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DRIVERS' SPEED BEHAVIOUR IN THE VICINITY OF ADDITIONALLY ILLUMINATED PEDESTRIAN CROSSINGS

Summary. The probability and severity of accidents at pedestrian crossings strongly depend on vehicles' speed; hence, drivers' speed control and awareness of driving conditions are very important. Lighting installations in the transition areas of pedestrian crossings have been set up in Polish cities in recent years to improve the visibility of pedestrian crossings and enhance drives' awareness while approaching sensitive spots in the road network. A key study focus is to evaluate the influence of additional lighting systems on drivers' behaviour in terms of travel speed. Drivers' speed measures were carried out under daytime and nighttime conditions on single carriageways. Speed measurements were performed in free flow driving conditions in the vicinity of zebra crossings located in mid-block segments and at intersection inlets. The analyses conducted have shown an ambiguous influence of lighting installations on drivers' behaviour. It has been found that drivers approaching pedestrian crossings with additional illumination systems decrease their speed significantly, but average speeds, even reduced, remain over posted speed limits. Moreover, at zebra locations, drivers' speed under night conditions in some cases was found to be significantly higher than during the day. Based on the results obtained, some recommendations have been made to improve drives' speed behaviour at pedestrian crosswalks.

1. INTRODUCTION

Road traffic crashes result from a combination of factors related to the road layout, the vehicles, the road users and the way they interact. Most accidents take place in urban areas within pedestrian crossings. Every year, about 8000 pedestrians are killed and many more are injured in road accidents in Europe. Approximately 1 in 4 of pedestrian fatalities occurs on or close to a pedestrian crossing. Some studies conducted across Europe found that nearly one in five pedestrian crossings scored poorly on night visibility [1]. Furthermore, ERSO [2] shows that nighttime accidents on crossings account for 46% of the total, despite the fact that nighttime traffic flow is only 20-35% of the total traffic flow. Contrasting statistics were found in USA [3], where 74% of pedestrian fatalities occurred in the dark and pedestrian deaths account for only 15% of all traffic fatalities in contrast to 22% on average in EU, with some major exceptions including Eastern European countries [4, 5]. In Poland, in the years 2014-2016, the number of pedestrian and bicyclist casualties accounted for over 40% of all fatalities [6]. Road safety is a key issue in many countries not only due to the number of deaths and injuries involved but also because of the costs. Disturbing statistics involving pedestrians deaths have contributed to many studies and analyses aimed at explorations of pedestrian crossing behaviour, explaining the causes of accidents and improving pedestrian safety at both uncontrolled and traffic light-controlled crossings. Cunbao [7] analysed pedestrian safety at uncontrolled mid-block crosswalks in relation to the number of vehicle lanes, traffic conditions and number of pedestrian–

vehicle conflicts. They established a model reflecting the impact of the number of driving lanes on pedestrian behaviour and safety. Similar research focusing on pedestrian behaviour at mid-block crossings was carried out by Chaudhari and others [8-11]. A survey conducted on midblock crossings enabled the development of regression models indicating that the pedestrian safety margin strongly depends on the vehicle speed, pedestrian speed and vehicle gaps, whereas pedestrians' age has distinctly lower impact. Hoareau and others [12-14] showed that to improve traffic safety, effective speed management is key. Keeping travelling speed at the level of under 50 km/h yields positive results in terms of pedestrian–vehicle accidents. The main conclusion of these investigations is that by decreasing the speed where pedestrians are at risk, the number of victims can be markedly reduced [15]. Investigations conducted in Hungary [16] focused on drivers' behaviour and investigated the effect of chosen road measures on the number of pedestrian-related accidents using before–after data. As a result, they found that crossings equipped with flashing yellow lights, refuge islands and traffic lights required car drivers to behave more appropriately. On the other hand, drivers' travel speed is most varied at crossings without a refuge island. Lee and Abdel [17] investigated pedestrian behaviour at signalized intersections and examined their behaviour in relation to the type of road crossing, pedestrian age, speed, obeying of traffic signals, etc. The simulator analysis of a driver–pedestrian interaction was carried out by Abkarian et al. [18]. The study looked at the driver–pedestrian interaction from the driver's perspective by quantifying the effects of different scenario variables on the driving behaviour of the participants using a driver simulator. They found that drivers' aggressive behaviour in the proximity of pedestrians significantly depends on velocity, presence of curb-side parking and the number of pedestrians crossing the street. Some of the studies dealt with the additional lighting systems at pedestrian crossings. Baleja et al. [19] described the criteria for the suitable additional lighting system on pedestrian crossings (horizontal and vertical illuminance) and described the choice of the colours of the light and its influence on visibility. The possibility of improvement of pedestrian visibility in relation to the correct value of illuminance and luminance ratios in the area of a pedestrian crossing was investigated by Blaha et al. [20].

In Poland, systematic studies of pedestrian behaviour and vehicle–pedestrian interactions are very limited, even though over 30 percent of all road fatalities involve pedestrians and around 34% of all accidents involving pedestrians occur at marked pedestrian zebra crosswalks [21]. This makes pedestrian crossing zones areas of elevated safety risk, and the need for improving the safety of vulnerable users has been underlined many times [22-23]. Investigations of pedestrian–vehicle interactions using digital footage at crossings located in urban roads with different safety measures validated the usefulness of video image analysis for assessing pedestrian safety [24]. Tomczuk et al. highlighted the importance of improving the visibility of pedestrians in crossing zones [25, 26]. They studied the luminance characteristics and lighting conditions. Investigating different lighting solutions used at pedestrian crossings, they compared the luminance, luminance contrast and effects of lighting of a pedestrian figure and found pedestrian visibility to be a decisive safety factor.

Despite numerous research studies on driver and pedestrian behaviours and their mutual interactions, little research has been devoted to investigations of crossings with additional lighting. Hence, the present study investigates the influence of zebra crossings with additional lighting on drivers' speed behaviour. To achieve these aims, speed measurements were conducted in free-flow driving conditions at pedestrian crossings in day and nighttime conditions.

2. TEST SITE AND SPEED MEASUREMENT CHARACTERISTICS

For detailed investigations, 6 zebra crossings with additional lighting systems located at single carriageways and operating for at least 18 months (marked as PC_1 to PC_6) and 2 zebra crossings without additional lighting system (reference crossings) were chosen (Table 1). Additionally lighted zebra crossings are equipped with two extra lamps - one on each side of the road. Fig. 1 shows examples of day and night views of the analysed pedestrian crossings. Speed measurements were conducted at two check points. The first one was located at a distance of 100-150m from the crossing location and reflected travel speed in a mid-block segment of a road (MB point). The second measurement point was set at the location of a pedestrian crossing (PC point). Speed measures were carried out during peak off periods. The speed data were obtained using a speed gun, and the accuracy of the equipment was +/- 3 km/h for speeds below 100 km/h. To minimize the effect of a surveyor with the radar gun on drivers' speed choice, the surveyor sat in a car that was parked by the roadside so as not to disturb drivers by its presence.

To fully ensure free flow driving conditions, the measurements were carried out without the presence of pedestrians on or near the pedestrian crossing. At each test site, on average, 120 vehicles were recorded. The previous results of travel speeds of drivers in relation to the road's cross section characteristics [27, 28] justified the selection of the study area and crossings located on single carriageways with two and four lanes (1x2, 1x4). The sections tested in this study included streets with speed limits of 30 km/h, 40 km/h to 50 km/h, and the width of the drive lanes varied between 3.00 and 3.25m. The results of the average speed, the 85th percentile of speed (V85), the standard deviation (SD) and percentage of drivers exceeding the speed limit (PSD%) are presented in Tables 1 and 2.

To examine the statistical significance of the speed data under different conditions, the analysis of Variance was utilized. The significance was verified using the Fischer–Snedecor test at the level of significance p=0.05 (95% of significance), and Levene's test was used to verify the assumption of homogeneity of variances.

Table 1

Geometry characteristics of the investigated pedestrian crossings

Pedestrian crossing	Cross section	Refuge island/median strip [m]	Speed limit [km/h]
PC_1	1x2	2.0	30
PC_2	1x2	-	40
PC_3	1x2	2.0	40
PC_4	1x2	2.0	50
PC_5	1x2	2.0	50
PC_6	1x4	-	40
PC_7	1x2	-	40
PC_8	1x2	2.0	50

Table 2

Descriptive statistics of speed data for pedestrian crossings during daytime conditions

Pedestrian Crossing	Speed Limit [km/h]	Daytime									
		V_{avg} [km/h]		V_{85} [km/h]		V_{15} [km/h]		SD		PSD%	
		MB	PC	MB	PC	MB	PC	MB	PC	MB	PC
PC_1	30	40.0	37.7	46.0	43.3	35.0	32.0	4.83	6.62	100.0	98.0
PC_2	40	42.5	39.3	48.0	45.3	38.8	35.0	4.54	4.99	62.0	35.0
PC_3	40	48.1	45.0	53.3	51.3	43.7	38.8	5.64	6.05	90.0	80.0
PC_4	50	59.5	56.9	64.3	63.3	54.8	52.0	5.91	5.67	97.5	92.5
PC_5	50	59.9	55.6	67.3	63.6	54.0	50.0	6.55	7.59	97.5	82.5
PC_6	40	56.5	51.5	63.3	57.3	49.0	45.0	6.48	6.41	100.0	97.5
PC_7	40	53.1	53.9	61.0	62.5	45.7	44.7	10.1	8.62	62.5	65.0
PC_8	50	61.5	55.2	71.0	61.0	52.0	49.0	8.61	7.33	92.5	70.0

3. RESEARCH RESULTS AND DISCUSSION

Based on the results obtained (Table 2 and 3), two main conclusions can be drawn. The first one is the prevailing excessive speed recorded in all investigated test sites. The second, even more disturbing, is that the average speeds (V_{avg}) in most cases were found to be higher under night conditions than during the daytime. This was rather unexpected due to obviously limited visibility conditions. On analysing 85th percentile, values above the default speed limit reach 41.2% (PC_6) in

MB locations and 35.3% (PC_1) in PC locations in the daytime. In the night-time conditions, these values reach, respectively, 53.5% (PC_6) and 50.6% (PC_6).

Table 3

Descriptive statistics of speed data for pedestrian crossings during night-time conditions

Pedestrian Crossing	Speed Limit [km/h]	Night conditions									
		V_{avg} [km/h]		V_{85} [km/h]		V_{15} [km/h]		SD		PSD%	
		MB	PC	MB	PC	MB	PC	MB	PC	MB	PC
PC_1	30	40.8	37.0	45.3	41.0	37.0	34.0	3.52	3.27	100.0	100.0
PC_2	40	43.7	40.4	50.3	47.0	37.0	34.8	6.46	6.17	67.0	42.5
PC_3	40	45.4	43.6	51.3	47.0	39.8	38.0	6.17	5.3	80.0	67.0
PC_4	50	57.9	54.7	62.3	59.3	51.8	49.0	5.74	5.34	90.0	80.0
PC_5	50	60.1	56.5	67.3	63.6	54.0	49.0	7.34	7.59	100.0	82.5
PC_6	40	63.6	60.5	74.0	70.6	56.5	53.8	6.94	7.55	100.0	100.0
PC_7	40	56.2	53.8	65.8	61.3	47.8	44.0	9.48	8.83	72.5	67.5
PC_8	50	62.2	56.6	69.6	64.6	53.0	48.5	8.31	8.96	100.0	75.0

Fig. 1. Day and night views: a) PC_2, b) PC_3 c) PC_6 and d) night view of the reference zebra crossing PC_8

Analysing the data presented in Fig. 2, a clearly positive tendency in speed reduction can be observed. Drivers' speeds at MB locations are higher compared with the values at PC points and, importantly, the results of ANOVA analyses showed that this reduction is statistically significant (Table 4). However, even this essential decrease in speed of many drivers still violates existing limits and does not comply with the traffic rules. This happens equally irrespective of the location of the test points and the time of day. At the PC locations, the percentage of speeding drivers varied from 35% to 98% (daytime) and from 42% to 100% (night-time conditions), while in MB points, these values were between 62% and 100%. A more in-depth examination of the data shows that it is extremely difficult for drivers to comply with and adjust their speed to a very low speed limit (PC_1, 30 km/h) and the very low speed limit set on multilane single-carriageway roads (PC_6, 40 km/h). A similar tendency was observed on the reference zebra crossings where majority of drivers exceeded the existed speed limits, and they didn't reduce their speed during approaching to the zebra at night-time conditions.

a) b)

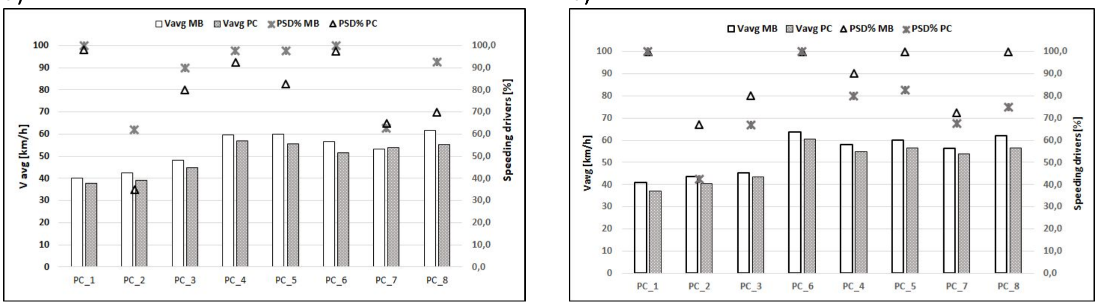


Fig. 2. Average speed and percentage of speeding drivers: a) daytime conditions and b) nighttime conditions

Focusing on the results of drivers' speed at PC locations, a similar phenomenon of drivers' ambiguous behaviour is shown in Fig. 3, which shows the average speeds under day and nighttime conditions and the intensity of speed reduction. It is clear that in half of the tested sites, the average speeds in the dark were higher than during the day. The maximum speed reduction within additionally illuminated pedestrian crossings reached 3.9% at PC_4 and was statistically insignificant (p=.0748), while at PC_7, the decrease in speed was also insignificant but lower and reached 0.2% (p=0.7427). The highest increase of speed reached 17.5% at PC_6 and was statistically significant (p=.0000). For the reference pedestrian crossing PC_8, the increase in speed was 2.5%, and this was statistically insignificant (p=0.2208). It is quite remarkable as the primary goal of the additional illumination, except for improving the visibility of pedestrians, is to improve drivers' attention when approaching a crossing and reduce the speed. The obtained results do not confirm that this goal has been achieved. Limited visibility conditions at night did not effectively or significantly influence drivers' speed reduction, and this should be a matter of serious concern for road authorities. This lack of statistical significance is clear from the results of ANOVA presented in Table 5.

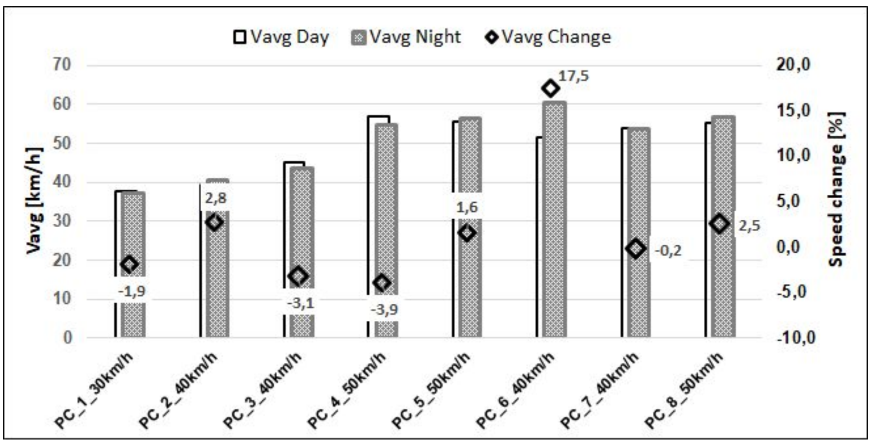


Fig. 3. Average speeds and speed reduction at PC locations

Table 4

Results of ANOVA for speed reduction between MB and PC locations

PC_1	PC_2	PC_3	PC_4	PC_5	PC_6
Day					
F =					
3.2234	8.7120	5.4397	3.9486	9.1235	11.9174
p =					
.0764	0.0041	0.0222	0.0504	0.0034	0.0009
Nighttime					
F =					
24.3763	5.4594	2.0143	6.6639	4.8520	3.3442
p =					
0.0000	0.0220	0.1598	0.0117	0.0305	0.0712

Table 5

Results of ANOVA for speed reduction between day and night conditions at PC locations

PC_1	PC_2	PC_3	PC_4	PC_5	PC_6
F =					
.2868	.7683	1.3001	3.2608	.3321	33.8656
p =					
.5937	.3834	.2576	.0748	.5660	.0000

Homogeneity of driving speeds is an important variable in determining road safety, and more homogeneous driving speeds increase road safety [29]. Hence, it could be expected that better visibility under night conditions of zebra crossings would positively influence speed uniformity. In this study, speed uniformity (SU) was conceptualized as a difference in values between V85 and V15 (Fig. 4a). The data obtained reveal that in the absence of any restrictions of speed choice (other than administrative regulations), the ranges of speeds are equally diverse in daytime and nighttime conditions, with no clear improvements at nighttime. Comparing the SU values obtained for pedestrian crossings with those for reference zebra crossings, the speed homogeneity presents better results, but this advantage disappears under night conditions – SU values remain at a similar level within the comparable speed limits.

To exclude possible dependency of SU values on the posted speed limit, the ratio of speed uniformity (R_{SU}) was calculated according to equation 1.

$$R_{SU} = \frac{V_{85} - V_{15}}{SL} \tag{1}$$

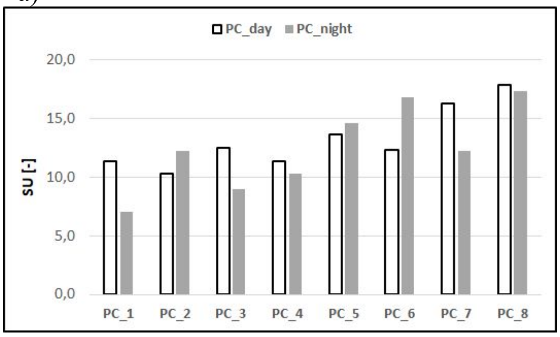
where SL – posted speed limit.

The R_{SU} values shown in Fig. 4b reveal, similar to SU values, that speed uniformity does not depend on the time of day and does not become more homogeneous in the dark. In the case of three test sites (PC_1, PC_3, PC_4), speed uniformity shows better characteristics under nighttime conditions, but in the other three test sites (PC_2, PC_5, PC_6), the reverse trends can be observed. Moreover, in the case of PC_4 and PC_5, the R_{SU} values were almost the same at night and in the daytime. A very similar unclear tendency is observed within reference pedestrian crossings – in the case of PC_7, the speed is more homogeneous during the day, which is in contrast to PC_8, where a lower speed variation is achieved under nighttime conditions. Based on the speed uniformity analyses, it can be stated that no significant improvement has been achieved due to additional lighting in the behaviour of drivers under night-time conditions.

4. CONCLUSIONS

The main goals of installing additional lighting systems on pedestrian crossings are to improve their visibility in the dark and make drivers aware that they are approaching a place of elevated road risk. This, in return, should contribute to improving pedestrians safety. The influence and effectiveness of such installations on drivers' speed behaviour have been assessed in this paper. For this purpose, six pedestrian crossings with additional illuminations operating for 18 months were chosen and speed measurements in daytime and night-time conditions were performed. The results were obtained on single carriageways in real conditions reflecting free flow speed.

a)



b)

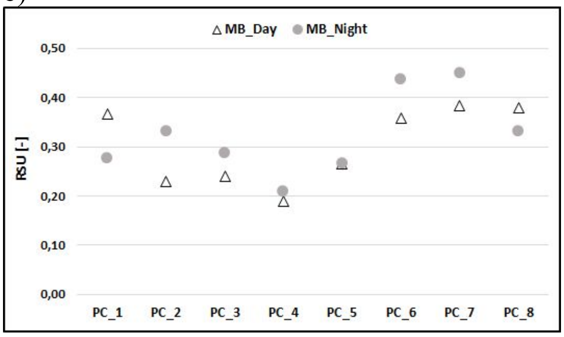


Fig. 4. Speed homogeneity expressed by: a) SU values and b) the R_{SU} ratio

The main conclusion of this the study is that pedestrian crossings with additional lighting do not have an impact on drivers as much as could be expected and drivers' behaviour does not differ significantly from that observed in the vicinity of zebra crossings without such systems. In general, the results showed a positive attitude of drivers whose speed was reduced at the pedestrian crossing, and the decrease in speed in most cases was significant during daytime and nighttime conditions. However, despite the reduced speed, average speeds still remained beyond the posted speed limit, and the 85th percentile was distinctly higher than the average values. The influence of additional lighting on speeding drivers after dark is also unsatisfactory. While it could be expected that the number of drivers violating traffic rules would be reduced, the present results showed no effect terms of this as the range of speeding drivers recorded at zebra crossings with additional lighting at nighttime conditions was higher than during a day. This behaviour is especially disturbing under nighttime conditions when good visibility of a crossing plays an important role in alerting drivers that they are approaching a place of increased risk. Another outcome of this study was related to the speed uniformity. It was found that the presence of additional illumination at zebra crossings does not lead to any improvements and drivers' travel speed does not become more homogeneous under nighttime conditions.

The findings of this paper show that the installation of additional illumination at pedestrian crossings may not be a sufficient solution in itself to significantly improve vulnerable users' safety as long as speed is a prevailing contributor in the severity of accidents. Based on the aforementioned outcomes, it must be stated that to provide an effective solution that can ensure that drivers reduce their speed considerably, additional lighting systems should be supplemented with physical or video surveillance restrictions or LED light connected to warning lamps and motion sensors activated by approaching pedestrians.

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References

1. THORN. *Lightning for pedestrian crossings. Identification, Visibility, Safety*. Available at: http://www.thornlighting.at/PDB/resources/teaser/FR/TLG_IVS_LED.pdf.

2. *European Road Safety Observatory ERSO*. Traffic Safety Basic Facts 2018. Main Figures. 2018. Available at: https://ec.europa.eu/transport/road_safety/sites/roadsafety/files/pdf/statistics/dacota/bfs2018_main_figures.pdf.
3. U.S. Department of Transportation. NHTSA's National Center for Statistics and Analysis. *Traffic Safety Facts. Pedestrians*. Washington. 2019. Available at: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812681.
4. European New Car Assessment Programme, EuroNCAP. European New Car Assessment Programme - 2020 ROADMAP. 2015. Available at: http://euroncap.blob.core.windows.net/media/16472/euro-ncap-2020-roadmap-rev1-march-2015.pdf.
5. Eurostat statistics. *Road accident fatalities*. 2018. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php/Road_accident_fatalities_-_statistics_by_type_of_vehicle#Road_accident_fatalities:_46_.25_involve_passenger_car_occupants_while_pedestrians_accounted_for_21.2_.25_of_road_traffic_deaths.
6. Police Headquarters. Traffic Department. *Road accidents in Poland*. 2018. Available at: http://statystyka.policja.pl/st/ruch-drogowy/76562,Wypadki-drogowe-raporty-roczne.html.
7. Cunbao, Z. & Feng, C. & Yuanyuan, W. Evaluation of pedestrian crossing behavior and safety at uncontrolled mid-block crosswalks with different numbers of lanes in China. *Accident Analysis & Prevention*. 2019. Vol. 123. P. 263-273.
8. Chaudhari, A. & Shah, J. & Arkatkar, S. & Joshi, G. & Parida, M. Evaluation of pedestrian safety margin at mid-block crosswalks in India. *Safety Science.* 2018. Vol. 119. P. 188-198. DOI: https://doi.org/10.1016/j.ssci.2018.12.009.
9. Raghuram, K.B. & Vedagiri, P. & Rathi, N. Models for pedestrian gap acceptance behaviour analysis at unprotected mid-block crosswalks under mixed traffic conditions. *Transportation Research Part F: Traffic Psychology and Behaviour.* 2015. Vol. 32. P. 114-126.
10. Raghuram, K.B. & Vedagiri, P. Proactive pedestrian safety evaluation at unprotected mid-block crosswalk locations under mixed traffic conditions. *Safety Science*. 2016. Vol. 89. P. 94-105.
11. Ishaque, M.M. & Noland, R.B. Behavioural Issues in Pedestrian Speed Choice and Street Crossing Behaviour: A Review. *Transport Reviews*. 2008. Vol. 28(1). P. 61-85. DOI: 10.1080/01441640701365239.
12. Hoareau, E. & Newstead, S. & Cameron, M. An evaluation of the default 50 km/h speed limit in Victoria. *Report no. 261*. 2006. Monash University, Accident Research Centre, Clayton.
13. Rosén, E. & Stigson, H. & Sander, U. Literature review of pedestrian fatality risk as a function of car impact speed. *Accident Analysis and Prevention*. 2011. Vol. 43(1). P. 25-33.
14. Elvik, R. A re-parameterisation of the Power Model of the relationship between the speed of traffic and the number of accidents and accident victims. *Accident Analysis and Prevention*. 2013. Vol. 50. P. 854-860.
15. Rosén, E. & Sander, U. Pedestrian fatality risk as a function of car impact speed. *Accident Analises & Prevention*. 2009. Vol. 41. P. 536-542.
16. Mako, E. & Szakonyi, P. Evaluation of Human Behaviour at Pedestrian Crossings. *Transportation Research Procedia*. 2016. Vol. 14. P. 2121-2128.
17. Lee, C. & Abdel-Aty, M. Comprehensive analysis of vehicle–pedestrian crashes at intersections in Florida. *Accident Analysis & Prevention*. 2005. Vol. 37(4). P. 775-786.
18. Abkarian, H.O.H. & Abkarian, H. & Abou-Zeid, M. & Kaysi, I.A. Analyzing driver-pedestrian interaction in a mixed-street environment using a driving simulator. *Accident Analysis & Prevention.* 2017. Vol. 108. P. 56-65.
19. Baleja, R. & Bos, P. & Novak, T. & Sokansky, K. & Hanusek, T. Increasing of visibility on the pedestrian crossing by the additional lighting systems. *Materials Science and Engineering.* 2017. Vol. 236. DOI: 10.1088/1757-899X/236/1/012099.
20. Blaha, Z. & Sokansky, K. & Novak, T. Solution of lighting for pedestrian crossing to increase their visibility. *15th International Scientific Conference on Electric Power Engineering (EPE).* 2014. DOI: 10.1109/EPE.2014.6839512.

21. Olszewski, P. & Szagała, P. & Wolański, M. & Zielińska, A. Pedestrian fatality risk in accidents at unsignalized zebra crosswalks in Poland. *Accident Analysis & Prevention.* 2015. Vol. 84. P. 3-91.
22. Jamroz, K. & et al. *Ochrona pieszych – Podręcznik dla organizatorów ruchu pieszego* [In Polish: *Pedestrian protection – Handbook for managers of pedestrian traffic*]. National Road Safety Council. 2014. Available at: https://www.krbrd.gov.pl.
23. Jamroz, K. & et al. Metodologia systematycznych badań zachowań pieszych i relacji pieszy-kierowca wraz z przeprowadzeniem badań pilotażowych. Etap I. [In Polish: *Methodology of systematic research on pedestrian behavior and pedestrian-driver relations along with conducting pilot studies. Stage I*]. 2015. Available at: https://www.krbrd.gov.pl/files/file_add/download/234_piesi-badania-pilotazowe.pdf.
24. Szagała, P. & Buttler, I. & Czajewski, W. & Olszewski, P. Safety Assessment of Pedestrian Crossings with Video Analysis. *27th ICTCT Workshop.* 2014. DOI: 10.13140/2.1.2680.6087.
25. Tomczuk, P. & Chrzanowicz, M. & Mackun, T. Methodology for assessing the lighting of pedestrian crossings based on light intensity parameters. *MATEC Web of Conferences.* 2017. No 122:01008. P. 1-8. DOI: 10.1051/matecconf/2017122.
26. Tomczuk, P. & Jamroz, K. & Mackun, T. & Chrzanowicz, M. Lighting requirements for pedestrian crossings – positive contrast. *MATEC Web of Conferences*. 2019. Vol. 262(3a): 05015. P. 5-15. DOI: 10.1051/matecconf/2019262.
27. Ziolkowski, R. Investigations of driver's speed at unsignalised pedestrian crossings. *MATEC Web of Conferences.* 2019. DOI: 10.1051/matecconf/201926205018.
28. Szczuraszek, T. *Prędkość pojazdów w warunkach drogowego ruchu swobodnego*. Studia z zakresu inżynierii. PAN KILiW. Warsaw. [In Polish: *Speed of vehicles in free road traffic conditions*. Engineering studies].
29. Van Nes, N. & Brandenburg, S. & Twisk, D. Improving homogeneity by dynamic speed limit systems. *Accident Analysis & Prevention.* 2010. Vol. 42(3). P. 944-52. DOI: 10.1016/j.aap.2009.05.002.

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