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Active Signage of Pedestrian Crossings as a Tool in Road Safety Management

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Abstract: The main objective of the study was to verify the effectiveness of active pedestrian crossings equipped with flashing lights activated automatically by detected pedestrians. A pilot study was conducted in two sites, where speed profiles of vehicles over the distance of 30 m before the crossing were analyzed. The study produced promising results in terms of reducing vehicle speeds so the next study investigated four other unsignalized pedestrian crossings. They were video-recorded for 48 h each, before, after and a year after installation. The ANOVA test was used to check the statistical significance of changes in selected indicators. Even after a year from the installation, the effect of the active signage remained significant. The average percentage of drivers yielding to pedestrians was 77.4% higher and the average waiting time 25.2% lower than before the installation. The average speeds of vehicles were 3.53 km/h lower on collector and 2.60 km/h lower on arterial streets. A decline in the probability of a pedestrian being killed or severely injured (KSI) ranged from 6.3 pp (9.4%) on the arterial streets immediately after the installation up to 12.9 pp (31.7%) on the collector streets one year after.

Keywords: pedestrian safety; unsignalized pedestrian crossing; active signage; yielding to pedestrians; vehicle speed

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1. Introduction

In order to minimize the number of road accident victims, many developed countries have introduced various traffic safety measures aimed at making both the infrastructure and vehicles safer, and have implemented numerous other means that have led to the reduction in road accidents' severity. Multiple factors interact in road crashes, which are generally grouped in relation to the infrastructure (road condition), the vehicle (state of the vehicle) and the driver (human condition) [1]. Pedestrians—the most vulnerable road users—and their interaction with vehicles are of key importance in this respect [2,3]. Interaction between pedestrians and vehicles takes place primarily when pedestrians are crossing roads and, therefore, proper arrangement of pedestrian crossings (or crosswalks) should be the focus of road safety management, especially in urban areas.

Pedestrians, not protected by a vehicle body, safety belts, airbags or helmets, are obviously the most vulnerable road users (VRUs), subject to a high risk of severe injury or death [4]. Figure 1 shows a function developed by Tefft based on US accident data [5] that relates the probability of a pedestrian being killed or severely injured (KSI) with the impact speed. It clearly shows that the vehicle speed when approaching a pedestrian crossing is critical to pedestrian safety.

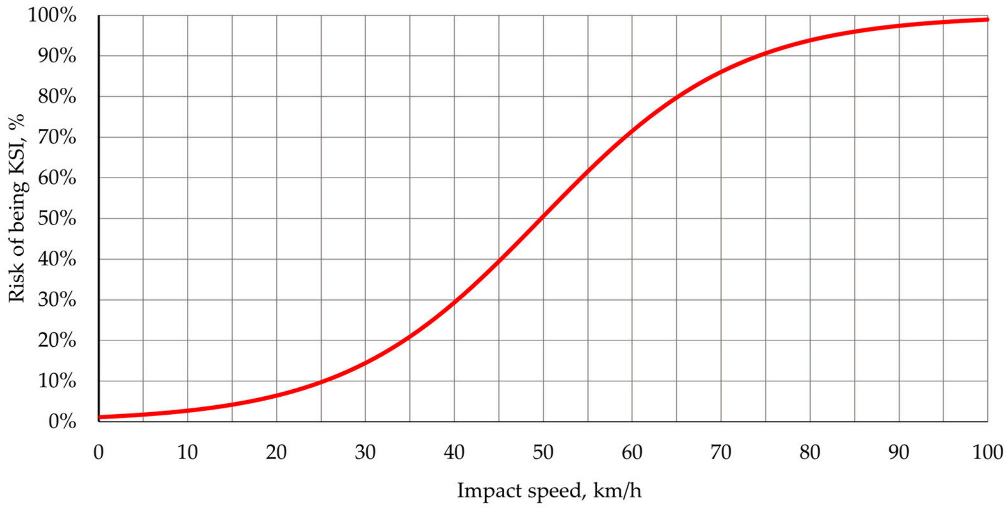


Figure 1. Risk of being killed or severely injured (KSI) in relation to impact speed, based on [5].

The number of pedestrian fatalities in the European Union fell from 5952 in 2010 to 4763 in 2018. This relative decrease of 20% is almost on par with the decrease in all road fatalities together in the same period (21%), which means that 1 in 5 road fatalities in the EU are pedestrians and this proportion has remained nearly constant. In almost all EU Member States, the number of pedestrian fatalities has decreased over the past decade, with Poland showing the strongest decline of 38%. Despite this, Poland had the highest number of pedestrian fatalities in 2018 (803), the fourth highest per million inhabitants (21.1), which is almost two times higher than the EU average (10.7) [6]. In 2019, 793 pedestrians were killed and 6361 were injured on Polish roads. These numbers correspond, respectively, to 27% of all traffic fatalities and 18% of all traffic injuries.

According to police records [7], in major Polish cities, pedestrians make up more than half of all road accident fatalities. In all traffic incidents in 2019 in Warsaw, 317 pedestrians were injured and 21 of them died. Although the number of pedestrian accidents decreased by 21% compared to 2018, they still accounted for over 33% of all accidents, and pedestrian fatalities in 2019 were as high as 60% of all fatalities on Warsaw's streets.

The problem is even more urgent when unsignalized crossings are considered. Throughout the years 2010–2016, the number of pedestrian fatalities at this type of crossing in Poland increased by 23% [8]. Because of this they are given special attention not only in Poland but also in European road safety programs [9]. Although traffic safety in Poland has been improving in general, the increasing number of accidents at pedestrian crossings in recent years is raising serious concerns. The problem of relatively low pedestrian safety in Poland is well known and has been described in the local and international literature (e.g., [10–13]). A large-scale evaluation of pedestrian crossings was recently conducted in Warsaw with results that are difficult to generalize and, therefore, an individual approach to each crossing is recommended [14]. For this reason, the Municipal Roads Authority in Warsaw installed active signage on 19 pedestrian crossings, wanting to analyze their operation and draw conclusions regarding future installations.

Various traffic calming measures (TCMs) are used around the world to increase pedestrian safety, such as raised crosswalks [15], speed cameras [16], traffic lights turning red when the speed limit is exceeded [17] or panels indicating the speed [18]. Poland's VRU accident risk level calls for innovative and effective solutions for improving safety at pedestrian crossings. Many of these solutions are already available on the market and are being tested in various countries [19]. One of them is an active signage system using pedestrian-activated flashing lights that warn drivers about the crossing location and pedestrian presence. The system is intended to increase the attention of drivers and make them lower their speed. According to American [20,21] and Israeli [22] field studies, active signage systems show promising results in decreasing vehicle approach speeds and improving driver behavior regarding yielding to pedestrians. The Polish experience in this matter described in [23,24] is also relatively positive.

The main aim of the current study was to verify the effectiveness of active pedestrian crossings equipped with flashing lights activated automatically when pedestrians are detected. The results show that the active signage systems have a positive safety effect and should be considered in the overall urban road safety management system.

2. Materials and Methods

2.1. Pilot Study

The pilot study on the effectiveness of active signage was carried out as a part of the Mobis research project [25] to develop a methodology for investigating pedestrian–vehicle interactions and assessing safety at pedestrian crossings. During the study, pedestrian and vehicle traffic were recorded at four unsignalized zebra crossings in Warsaw and Wrocław, for a period of approximately two months. Two of the surveyed sites, one in Warsaw and one in Wrocław were analyzed. Layouts of the two sites are shown in Figure 2.

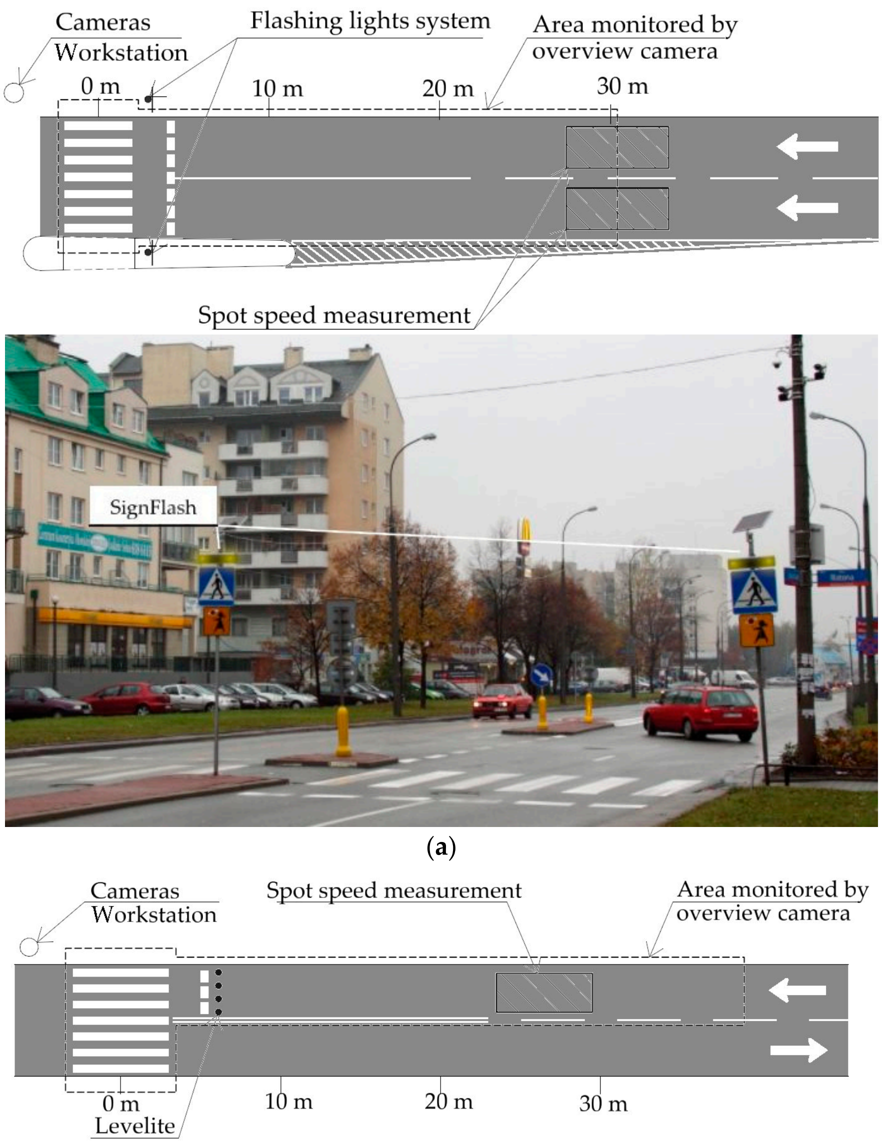
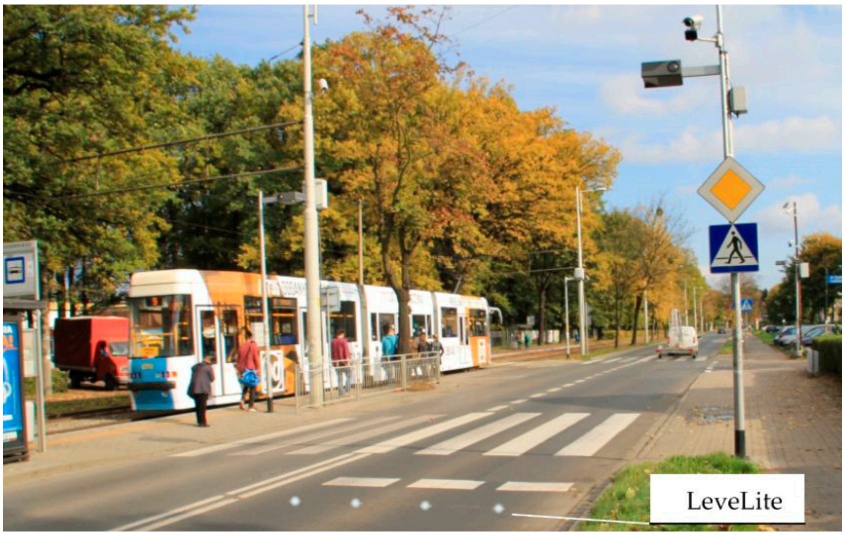


Figure 2. *Cont*.



(b)

Figure 2. Layouts and photographs of the pilot study test sites in (**a**) Warsaw and (**b**) Wrocław.

The SignFlash system (SF) was installed in Warsaw. This active signage system is equipped with pedestrian sensors that activate yellow flashing lights mounted on poles near the zebra crossing [19]. Traffic was recorded both before and after the installation, and 23 days of favorable weather conditions were selected for in-depth analysis—12 days without the SF system and 11 days with the system. In Wrocław, another type of active signage was used, namely the LeveLite (LL), i.e., blinking LED lights embedded in the road surface before the zebra crossing. A continuous flashing mode was tested for 18 days. A custom-made video recording and processing system was installed at both sites. It consisted of:

- a digital overview camera covering the area of the pedestrian crossing and its approach about 30–40 m long;
- one digital directional camera per lane (for spot speed measurement), aimed at a small road section located within the approach area monitored by the overview camera;
- a workstation used for recording and preliminary analysis of the recorded videos; it also enabled remote control of the recording and diagnostics.

2.2. Implementation Study

The experience gained and the methodology of assessing active crossings developed as part of the pilot study allowed for an implementation study. For this purpose, an analysis of the operation of active pedestrian crossings installed in Warsaw by the Municipal Roads Authority was performed. A total of 19 crossings were fitted with active signage, of which 8 crossings with different characteristics were analyzed by the research team. This article is focused on four of them divided into two groups of similar characteristics: two crossings on class G (arterial) streets and two on class Z (collector) streets. The speed limit at all four sites is 50 km/h. As in the pilot study, a before–after approach was used. The crossings were video-recorded using two MioVision Scout cameras per site for a period of 48 h, before, immediately after and a year after installation of the equipment. The recordings were made in the period of July–November 2017 and October–November 2018. The following safety characteristics were analyzed: pedestrian and vehicle traffic volume, the percentage of drivers yielding to pedestrians, the time lost by pedestrians waiting to cross, and the average spot speeds of vehicles approaching the crossings (10 m before the crossing). Only drivers intentionally yielding to pedestrians were taken into consideration. A typical layout of a test site is shown in Figure 3.

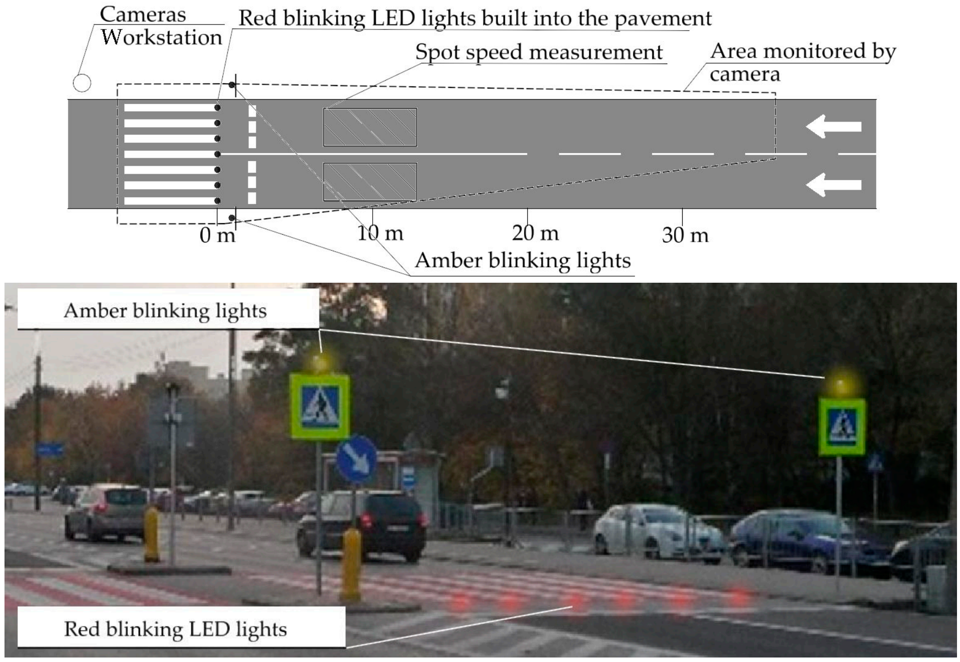


Figure 3. Typical layout and photograph of the implementation study test site.

The main characteristics of the analyzed sites in the implementation study are shown in Table 1.

Table 1. Main characteristics of the analyzed sites in the implementation study.

Site	Street Class	Cross-Section [1]	Maximum Vehicle Traffic Volume [veh/h]	Maximum Pedestrian Traffic Volume [ped/h]
Ludna	collector	1 × 3 lanes	679	155
Grzybowska	collector	2 × 2 lanes	604	443
Popiełuszki	arterial	2 × 2 lanes	1006	124
Powstańców Śl.	arterial	1 × 4 lanes	1266	93

[1] Only one direction was analyzed.

2.3. Analysis Methods

In order to exclude the impact of changes in traffic volume on vehicle speeds, a multiple linear regression analysis was performed, expressing the average vehicle approach speed as a function of the hourly vehicle traffic volume and the presence of the active signage.

Other performance indicators used were: percentage of drivers yielding to pedestrians and pedestrian waiting time. The percentage of drivers yielding to pedestrians was defined as a quotient of the number of drivers that yielded to pedestrians waiting to cross to the number of drivers that yielded and did not yield (among those who were in interaction with pedestrians). In contrast to other studies of this type [26], it was assumed that situations in which a pedestrian entering the crossing forced the vehicle to stop were not regarded as yielding. The time lost by pedestrians waiting to cross was defined as the average waiting time of all pedestrians at a particular site. Zero waiting times were not included in the calculations.

In the pilot study, a standard two means test was used to check the statistical significance of approach speed reduction due to active signage. In the implementation study, a test of two proportions was used to evaluate the effect on percentage of drivers yielding to pedestrians. In addition, an ANOVA test was used to check the statistical significance of changes in pedestrian delay due to the introduction of the active signage.

Finally, an analysis of the possible safety benefits was conducted. It was assumed that the benefits resulted from the reduction of the vehicle speeds on the approach to the crossings. The analysis was based on the reduction of the probability of a pedestrian being killed or severely injured (KSI) as a function of the impact speed. The function developed by Tefft [5] and described in the introduction was used in the calculations (Figure 1). It should be noted that Tefft's definition of severe injury is a maximum AIS score of 4 or greater, which is different from the commonly accepted MAIS 3+ criterion. For the average vehicle speeds measured during the periods before, immediately after and a year after, the corresponding probabilities of being KSI were calculated and compared.

3. Results

3.1. Pilot Study

Overview cameras used in the pilot study (Figure 2) allowed for speeds to be measured not just at a single spot but along the whole 30 m approach. Speed profiles of vehicles over the distance of 30 m before the crossing were examined and analyzed statistically. Differences between behavior under day and night conditions were identified. Figure 4 shows examples of speed profiles for the Warsaw (WAW) and Wrocław (WRO) sites for periods before and after the installation of the active signage.

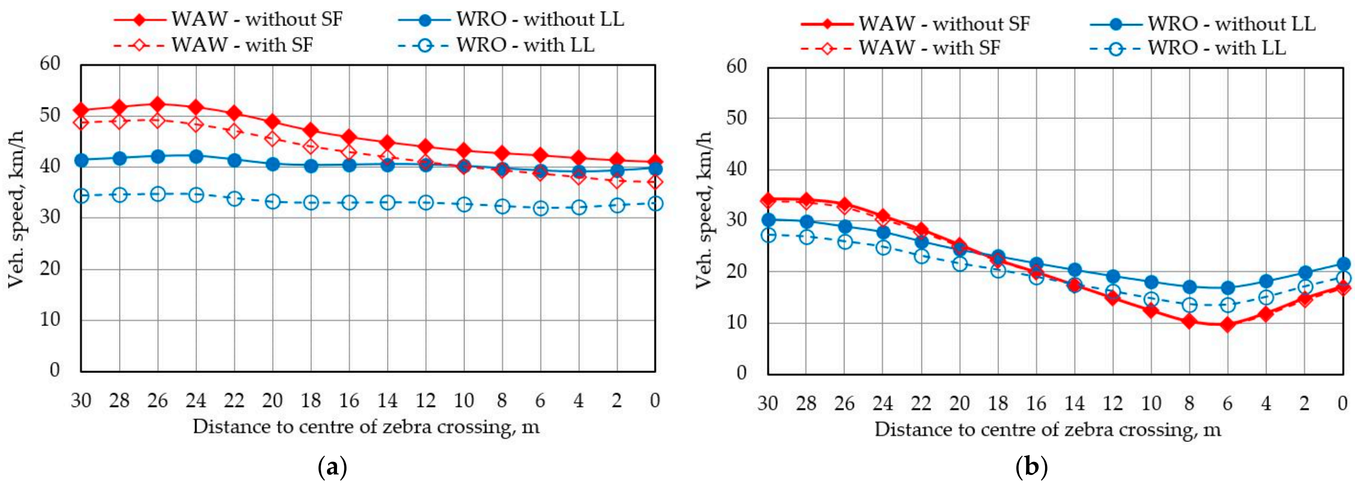


Figure 4. Average speed profiles for situations: (**a**) not yielding and (**b**) yielding to pedestrians (WAW—Warsaw site, WRO—Wrocław site).

Spot speeds at a distance of 10 m (for WAW—12 m from the center of the zebra crossing and for WRO—13 m from the center of the zebra crossing) upstream of the crossings were analyzed at both sites for the periods without and with safety measures. The mean speeds calculated for both periods for not yielding and yielding to pedestrian situations, and for daytime and nighttime conditions, were compared separately. After that, statistical hypotheses were tested stating that the means calculated for both periods were equal. The analysis results for the Warsaw and Wrocław sites are shown in Tables 2 and 3, respectively.

Table 2. Vehicle speed analysis—Warsaw site.

Situation	Conditions	Period without SF			Period with SF			Speed Diff. [km/h]	Z	*p*
		n	Mean [km/h]	Sd [km/h]	*n*	Mean [km/h]	Sd [km/h]			
not yielding	Daytime	197	45.0	13.8	237	41.4	13.8	−3.6	−2.65	0.004 *
	Nighttime	81	41.6	11.1	50	38.8	11.2	−2.7	−1.36	0.086
yielding	Daytime	2647	15.0	5.2	3242	15.1	5.3	0.1	0.92	0.822
	Nighttime	1909	15.5	5.7	917	15.7	5.4	0.2	0.85	0.804

* speed reduction significant at α = 0.05.

Table 3. Vehicle speed analysis—Wrocław site.

Situation	Conditions	Period without LL			Period with LL			Speed Diff. [km/h]	Z	p
		n	Mean [km/h]	Sd [km/h]	n	Mean [km/h]	sd [km/h]			
not yielding	Daytime	1079	39.2	12.2	323	33.5	13.0	−5.8	−7.12	<0.001 *
	Nighttime	222	41.8	11.4	56	32.7	12.1	−9.0	−5.04	<0.001 *
yielding	Daytime	3763	19.0	11.4	1161	16.9	9.9	−2.1	−6.18	<0.001 *
	Nighttime	680	20.7	12.5	282	16.8	9.6	−3.9	−5.21	<0.001 *

* speed reduction significant at $\alpha = 0.05$.

Both safety measures had a positive effect on reducing vehicle speeds. The effect of the LeveLite system seems to be greater than SignFlash, but the two sites were of different characteristics, so the results are not fully comparable for both systems.

The Warsaw site mean speeds with SF were generally lower than without SF. However, only in the case of not yielding to pedestrians the hypothesis stating that there is no speed reduction with SF can be rejected at the assumed level of significance $\alpha = 0.05$ for daytime and $\alpha = 0.1$ for nighttime. In the case of yielding to pedestrians, the speeds were actually slightly higher with SF.

Regarding the Wrocław site, the effect of introducing safety measures (the LeveLite system) was much more significant than in Warsaw (up to a 9 km/h reduction) and it was statistically valid for all combinations of situations and time of day.

3.2. Implementation Study

3.2.1. Yielding to Pedestrians

A high increase in the percentage of vehicles yielding to pedestrians was recorded at the analyzed crossings. The details are shown in Figure 5.

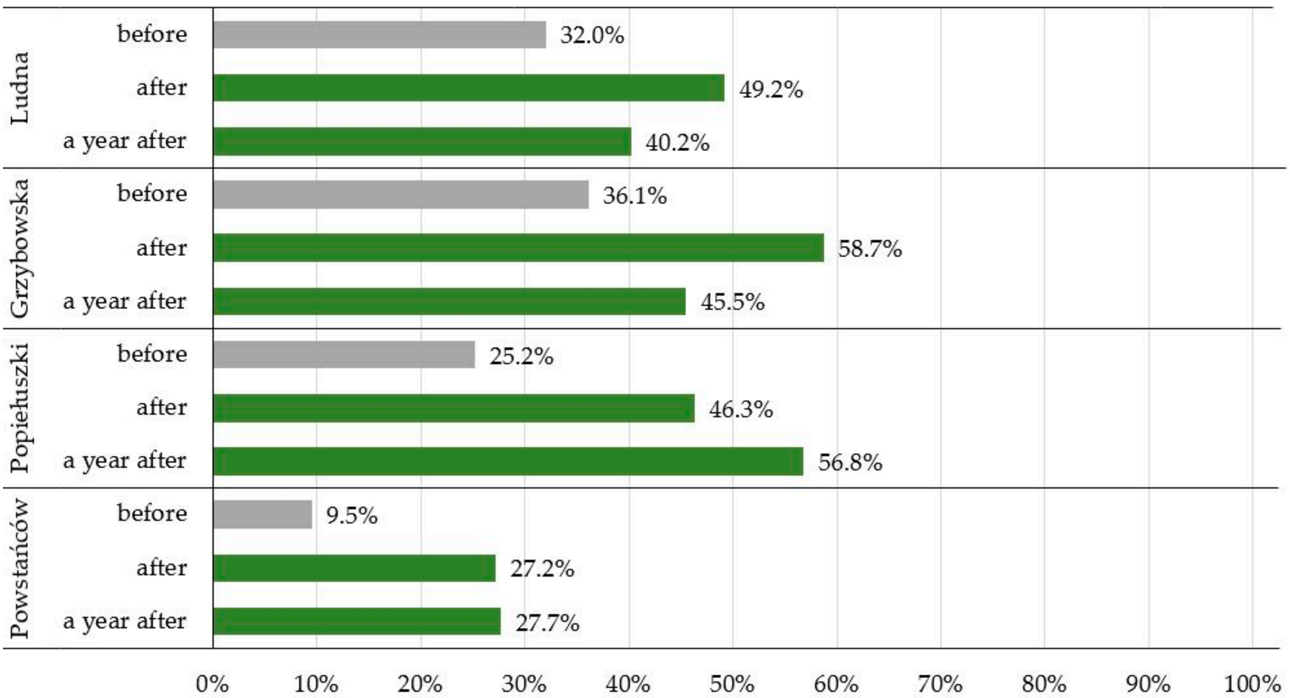


Figure 5. Percentage of drivers yielding to pedestrians (significant differences are shown in green).

The analysis showed that a year after the installation the percentage of drivers yielding to pedestrians was still higher than in the period before the installation in all tested sites. According to the ANOVA test performed, in the case of the Grzybowska and Powstańców Śl. sites, the results cannot be considered statistically significant (Table 4).

Table 4. Statistical significance of the change in percentage yielding to pedestrians.

Site	Mean % Yielding		A Year after–before Difference (pp)	Change [%]	Test of Two Proportions Results		Mean % Yielding
	before	**A Year after**			**Z**	***p***	**after**
Ludna	32.0%	40.2%	8.2	25.5%	−3.43	<0.001	49.2%
Grzybowska	36.1%	45.5%	9.4	26.1%	−5.82	<0.001	58.7%
Popiełuszki	25.2%	56.8%	31.6	125.8%	−22.67	<0.001	46.3%
Powstańców Śl.	9.5%	27.7%	18.2	192.1%	−14.50	<0.001	27.2%

Z—normally distributed statistics used to assess significance level *p*.

3.2.2. Pedestrians' Average Waiting Time

After installing the active signage, the average waiting time to cross for pedestrians was significantly reduced on all the surveyed sites. This is directly related to the increase in yielding percentage—the drivers were more willing to give way to pedestrians. The results are shown in Table 5 and Figure 6. According to the ANOVA test performed, in the case of the Ludna and Powstańców Śl. Sites, the results cannot be considered statistically significant.

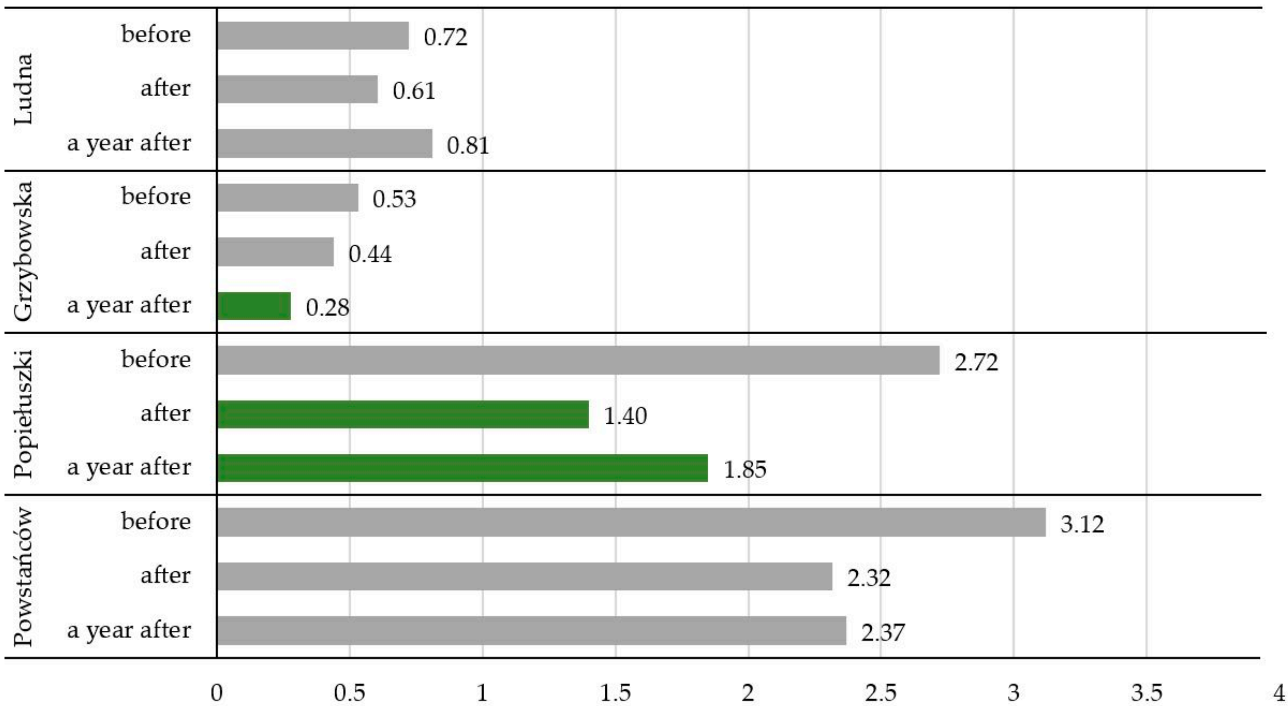


Figure 6. Pedestrians average waiting time [s] (significant differences are shown in green).

Table 5. ANOVA test results of the statistical significance of change in the average waiting time of pedestrians.

Site	Pedestrian Average Waiting Time [s]		A Year after–before Difference [s]	Change [%]	ANOVA Test Results		Pedestrian Average Waiting Time [s]
	before	A Year after			F	*p*	after
Ludna	0.72	0.81	0.09	11.9%	1.470	0.230	0.61
Grzybowska	0.53	0.28	−0.25	−47.3%	14.261	<0.001 *	0.44
Popiełuszki	2.72	1.85	−0.87	−32.0%	7.920	0.006 *	1.40
Powstańców Śl.	3.12	2.37	−0.75	−24.0%	0.055	0.815	2.32

F—Fisher's test used to assess confidence level *p*; *—change significant at α = 0.05.

3.2.3. Vehicle Speeds

In order to exclude the impact of changes in traffic volume on vehicle speeds, a regression analysis of average hourly vehicle speed was performed. Because of the different classes of the considered streets, and therefore different vehicle speed levels, they were analyzed in groups: Ludna together with Grzybowska (collector streets) and Popiełuszki together with Powstańców Śl. (arterial streets). Table 6 shows the regression analysis results of the hourly average vehicle speed in the period one year after the installation, as a function of the hourly traffic volume of vehicles and the presence of the road safety measure. The results are illustrated in Figures 7 and 8.

Table 6. The results of the regression analysis of the average hourly vehicle speeds.

Site	Speed Difference A Year after–before [km/h]	Standard Error [km/h]	*t*-Statistic	*p*-Value	R^2	Speed Difference after–before [km/h]
Ludna + Grzybowska (collector)	−3.53	0.76	−4.66	0.000	0.58	−2.78
Popiełuszki + Powstańców Śl (arterial)	−2.60	0.68	−3.84	0.000	0.48	−3.01

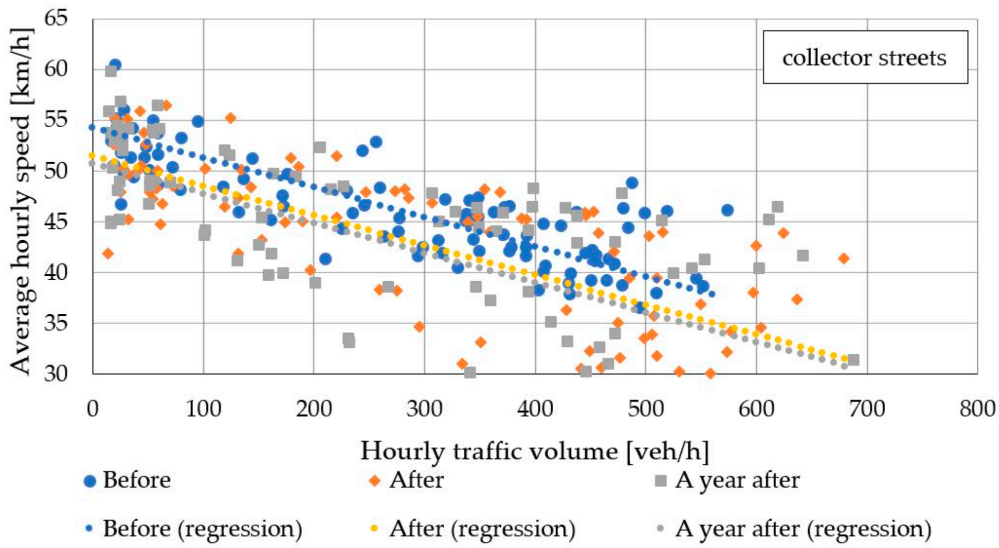


Figure 7. Vehicle speed linear regressions for Ludna and Grzybowska (collector) sites combined.

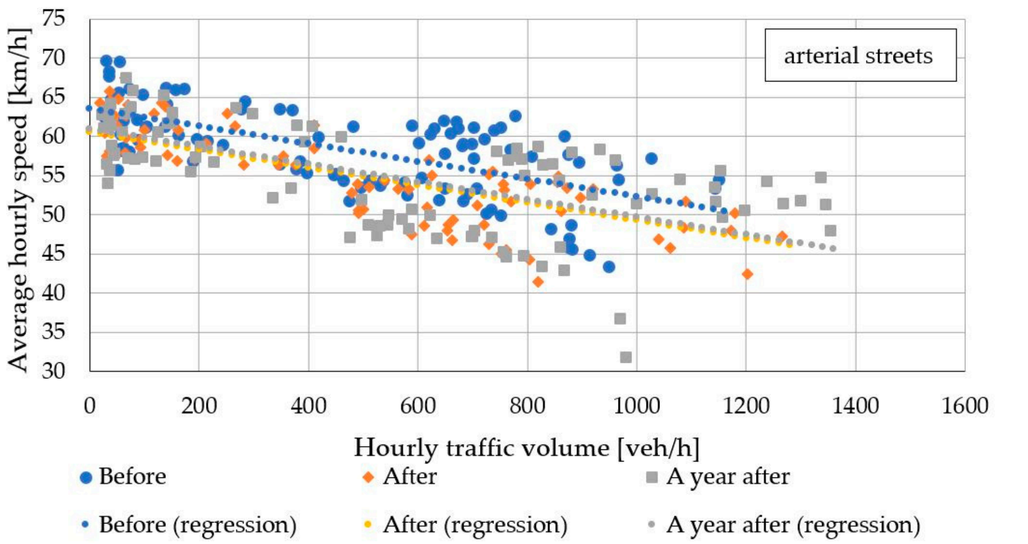


Figure 8. Vehicle speed linear regressions for Popiełuszki and Powstańców Śl. (arterial) sites combined.

As can be seen from the above results, a drop of speeds was observed on the streets of both classes, but it was higher on collector than arterial streets. It is noteworthy that the initial drop in vehicle speed was kept at a similar level one year after installation in both cases.

Apart from the regression, the average speeds for the periods before, immediately after and a year after were calculated in order to determine the probabilities of a pedestrian being killed or severely injured (KSI) based on the curve presented in Figure 1. They are shown in Table 7. The KSI probabilities for the periods before, immediately after and a year after are shown in Figure 9.

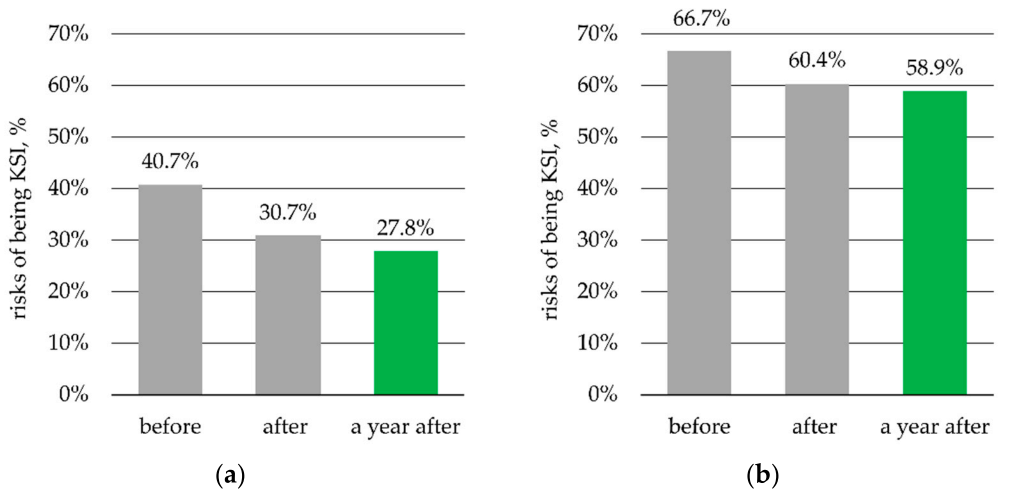


Figure 9. Risk of being KSI calculated for collector (**a**) and arterial streets (**b**).

Table 7. Average vehicle speeds calculated for the analyzed collector and arterial streets.

Period	Collector Streets		Arterial Streets	
	Average Speed [km/h]	**Reduction [km/h]**	**Average Speed [km/h]**	**Reduction [km/h]**
Before	45.6	–	57.5	–
After	40.8	−4.8	54.4	−3.1
A year after	39.2	−6.4	53.8	−3.7

As can be seen from the bar graphs, the reduction of the KSI probability ranges from 6.3 pp (improvement of 9.4%) on the arterial streets immediately after the installation and up to 12.9 pp (improvement of 31.7%) on the collector streets one year after.

4. Discussion

The results obtained during the pilot study show that there is generally a positive reaction to the blinking lights in terms of approach speed reduction. However, the results cannot be generalized because of the uneven sample size and the fact that in Wrocław the lights were not activated by pedestrians but were blinking continuously. The advantage of the pilot study was that the overview cameras allowed for speeds to be measured along the entire 30 m long approach. Thanks to that, speed profiles of vehicles over this distance could be examined. They show that vehicle speeds were reduced after the installation of the active signage within the entire analyzed sections. However, the reduction was greater in the case of the LeveLite system.

A very encouraging finding from the implementation study is that the positive values of the indicators achieved in the after period were generally maintained in the long term, i.e., a year after. It is often the case that safety measures have a positive effect immediately after their introduction, but then the effect diminishes or even disappears over time.

It is worth noting that the percentage of drivers yielding to pedestrians was higher on collector than on arterial streets in all analyzed periods. This can be attributed to the higher vehicle speeds on the latter due to a higher street class and its different function. As a consequence, the pedestrian average waiting time before being able to cross was lower on collector streets.

An aspect that needs to be commented on is that the reductions of average speeds in Table 7 differ from those determined in the regression analysis (Table 6). This has to be attributed to the distribution of the average hourly speeds in relation to the traffic volumes.

The more significant reduction in the KSI probability on the collector streets compared to the arterial streets is a consequence of the drivers' greater willingness to yield to pedestrians on the former, as discussed earlier. When driving faster, drivers may be less likely to slow down and less willing to yield to pedestrians.

A reservation has to be formulated that the Tefft's function relates to the impact speed of a vehicle hitting a pedestrian, which presumably would be lower than the speed of a vehicle approaching the crossing. This would result in somewhat lower effects of the active signage measured by the reduction in probabilities of being KSI. Therefore, further research is needed in this field to determine the relation between the two speeds.

It is worth mentioning that in a study by Hakkert et. al. [22], similar results were obtained. Regarding the average vehicle speeds, a reduction of 2–5 km/h was achieved (2.6–3.5 km/h in this study) and the percentage of vehicles yielding to pedestrians increased from about 20% to 40% (on average from 26% to 43% in this study).

It should also be added that the research was carried out before the introduction in Poland of the law obliging drivers to yield to pedestrians intending to enter at pedestrian crossing (a law that came into effect on 1 June 2021). It is expected that the percentage of drivers yielding to pedestrians and pedestrian waiting time will change as a consequence of the new law, and this requires further investigation.

5. Conclusions

The general conclusion is that active signage systems have a positive impact on pedestrian safety and comfort at unsignalized crossings. When the blinking lights are activated by pedestrian presence, there is a marked reduction in the speed of approaching vehicles and a higher willingness of drivers to yield to pedestrians, resulting in lower pedestrian waiting times. The extent of these effects varies according to the road class, type of cross-section and local characteristics. It seems that active signage is more suitable for collector streets where speeds after implementation result in acceptable levels of pedestrian risks.

Pedestrian crossings on arterial streets should rather be signalized because of unacceptably high levels of pedestrian risks.

It can be concluded that active signage systems are useful safety tools and should be considered as a part of a pedestrian safety improvement plan.

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