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Pedestrian safety assessment with video analysis

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Abstract

Pedestrian fatality rate in Poland of 30 deaths per year per million population was the second highest among the EU countries in 2013. In the years 2007-2013 some 13% of pedestrian fatalities and 26% of injuries occurred at unsignalized pedestrian crossings where pedestrians should theoretically be safe. The paper presents results of research project MOBIS which was aimed to develop surrogate safety measures based on detection of dangerous situations or near-accidents. Within the project, pedestrian and vehicle traffic was recorded at four pedestrian crossings in Warsaw and Wrocław, for a period of approximately 2 months per crossing. Motion trajectories of vehicles and pedestrians were determined and certain parameters describing the pedestrian-vehicle encounters calculated. The average number of such encounters was over 1000 per day in both Warsaw and Wrocław. Dedicated video and data analysis algorithms were used to extract interactions that met certain criteria. To this end the following parameters were used: velocity profiles of pedestrians and vehicles, minimum distance between the participants, deceleration during braking, etc. These variables were used to develop surrogate safety indicators for pedestrian-vehicle encounters. A classification of encounters based on the characteristics of pedestrian-vehicle interaction is also proposed. Within the project certain solutions for increasing pedestrian safety at road crossings were installed and evaluated. These included speed cushions and flashing lights warning the drivers about pedestrian presence that were either mounted on traffic poles or embedded in the road surface. The evaluation of these solutions will be based on surrogate safety measures developed in the MOBIS project.

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1. Introduction

Pedestrian fatality rate in Poland of 30 deaths per year per million population was the second highest among the EU countries in 2013. In the year 2014 on Polish roads 1116 pedestrians were killed (35% of all traffic fatalities) and 8398 were injured (20%). Accidents involving pedestrians most frequently occur in built-up areas where over 60% of all pedestrian fatalities and more than 90% of injuries are recorded. In the years 2007-2013 some 13% of pedestrians were killed and 26% injured at unsignalised pedestrian crossings where pedestrians should theoretically be safe (Olszewski et al. 2015). This raised serious concerns and improvement of pedestrian safety became one of the priority goals of the Polish National Road Safety Programme (2013).

Assessment of pedestrian safety based on the number of accidents is no longer sufficient. Accidents occur rarely and their number is expected to gradually decrease in the coming years, along with the improvement of road safety. Therefore, development of surrogate measures that are based on detection of traffic conflicts, or near-accidents, seems to be necessary. According to the literature, it is estimated that for one pedestrian-vehicle accident there are around 3000 conflicts and thus it is possible to conduct reliable safety assessment based on relatively short observation periods (Laureshyn et al. 2010). Video processing and analysis methods have recently started to be used to this end (e.g. Ismail et al. 2009).

In the classical Swedish conflict method developed in 1970s, conflict was defined as the situation in which two road users approach each other in time and space in such a way that an accident is highly probable if their movements remain unchanged (Laureshyn et al. 2010). In the Dutch conflict technique called “Doctor” (van der Horst and Kraay 1986) in addition to conflicts as defined above, situations when two road users crossed paths within a very short time are also regarded as dangerous. Conflict identification is based on estimated time to collision at the moment when an evasive action was initiated. This value, called “time-to-accident” together with vehicle speed is used to determine the seriousness of a conflict situation. As these parameters are rather difficult to determine precisely based on automatic video analysis, surrogate safety measures based on parameters other than the number of serious conflicts were proposed by other researchers. In the British method of assessing pedestrian safety (Kaparias et al. 2010), distance to collision as well as severity and complexity of evasive action are also considered. The Italian-Spanish method (Cafiso et al. 2011) proposed a new Pedestrian Risk Index which is based on estimated probability of accident occurrence and the seriousness of its probable consequences.

2. Project MOBIS

2.1. *Aims of the project*

The paper presents results of research project MOBIS (Szagała et al. 2014), funded by the Polish National Centre for Research and Development (NCBR) and carried out by Warsaw University of Technology, Motor Transport Institute and Neurosoft Ltd. The aim of the project was to develop and test a method of assessing safety of pedestrian road crossings using automatic video image analysis. During the project, field tests were conducted at several zebra crossings with different configurations. Pedestrian and vehicle traffic was recorded in order to capture and analyse pedestrian-vehicle encounters, some of which could be dangerous to pedestrians. Statistical analysis of dangerous situations was conducted in order to develop surrogate safety indicators, appropriate for pedestrian crossings. It is hoped that safety assessments can then be made based on relatively short observation periods and will provide an objective evaluation of measures used to improve pedestrian safety.

The paper presents findings from the project, based on field tests conducted in Warsaw and Wrocław. Pedestrian and vehicle traffic was recorded at selected sites before and after installation of safety measures which included active signage systems: SignFlash (SF) and Levelite (LL). According to Retting et al. (2003) active signage systems which involve flashing lights warning drivers about the crossing location and pedestrian presence help to improve safety by increasing pedestrian visibility and inducing drivers to lower their speeds. According to American (e.g. Prevedouros 2001, Turner et al. 2006) and Israeli (Hakkert et al. 2002) field studies, active signage systems are quite effective in decreasing vehicle speeds and improving driver behaviour in terms of willingness to give way to pedestrians.

2.2. Data collection

Within the project, pedestrian and vehicle traffic was recorded at four pedestrian crossings in Warsaw and Wrocław, for a period of up to 4 months per crossing (less than 1 month of preselected footage was used later for detailed analysis). According to police records, at both locations 5 pedestrian-vehicle accidents occurred during the period 2006-2011. The zebra crossing at the Warsaw site was located on a 4-lane undivided road with a refuge island. All lanes were monitored in the direction of the incoming traffic (direction East-West was named POW and West-East was named RAD). Layouts of the test sites in Warsaw are shown on Fig. 1.

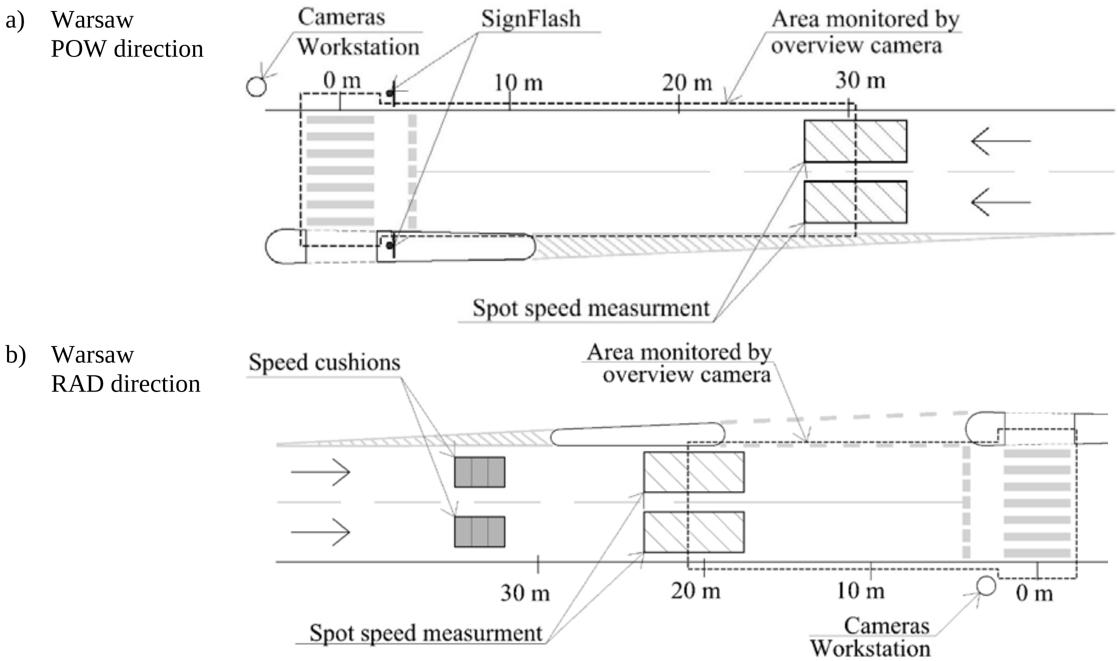

Fig. 1. Layouts of the test sites in Warsaw.

The Wrocław site was a two-lane undivided road with two zebra crossings in the vicinity of an intersection. Each pedestrian crossing was fully covered by the vision system, but due to technical reasons the vehicle traffic was monitored from only one direction for each zebra (direction East-West was named CEN and West-East was named SWO). Fig. 2 shows the layout of the zebra crossing sites in Wrocław.

A dedicated video recording and processing system was installed for each site and finally a batch of approximately three weeks of data from each crossing (except for RAD – due to technical problems) was selected for further processing. The recording system, installed at each crossing and in each direction, consisted of:

- a digital overview camera covering the area of the pedestrian crossing and its approach road section of around 30-40 m;
- one digital directional camera per lane, covering road section approximately 3.5 m wide and 6 m long, located within the approach area monitored by the overview camera;
- a workstation used for recording and preliminary analysis of the digital video signal taken from the cameras and enabling remote control and diagnostics.

Table 1 summarizes data collected during the surveys.

Table 1. Summary of the collected data.

Site	Period		No of days with	No of days with	Safety measure
	from	to	spot speed data	trajectories	used
Warsaw POW	23.09.2013	19.12.2013	49	23	SignFlash (SF)
Warsaw RAD	23.09.2013	19.12.2013	59	4	Speed cushions
Wrocław CEN	01.08.2014	27.11.2014	103	24	LeveLite (LL) continuous
Wrocław SWO	01.08.2014	27.11.2014	113	24	LeveLite (LL) activated

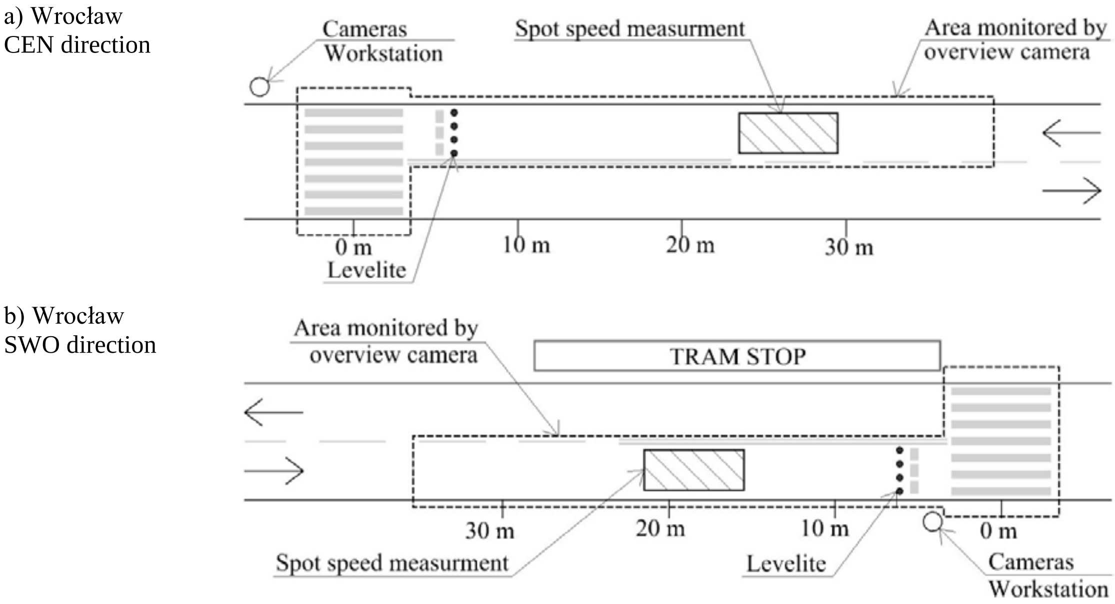

Fig. 2. Layouts of the test sites in Wrocław.

2.3. Video analysis

Video-based detection and tracking of vehicles and people is often used due to its versatility, low cost and content-rich data that can be easily understood by humans. This is particularly important in conflict analysis, where semi-automatic systems require pre-configuration and post-verification by human experts. The video recording and processing system used within the project required a calibration procedure that was applied to the cameras to ensure minimal distortions in object detection and tracking. Initial processing for the purpose of pedestrian detection and dynamic signage control was done on site in real time, while precise object tracking and further analysis was performed later off-line.

Vehicles are initially detected by the long range cameras 20-30 meters before the crossing and their instantaneous position and velocity is calculated. This triggers the tracking algorithm working on the overview camera sequence of images. It uses the front of the detected vehicle along with its licence plate as a characteristic determinant to be tracked. Trajectories of vehicles obtained in this way are modelled by cubic splines with certain constraints set on vehicles' position, velocity and acceleration. In the end, trajectories of vehicles with an average position error of less than 10 cm in the area of the zebra crossing are generated. Practically all the vehicles with discernible licence plates were correctly detected and nearly all of them were tracked properly, provided they were not occluded by other vehicles or heavy weather conditions. Yet another source of incorrect trajectories was sudden change of car dynamics, but such cases were very rare (less than 0.5%) and easy to filter out from further processing.

Pedestrians are detected and tracked exclusively in the overview camera images with a motion detection algorithm based on a Gaussian Mixture Model (GMM). Initial trajectories can be quite rough so they are iteratively refined by employing the likelihood probability test applied to the GMM models of pedestrian and background around the initial pedestrian position. As the result, in good visibility conditions (daytime, no shadows, occlusions or precipitation), smooth trajectories of pedestrians are generated. Unfortunately, since the method applied relies on motion detection only, all the moving objects within the crossing (such as animals, vehicles' headlights, reflections or shadows) are treated as potential pedestrians. This generates a lot of false detections and false trajectories occur (approximately 10% for Warsaw and even 50% for Wrocław where the observed area was larger). They can be, however, easily excluded from further processing based on their characteristics that differs significantly from a trajectory of a real pedestrian crossing the street. For this purpose random trees classifiers – each trained with over 1000 manually labelled trajectories – were used for each crossing with error rate less than 1 percent.

As pedestrian detection is based exclusively on motion analysis, some trajectories have a tendency of splitting when there is no motion (e.g. pedestrian stops at a curb) or motion is hard to detect (e.g. dark or white dressed pedestrians disappearing on zebra stripes). Sometimes, on the other hand, trajectories of two or more pedestrians that walk close to each other are merged into a single trajectory. This is particularly evident with groups of people, who are usually treated as one person or just two or three in case of big and dispersed groups. The latter are rather unlikely to be a part of a traffic conflict, so they can be represented as a single object or even disregarded. It is important, however, to track single pedestrians, who are most often exposed to danger. The algorithm applied is capable of correctly tracking 87% individual pedestrians and this number rises to 99% if pedestrians in groups are excluded from the analysis.

Strong sunshine as well as fog, rain or snow had a negative effect on motion detection and often produced distorted trajectories. In order to minimize the influence of incorrect data on statistical analysis, such days were removed from processing.

3. Analysis of pedestrian-vehicle interactions

3.1. Traffic characteristics

The volume of pedestrians crossing the street between 7 am and 7 pm at both crossings in Warsaw ranged from 150 to 420 persons per hour. Pedestrian traffic in Wrocław was significantly lower (see Table 2), but the vehicle flow was clearly higher. As the result, the average number of pedestrian-vehicle encounters was similar and amounted to 1100 for Warsaw and 1000 for Wrocław, in both directions.

Table 2 presents pedestrian and vehicular traffic characteristics of the particular sites. Unfortunately, due to technical reasons most of the pedestrian data from the overview camera at the RAD site turned out to be corrupted and thus this site was excluded from further analysis of vehicle-pedestrian encounters.

Table 2. Traffic characteristics of the test sites.

Site	Daily veh. traffic [vehicle/day]	Daily ped. traffic [person/day]	Peak hour of pedestrian traffic		
			Hour	Ped. flow [person/h]	Veh. flow [vehicle/h]
Warsaw POW	4693	2663	16:00-17:00	235	390
Warsaw RAD	5303	2663	16:00-17:00	235	376
Wrocław CEN	7600	1093	15:00-16:00	93	476
Wrocław SWO	7150	514	15:00-16:00	51	568

3.2. Parameters describing pedestrian-vehicle encounters

A pedestrian-vehicle encounter is defined as a situation when both parties are within the field of view of the overview camera used in the system. This usually means a distance of about 30 meters. It must be noted, however, that an encounter is not necessarily a conflict, as when the distance between participants is long there might be no need of taking evasive actions to avoid collision.

Certain parameters describing the pedestrian-vehicle encounters can be calculated. Dedicated video and data analysis algorithms were used to extract only these interactions that met the conflict criteria. To this end the following parameters were used: trajectories and velocity profiles of pedestrians and vehicles, minimum distance between the participants, deceleration during braking, etc. These variables are being used to develop surrogate safety measures for pedestrian crossings.

3.3. Classification of pedestrian-vehicle encounters

Video material recorded at the test sites by the overview cameras was the basis for a more detailed examination of vehicle-pedestrian encounters. These are defined as situations where both vehicles and pedestrians were simultaneously present in the area being monitored. All the encounters were classified into the following categories (see Fig. 3):

- Situation A1 - vehicle passes directly in front of a pedestrian who is on the zebra crossing,
- Situation A2 - vehicle passes directly in front of a pedestrian who is on the sidewalk,
- Situation B - vehicle passes immediately behind a pedestrian who is still on the zebra crossing,
- Situation C - vehicle clearly slows down or stops on the approach to the pedestrian crossing.

Situations A1 and B imply that drivers are likely to be violating the law as pedestrians have the right of way once they are on the zebra crossing. Situation C represents drivers properly giving way to pedestrians. The total numbers of registered encounters and their distributions are shown in Table 3.

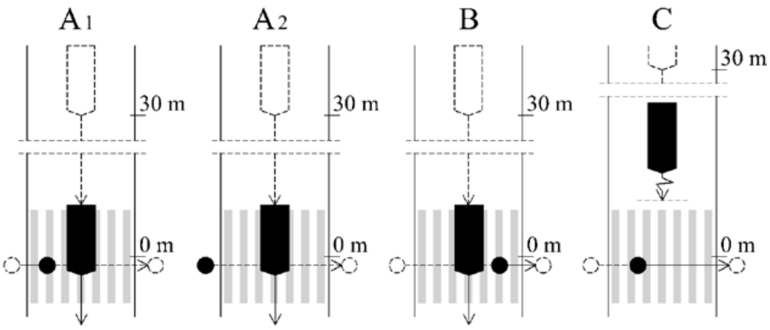

Fig. 3. Sketches of analysed situations.

Table 3. Numbers and distribution of registered encounters.

Site	Stage	Total number of encounters	Encounters per day	A1	A2	B	C	Total
Warsaw POW*	without SF	7088	591	3.9%	16.2%	15.4%	64.5%	100%
Warsaw POW*	with SF	6418	583	4.6%	15.9%	14.5%	65.0%	100%
Wrocław CEN	without LL	5388	770	11.4%	44.2%	7.6%	36.8%	100%
Wrocław CEN	with LL	5865	838	14.0%	36.4%	7.2%	42.4%	100%
Wrocław SWO	without LL	4425	316	15.1%	40.8%	7.2%	36.9%	100%
Wrocław SWO	with LL	3289	329	13.7%	33.9%	9.4%	43.0%	100%

*(both lanes)

4. Safety indicators

4.1. Danger perception survey

Majority of commonly used methods for studying road safety are based on detecting conflict situations and calculating certain safety measures/indicators such as: Time to Accident (TA), Time to Collision (TTC), Post Encroachment Time (PET), etc. Other methods measure the reaction necessary to evade the collision – e.g. Deceleration to Safety Time (DST). However, sometimes these parameters cannot be automatically calculated.

Therefore, one of the objectives of the MOBIS project is to define a new surrogate safety indicator of vehicle–pedestrian encounters. This index should describe pedestrian safety in an automated way, based exclusively on video recordings on a given crossing. For this purpose, a survey of danger perception was conducted with 32 video clips of different vehicle-pedestrian interactions (16 of them were of type A1 and 16 of type B). These situations were selected as they represented cases when drivers were violating the traffic rules. They were selected based on minimum pedestrian-vehicle distance (S, m), vehicle speed at the minimum pedestrian-vehicle distance (V_V, m/s) and are typical encounters where driver does not yield to pedestrian. Respondents watched these situations and assigned "danger scores" from 1 through 10 for each of them to describe pedestrian danger perception (where 1 denoted an absolutely safe situation and 10 – a highly dangerous one). In the end, 135 completed questionnaires were collected and mean respondents' scores for situation type A1 and B were calculated and are shown in Figure 4. It can be seen that high scores are associated with small minimum distances and vice versa.

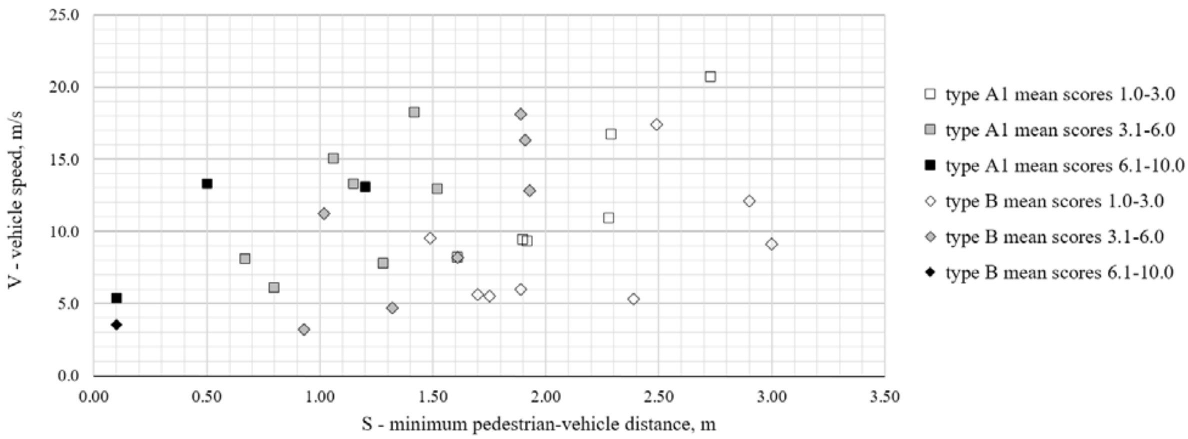

Fig. 4. Mean scores for situation type A1 and B based on the conducted poll.

4.2. Regression analysis

The main objective of this study is to investigate how known parameters by which situations were selected affect the assessment of pedestrian safety according to the conducted survey. In order to find which factors have impact on respondents' scores (scores have been scaled from a range of 1-10 to a new range of 0-1), a regression analysis of vehicle and pedestrian speed at the minimum pedestrian-vehicle distance was performed using three different functions. The equations used had the following general form:

$$W_1 = a \cdot c^X \cdot {V_V}^d \cdot {V_P}^f \cdot e^{S \cdot g} \quad (1)$$

$$W_2 = a \cdot c^X \cdot {V_V}^d \cdot e^{S \cdot f} \quad (2)$$

$$W_3 = a \cdot c^X \cdot e^{d \cdot V_V + S \cdot f} \tag{3}$$

where:
W– danger indicator; S – minimum pedestrian-vehicle distance (m); V_V – vehicle speed at the minimum pedestrian-vehicle distance (m/s); V_P – pedestrian speed at the minimum pedestrian-vehicle distance (m/s); X – dummy variable for type of encounter: equal to 0 when type is A1 and 1 for type B; a, c, d, f, g – parameters to be calibrated.

Next, each of these equations can be presented in a linear form. As an example, linear form of equation (1) is shown below:

$$lnW_1 = lna + lnc \cdot X + d \cdot lnV_V + f \cdot lnV_P + g \cdot S \tag{4}$$

The results of regression analyses are presented in Table 4. Both the vehicle speed and the minimum pedestrian-vehicle distance were statistically significant at 5% level (p-value < 0.05) for each of the analysed equations.

Table 4. Regression analysis results.

	W_1			W_2			W_3		
Variable	Coefficients	t Stat	P-value	Coefficients	t Stat	P-value	Coefficients	t Stat	P-value
Constant (lna)	-1.591	-4.664	0.000	-1.505	-4.850	0.000	-0.840	-4.797	0.000
X	0.315	2.130	0.050	0.278	2.068	0.048	0.238	1.852	0.075
lnV_V	0.591	3.976	0.001	0.575	3.967	0.000	-	-	-
V_V	-	-	-	-	-	-	0.058	4.069	0.000
lnV_P	0.155	0.639	0.717	-	-	-	-	-	-
S	-0.820	-8.365	0.000	-0.812	-8.445	0.000	-0.792	-8.572	0.000
R^2	0.731			0.727			0.732		

Table 4 shows that for the W_1 and W_3 equations, pedestrian speed V_P and type of encounter X were not statistically significant at 5% level (p-value > 0.05). Thus, it can be concluded that W_2 equation that takes vehicle speed V_V and minimum pedestrian-vehicle distance S into account is the one that most accurately describes pedestrian safety as assessed in the survey. As the result, the W_2 function has the final form:

$$W_2 = 0.22 \cdot 1.32^X \cdot {V_V}^{0.58} \cdot e^{-0.81 \cdot S} \tag{5}$$

Equation (5) shows that "danger perception" indicator W increases non-linearly with the vehicle speed and with decreasing minimum pedestrian-vehicle distance. Type B encounters are perceived as about 30% more dangerous than type A1, with the same minimum distance and vehicle speed.

The results of danger perception survey presented in this section should be treated with caution as it has been found that human perception of risk is very subjective and can be biased (Elvik 2015). For example, the perceived increase of risk associated with increase of vehicle speed is lower than actually measured increase in risk.

4.3. Safety improvement measures

Certain measures for increasing pedestrian safety at the surveyed road crossings were installed and evaluated. At one approach at the Warsaw test site (POW direction) the SignFlash system (SF) was installed as an example of an active signage system. It was equipped with sensors activating yellow flashing lights when pedestrians crossed the road (Czajewski et al. 2013). At the other Warsaw site approach (RAD direction) speed cushions were installed at each traffic lane. Traffic was registered before and after the installation. Some 23 days of favourable weather conditions (overcast, no shadows or rain) were selected for in-depth analysis – 12 days without the SF system and 11 days with the SF.

The Wrocław site was selected to test another type of active signage – Levelite (LL), i.e. flashing lights embedded in the road surface. Two modes of its operation were tested at two Wrocław test sites: continuous flashing in the CEN direction and pedestrian activation in the SWO direction.

4.4. Speed measurement

The directional cameras determined vehicles' speeds by measuring the distance travelled between subsequent frames of the recorded video. The cameras underwent a calibration process in order to determine the three parameters – two camera tilt angles (external parameters) and a scaling factor (an internal parameter dependent on focal length). The measurements were taken between 17 and 32 m upstream of the crossing. Such a measurement does not allow for precise assessment of the drivers' behaviour but they allow for assessing the impact of the introduced improved safety measures on speed. The spot speeds were analysed at four sites: Warsaw direction POW (lane L1 and L2), Warsaw direction RAD (lane L1 and L2), Wrocław direction CEN and Wrocław direction SWO. Table 5 shows the analysis results aggregated in 1-hour intervals.

Table 5. Vehicle spot speed analysis for the four sites.

Site	Safety measure	Sample size [hours]	Mean traffic volume [veh/h]	Mean speed [km/h]	Speed SD [km/h]
Warsaw POW L1	none	648	110	45.1	3.82
	SignFlash	535	101	43.9	4.13
Warsaw POW L2	none	648	92	50.5	6.05
	SignFlash	535	84	49.5	6.27
Warsaw RAD L1	none	648	128	41.8	4.42
	Speed cushions	790	123	29.6	3.66
Warsaw RAD L2	none	646	94	32.9	5.95
	Speed cushions	788	93	24.4	4.01
Wrocław CEN	none	1 782	307	48.8	9.63
	LeveLite	700	341	42.7	9.81
Wrocław SWO	none	1 851	296	45.5	7.36
	LeveLite	864	303	43.4	8.90

It could be noticed that for all the sites the average speeds calculated for "with safety measure" periods are lower than those calculated for "without safety measure" periods. As expected, the most significant speed reduction was achieved for speed cushions installed at Warsaw RAD site. It is also worth noticing that the values of standard deviations of speeds derived for Wrocław sites are higher than at the Warsaw sites. This is mainly due to different cross-sections (4 lane road divided with a refuge island in Warsaw and two-way two-lane road in Wrocław).

It is important to note that the speeds were analysed for all vehicles, not only those encountering pedestrians. It could be expected that differences in speeds calculated only for vehicles encountering pedestrians are bigger than those presented in the table. Another reservation is that the analysis presented in Table 5 does not take into account the effect of traffic volume on speeds.

5. Conclusions

The results obtained from video analysis of the material recorded at the test pedestrian crossing sites in Warsaw and Wrocław show that both the recording system and the analytical algorithms used allow us to detect and determine vehicle trajectories with sufficient accuracy. However, detection and tracking of pedestrians pose more problems, especially under difficult weather and lighting conditions. An improved offline algorithm allows for a high pedestrian detection rate and promises to increase the accuracy of mapping pedestrian trajectories.

Analysis of spot vehicle speeds before the pedestrian crossing shows that both systems of active signage: SignFlash and Levelite cause a statistically significant reduction of the mean speed of vehicles approaching the crossing. As expected, the effect of speed cushions is even greater.

A method has been developed for automatic detection of situations such as: dynamic/abrupt breaking in front of a pedestrian and passing directly in front or behind a pedestrian at high speed. A reduction in the proportion of such situations during the period when active signage systems were in operation suggests that they have a moderately positive influence on driver behaviour and thus increase pedestrian safety.

The method used for determining pedestrian and vehicle trajectories allows for computation of Time to Collision (TTC) and Post Encroachment Time (PET) parameters. However, TTC calculation is only possible for some encounters, namely those involving a collision course. Furthermore, these calculations cannot be fully automated. Further research is focused on classification of pedestrian-vehicle interactions using pedestrian-vehicle distance and the relative speed at the moment when that distance is minimal. It is hoped that this approach will lead to a surrogate safety measure for pedestrian crossings which could be computed automatically. A survey of pedestrian risk perceived by observers viewing dangerous pedestrian-vehicle encounters confirmed that both speed and minimum distance at which vehicle passed the pedestrian are correlated with the perceived danger. However, the results of this survey should be treated with caution as it has been found that human perception of risk is very subjective and can be biased.

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