the risk factors based on the KIPA analysis

As first step of the analysis, the relative standard deviations of the average scores of experts have been calculated to confirm the adequacy of the data (see in the last column of Table 2). The relative standard deviations were higher than the expected 0,2 threshold in only three cases, and even in these cases the difference was small, and no outlier data could be observed. This shows the heterogeneous structure of the scoring. Thus, in our primary studies the sample has been considered to be well characterized by the means of the values, and the KIPA method was found to be applicable.

The KIPA method is suitable for comparing complex systems, with the help of which the identified 18 potential risk factors can be ranked taking into account all the examined aspects (Kindler & Papp, 1977). Using the method, the most critical risk factors can be identified based on the experts' opinion.

The alternatives have been characterized on scales based on the weight of the evaluation criteria, by pairwise comparison. The main steps of the procedure are the following:

1. construction of scales for measuring evaluation criteria (taking into account weights);
2. preparation of the basic table of the KIPA method (transforming the scores of experts to the previous scales);
3. preparation of the KIPA matrix (pairwise comparison);
4. setting preference and disqualification thresholds;
5. determining the order of preference (ranking of risk factors).

The KIPA method also provides an opportunity to take into account weights of the evaluation criteria. In case of our research, all 5 defined evaluation criteria were considered equally important (with equal weight of value 1). Thus, the measurement scales of the first step were the same as the original evaluation scales (ranging from 1 to 5), and the basic table of the KIPA analysis included the average scores given by the experts.

To produce the KIPA matrix, the preference (c_{ij}) and disqualification (d_{ij}) indicators have been calculated based on pairwise comparisons. The preference indicator provides information on the advantage of the i-th alternative over the j-th, and is calculated for each relationship. Its value is obtained by summing the weights of the evaluation criteria for which the given alternative is preferred or indifferent (the value assigned to it in the basic table is greater than or equal to) compared to the other alternatives. The disqualification indicators have also been calculated in all respects, but only the evaluation criterion for which the preference intensity was highest had to be taken into account. Thus, in order to determine the value of the disqualification indicators, the evaluation criterion that meets the following two conditions has been selected:

- according to the investigated criterion, the value assigned to the j-th alternative is higher than the value assigned to the i-th;
- the absolute value of the difference between the values assigned to the i-th and j-th alternatives is the largest.

The absolute value of the difference between the values selected in this way is the largest scale difference where the examined i-th alternative is at a disadvantage compared to the j-th alternative. To calculate the disqualification indicator, this value has been divided by the size of the largest scale. Note that in our case the size of each scale was the same since all evaluation criteria were given the same weight. The result has been transformed to the percentage form.

With the use of the calculated preference and disqualification indicators, the KIPA matrix has been created. The matrix compares the alternatives (risk factors) to each other, therefore the size of it is 18x18. The intersection of the i-th row and the j-th column contains both the c_{ij} and d_{ij} indicators. Due to space constraints, the matrix has not been visualized in the article.

The determination of the order of preference (the ranking of the risk factors) has been performed based on the data of the matrix. The preference threshold was considered at 70% ($c_{ij} > 0{,}7$) and the disqualification threshold at 20% ($d_{ij} < 0{,}2$). A total of 66 pairwise comparisons met both of these criteria.

According to the results of the pairwise comparisons, an assortment graph have been elaborated. Nodes of the graph represent the examined risk factors. The edges between the compared risk factors are directed, starting from the preferred alternative and pointing towards the other node (representing the results of the comparison of the given alternatives). Based on the directed edges, the preference order of the compared alternatives (risk factors) has been determined. An alternative is more favorable the more arrows start from it, and the more unfavorable the more arrows pointing there.

The graph illustrates the results well in case of less compared alternatives, but the presentation of it has been excluded from our article due to the high number of considered risk factors. In Figure 3 however the ranking of the alternatives are well illustrated (the most preferred alternatives are on the top of the pyramid), and the structure of the graph has also been represented by the numbers in the brackets. The first number in the bracket indicates the number of alternatives over which the given factor is preferred (number of edges starting from that node), while the second

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number represents the opposite (number of alternatives that are preferred over the given factor, i.e. the number of edges arriving to that node).

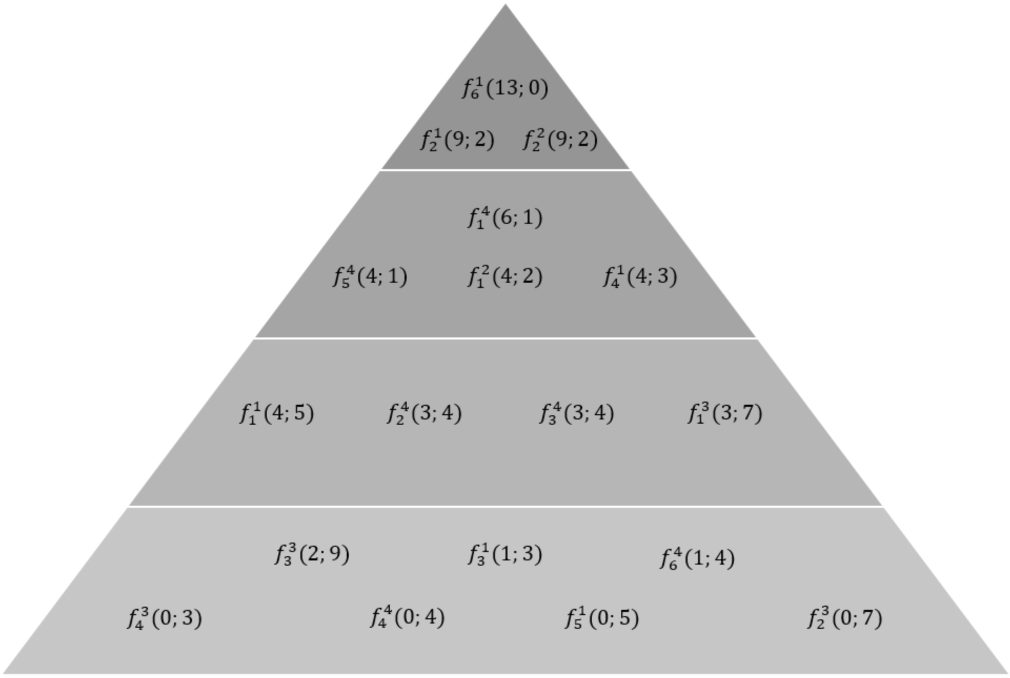

Figure 3. Ranking of the examined potential risk factors

The ranking was based on the level of safety risk assigned to the alternatives. According to the results of the KIPA analysis based on the evaluation of the experts, the factors at the top of the pyramid can be considered to be the most critical risks at urban pedestrian crossings. The less preferred alternatives at the bottom of the pyramid represent the factors with the lowest risks. These were preferred in less than 20% of their pairwise comparisons.

The results showed, that – according to the experts - the absence or inadequacy of public lighting was considered the most critical problem in the case of designated pedestrian crossings within urban area (taking into account all criteria). In the ranking, this is followed by risks due to the possible difficulties in detecting pedestrians or drivers (covering effect of parallel traffic in the same direction; obscuring roadside elements like trees, vegetation, parking vehicles). Each of the three most critical risks is therefore directly related to the issue of visibility at the pedestrian crossings.

The following factors have also been found to be among the most critical risks based on the analysis (second level of the pyramid):

- the presence of a situation that divides the attention of drivers right in front of to the pedestrian crossing;
- generally high traffic speed in the vicinity of the pedestrian crossing;
- the pedestrian crossing cannot, or can hardly be recognized from a distance of at least 50 metres;
- the uncontrolled pedestrian crossing is within 100m to an intersection/crossing controlled by traffic light, or can be found on a route controlled by coordinated traffic lights.

It is interesting to note, that all of the factors related to the traffic engineering design were in the back half of the ranking so can be considered less critical from the road safety point of view. The average scores of the four main groups of risk factors were:

- 3.11 points in case of factors related to the technical design and control ($i = 1$);
- 3.53 points in case of factors related to the construction design and close environment ($i = 2$);

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- 2.64 points in case of factors related to the traffic engineering design ($i = 3$);
- 3.34 points in case of factors related to traffic characteristics, distracting situations and objects ($i = 4$): 3.34 points.

That is, based only on the average scores of the experts, the risks related to the construction design of the pedestrian crossings were rated as the most critical.

Based on the KIPA analysis, the following 4 factors were not "preferred" to any of the other risk factors so have been considered to be the least critical:

- the absence of the prohibition of overtaking in front of the pedestrian crossing;
- generally high traffic volume in the vicinity of the pedestrian crossing;
- the minimum width of the designated pedestrian crossing is not ensured, or the angle with the road axis is not perpendicular;
- the absence of road markings or traffic sign predicting the pedestrian crossing where it would be justified.

3. Grouping of the risk factors based on cluster analysis

Following the ranking process, the risk factors have been investigated also with the use of cluster analysis. Clusters have been created based on the average scores given by the experts, using the SPSS statistical program.

To perform the classification, the hierarchical Ward-method was used. This procedure is very common in economic applications, can be interpreted well in practice, and results in groups of roughly the same size (Simon, 2006). The method is based on aggregation. In the first step it considers each element as a separate cluster and connects to each other, while forming larger and larger groups. The mean and the sum of the squared deviations from the mean are calculated for all points within the cluster. For the larger cluster formation, the point or cluster is used with which the difference in the sum of squares of the deviation is the smallest.

During the clustering, the examined 18 risk factors have been classified into 3-8 clusters. Based on the examination of the results, the 5 cluster solution was found to be the most suitable for the characterization. The results are showed in Table 3, where all clusters have been characterized based on the average score (and standard deviation in brackets) given for the elements according to the defined criteria.

The table also shows the average based on all of the factors, which can be used for comparison when analyzing the characteristics of the different clusters. Significant downward deviations from the mean were highlighted by italic numbers (difference was greater than 10%), while the significant positive deviations have been indicated by gray background color. In the last column, the risk factors included in each cluster are presented.

Table 3. Average score (and standard deviation) of the clusters according to the criteria

	Number of elements	C_1	C_2	C_3	C_4	C_5	Cluster elements
All risk factors	18	3,65 (0,68)	2,55 (0,77)	3,27 (0,66)	2,96 (0,56)	3,21 (0,76)	
Cluster 1.	3	3,52 (0,58)	3,05 (0,08)	3,10 (0,30)	2,76 (0,46)	3,43 (0,14)	$f_1^1; f_4^1; f_4^4$
Cluster 2.	6	4,33 (0,28)	2,86 (0,54)	3,93 (0,31)	3,26 (0,46)	3,79 (0,43)	$f_2^1; f_6^1; f_1^2; f_2^2; f_1^4; f_5^4$
Cluster 3.	3	*2,81 (0,58)*	3,24 (0,33)	*2,67 (0,54)*	*2,48 (0,36)*	*1,95 (0,22)*	$f_3^1; f_5^1; f_6^4$
Cluster 4.	5	3,57 (0,32)	*1,74 (0,33)*	3,23 (0,33)	2,83 (0,57)	3,34 (0,39)	$f_1^3; f_2^3; f_3^3; f_2^4; f_3^4$
Cluster 5.	1	*2,86 (-)*	*1,14 (-)*	*1,86 (-)*	3,86 (-)	*2,14 (-)*	f_4^3

The most critical factors, characterized by the highest average scores have been included in Cluster 2. The elements of this cluster were associated with higher risks of accidents, higher effects on the rate of giving the priority, higher probability of distracting drivers' attention, and were also considered to be frequent on the road network. The result is in line with our previous analysis, the elements of the most critical cluster have been assigned from the first elements of the rank determined by the KIPA analysis.

Based on the examination of the further clusters, the following conclusions can be made. There were 3 elements in Cluster 1 that were rated as average by experts according to the most criteria. However, in case of the elements of this cluster, the risk of accidents due to pedestrian fault was considered higher than average. Thus, these are situations

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where pedestrians can make mistakes more easily than average, while the risks are not higher than the average in terms of the other criteria.

Cluster 3 contains similar elements. Here the risk of accidents due to pedestrian error is also higher than the average, but these factors were characterized by lower-than-average risks in all other respects.

Cluster 4 is the “opposite” of Cluster 1. It contains elements where the risk of accidents due to pedestrian error was considered to be lower than average, while the risk was considered average in all other respects. These factors have less influence on the frequency of pedestrian errors, which seems valid since the factors listed in this cluster are conditions that distract the drivers.

A single risk factor ("the absence of the prohibition of overtaking in front of the pedestrian crossing") forms an independent cluster. According to the experts, this factor is not so significant in terms of influencing traffic safety, the level of giving the priority and the level of attention, however, it was identified as the most common factor on the road network.

Conclusions

Pedestrian crossings are the points of the road network designated to ensure the safe crossing of pedestrians. However, as it has been pointed out by our analysis, a significant proportion of pedestrian accidents occurs at these places. This fact justified the need of assessing the potential risks at designated pedestrian crossings and their environments. During our research, potential risk factors that may negatively affect the level of traffic safety have been identified in a systematic approach. Our investigations focused on the designated pedestrian crossings within residential areas.

The factors were evaluated on the basis of expert opinions, using the KIPA method, which allows the ranking of data by several aspects, as well as with the help of cluster analysis. Our goal was to identify the most critical risk factors, by eliminating which the greatest traffic safety benefits can be achieved.

The results of the ranking and clustering pointed in the same direction, clearly identifying the factors considered by experts to be the most critical:

- crossing of parallel traffic lanes (with vehicle traffic towards the same direction);
- the absence, or inadequacy of public lighting;
- difficult identification of the designated pedestrian crossing from a suitable distance;
- obstruction of the mutual detection of pedestrians and drivers due to obscuring elements;
- the presence of a situation that divides the attention of drivers right in front of to the pedestrian crossing;
- generally high traffic speed in the vicinity of the pedestrian crossing.

These were the factors which were considered by the experts the most critical in terms of the risks of accidents and the distraction of drivers’ attention level. In addition they have been evaluated as relatively common risks, having a greater than average impact on the rate of giving the priority for pedestrians. When designing new pedestrian crossings and reviewing existing ones, it is important to focus on eliminating, or reducing the risks arising from the above presented factors in order to increase the safety of pedestrian crossings in the most effective way.

Disclosure Statement

Authors declare that they have no competing financial, professional, or personal interests from other parties.

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