OBSERVATIONAL STUDY OF PEDESTRIAN BEHAVIOR AT SIGNALIZED CROSSWALKS

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Resume

The pedestrian behavior at five signalized crosswalks in Kielce, was analyzed in this study with a particular focus on the increasing use of mobile phones and other electronic devices while crossing the street. Compared to previous ITS studies, which showed that 7% of pedestrians used phones, the current study reveals a significant increase in this phenomenon, with percentages ranging from 14 to 60%. The highest levels of phone usage and risky behaviors were observed at the intersection of Aleja Solidarnosci and Swietokrzyska Street. The results also indicate a decrease in the number of cases of crossing on a red light but an increase in the number of pedestrians crossing during the flashing green signal. The study results point to the need for targeted educational campaigns and the adaptation of infrastructure to address the new challenges associated with mobile device use by pedestrians.

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1 Introduction

A pedestrian, as a road user, plays a key role in urban dynamics. Pedestrians, who travel without any transportation means, are vulnerable and dependent on both the infrastructure and adherence to traffic rules. Unlike drivers or cyclists, they are completely exposed, making them the most at risk in road traffic [1-3]. Crossing streets is often necessary in cities, highlighting the need for pedestrian-friendly solutions that do not reduce the road capacity [4-5]. Modern urban planning aims to balance the pedestrian safety with transportation efficiency [6-7]. A growing concern is the distraction caused by mobile devices. Studies show that using a phone while crossing significantly increases accident risk by impairing focus and decision-making [8-9].

Pedestrian crossings vary in safety. Collision-prone crossings require more caution, while non-collision crossings, such as overpasses or tunnels, provide the greater safety but may be less convenient [10-12]. Enforcing pedestrian right-of-way is crucial, and in many countries, penalties for violations are strict, helping to improve the compliance. However, pedestrian accidents remain high in Poland due to improper behavior by both drivers and pedestrians [13]. The lack of awareness of the risks, such as using phones or headphones while crossing, exacerbates the problem [14].

Improving pedestrian safety requires both better infrastructure and societal change. Solutions like well-marked crossings, better lighting, and technologies to minimize distractions, such as phone-blocking apps, are vital. In Europe, consistent efforts in education, enforcement, and technology have led to significant accident reductions [15-17]. Examples include smart crossings with pedestrian detection systems, illuminated crosswalks, speed bumps, and safety islands. These innovations, along with the driver alert systems and traffic monitoring cameras, are key to improving safety [18-19].

2 Pedestrian accidents in Poland

Between 2019 and 2023, the number of pedestrians who died as a result of road accidents in the European Union remained relatively high, despite the introduction of new safety measures. In 2019, approximately 3,900 pedestrians died in the EU, and by 2023, this number had decreased slightly to around 3,700, indicating

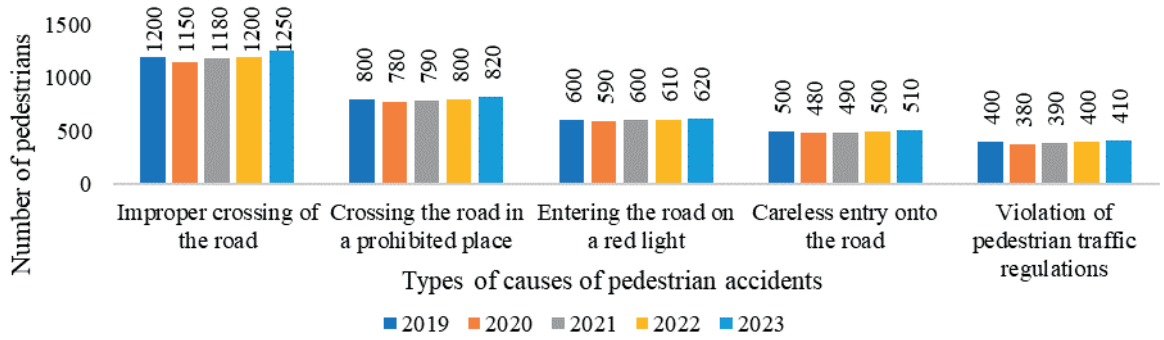

Figure 1 *Statistics of accidents caused by pedestrians in 2019-2023*

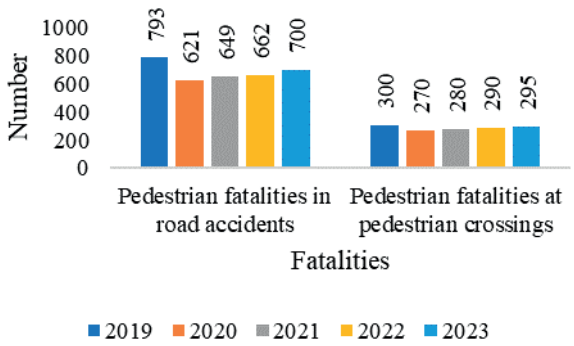

Figure 2 *Pedestrian fatalities in 2019-2023*

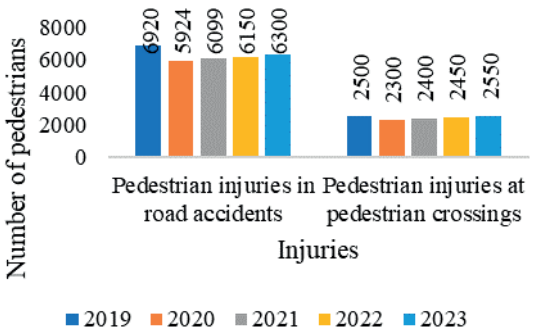

Figure 3 *Number of injured pedestrians in 2019-2023*

a small but noticeable downward trend [20]. The number of pedestrian accidents at crosswalks was around 20,000 in 2019 and decreased to approximately 19,000 by 2023, suggesting that engineering and technical solutions are gradually yielding positive results [21].

In Poland, the pedestrian safety situation is particularly concerning. In 2019, there were 7,549 road accidents involving pedestrians, resulting in 793 deaths and 6,920 injuries. In 2020, despite the pandemic, the number of accidents dropped, but in 2023 it rose again to 7,000, indicating an urgent need for intensified efforts to improve the pedestrian safety at crosswalks [22]. Key issues in Poland include insufficient enforcement of pedestrian right-of-way laws and low driver awareness of the dangers posed by improper behavior near the crosswalks.

An analysis of pedestrian-caused accidents shows that improper road crossing cases decreased in 2020, but rose in subsequent years, reaching 1,250 incidents in 2023 [23]. A similar increase was observed in accidents caused by pedestrians crossing at unauthorized locations and entering the road at red lights [24-25]. The statistics of pedestrian-caused accidents from 2019 to 2023 are presented in Figure 1.

The analysis shows that although there were decreases in pedestrian-caused accidents in some years, the overall trend indicates an increase, especially in cases of improper road crossing, crossing at unauthorized locations, and entering the road on a red light. These trends highlight the need for ongoing education and infrastructure improvements.

Pedestrian fatalities peaked at 793 in 2019, dropped to 621 in 2020 due to COVID-19 traffic reductions, but rose again to 700 by 2023, marking a 5.7% increase [20-21]. Fatalities at crosswalks followed a similar pattern, decreasing from 300 in 2019 to 270 in 2020, and rising to 295 in 2023, a 1.7% increase [22-23].

Pedestrian injuries fell from 6,920 in 2019 to 5,924 in 2020, but rose to 6,300 by 2023, reflecting a 2.4% increase [24]. Injuries at crosswalks also fluctuated, dropping to 2,300 in 2020 but increasing to 2,550 in 2023, a 4.1% rise [25]. Figures 2 and 3 present the numerical data on pedestrian fatalities and injuries from 2019 to 2023.

The data indicate that while the pandemic contributed to a reduction in pedestrian accidents and casualties in 2020-2021, there has been a gradual increase since 2021. The rise in casualties at pedestrian crossings underscores the need for continued road safety education and infrastructure improvements. Pearson correlation analysis (using STATISTICA 13) revealed significant relationships between the pedestrian behavior and accidents. The strongest correlation (0.998) was found between the crossing at unauthorized locations and improper road crossing, suggesting that these behaviors often occur together. A high correlation (0.995) also exists between the pedestrian injuries and fatalities, indicating that an increase in one often

accompanies an increase in the other.

Careless road entry and injuries at pedestrian crossings show a correlation of 0.980, highlighting the impact of distractions on accident rates. Violations of pedestrian traffic regulations and unauthorized crossings are similarly correlated (0.976), as is the relationship between careless entry and improper crossing (0.974). These findings suggest that distractions, such as mobile phone use, play a significant role in pedestrian-involved accidents.

However, there is a lack of precise data quantifying pedestrian distractions, such as phone use or listening to music, during accidents. Current road safety data collection methods are insufficient in this area, relying on subjective testimony. Introducing more advanced monitoring technologies, such as street cameras or surveys, could provide better insights into the impact of distraction on pedestrian safety and lead to more effective preventive measures.

3 Methodology

The main objective of the study was to analyze the pedestrian behavior at signaled intersections, with particular emphasis on the impact of the use of mobile devices on their decisions and safety. The study aimed to measure the frequency with which the pedestrians use mobile phones or other electronic devices when crossing the road, and to assess how this behavior affects the overall road safety. The results of the study were to be used as a basis for making recommendations for potential infrastructure improvements and educational initiatives to improve pedestrian safety.

A review of the existing literature revealed that the study lacks a detailed analysis of the impact of mobile use on pedestrian decisions. Most studies to date have focused on pedestrians' general traffic light compliance, but have not taken into account the impact of different types of mobile device use (e.g., holding the phone, talking, active screen use) on their behaviour. In addition, few studies have looked at high-traffic intersections, where pedestrians and drivers have to manage limited time and space, further complicating safety issues. The increasing number of accidents involving pedestrians using mobile devices highlights the urgent need to understand these behaviors and identify the factors that influence pedestrian decisions. The aim of this study was to fill this gap and provide practical information for improving road safety policies and adapting infrastructure to changing pedestrian behaviour.

3.1 Location and context of the study

Five high-traffic intersections, representing commercial, educational and residential areas, were selected for the study, which allowed the analysis of pedestrian behaviour in different contexts. Each intersection was equipped with traffic lights, which made it possible to analyse the pedestrian behaviour according to the different phases of the traffic lights.

3.2 Observation procedure

The observations were carried out by a team of nine researchers who were divided into three groups. Two groups were on opposite sides of each crossing, recording pedestrian behavior, with a focus on mobile device use and traffic light response. The third group documented the length of traffic light phases and the pedestrian crossing time. Each crossing was observed through 51 signaling cycles, with sessions running on different days and times of the day to ensure comprehensive data collection.

3.3 Data collection tool

A detailed observation checklist (observational questionnaire) was used as a tool to classify the pedestrian behavior according to traffic lights and mobile device use. The checklist included variables such as:

- Traffic light compliance: Entrance to the crossing at a green, flashing green or red light.
- Mobile Usage: A type of interaction with a device, including holding a phone, using headphones, talking on the phone, or actively using a screen.
- Other factors: use of personal transport devices (e.g., bicycles, scooters) and red light cases.

3.4 Data analysis

After the data collection was completed, quantitative and statistical analysis was carried out using the STATISTICA 13 software. The analysis included both quantitative summaries and statistical assessments of factors influencing pedestrian decisions. Particular attention was paid to pedestrians using mobile devices, and the results were compared to the available literature. Pearson correlation analysis was used to detect relationships between behaviours (e.g., crossing red lights and using mobile devices) and demographic variables. These results are expected to form the basis for future actions to improve the road safety.

Although the study provides valuable information on pedestrian behaviour at signalled crossings in Kielce, it is limited to one city, which may affect the generalizability of the results. In addition, direct observation, despite the use of a checklist, could introduce subjectivity of the researchers. Future research could consider using automated monitoring technologies to mitigate the impact of this bias.

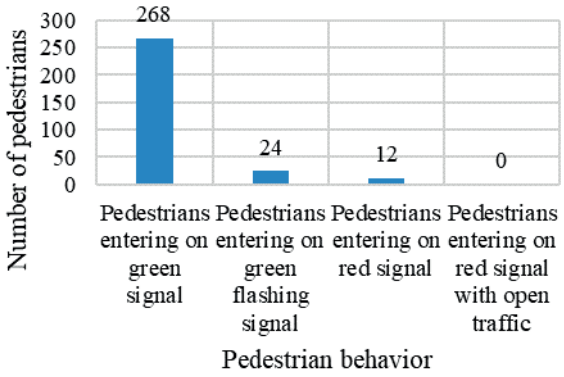

Figure 4 *Number of pedestrians who used the crossing at the intersection of Warszawska Street and Aleja Tysiaclecia Panstwa Polskiego during 51 cycles*

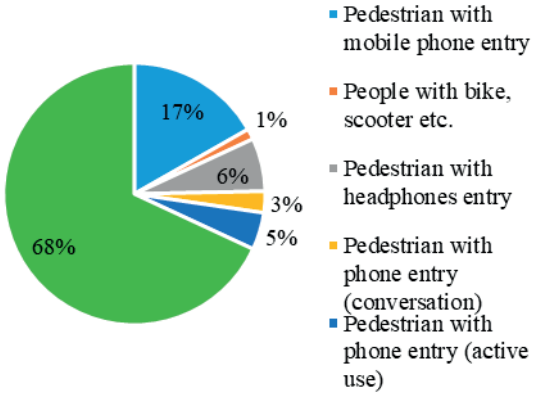

Figure 5 *Pedestrian behaviour at the intersection of Warszawska Street and Aleja Tysiaclecia Panstwa Polskiego during 51 cycles*

4 Observational studies of pedestrians

A significant gap in the literature on the impact of various forms of mobile device use (e.g., talking on the phone, active use of the screen) on pedestrian behaviour was addressed in this study. Most previous studies have focused only on pedestrians' compliance with traffic lights, without a detailed analysis of the impact that different types of mobile device use have on decision-making. Additionally, previous studies have rarely looked at the context of high-traffic intersections, where limited time and space increase the risk of collisions. The results of this study are expected to provide practical guidelines for improving the road infrastructure and shaping pedestrian safety policy. The ability to identify the riskiest pedestrian behaviors related to the use of mobile devices allows for the design of more precise educational and infrastructural activities. As a result, the recommendations resulting from this study could contribute to development of preventive measures that will effectively reduce the number of accidents involving pedestrians, supporting the creation of more friendly and safer urban spaces.

4.1 Pedestrian crossing at the intersection of Warszawska Street and Aleja Tysiaclecia Panstwa Polskiego

The first examined site, is a signalized pedestrian crossing located at the intersection of Warszawska Street and Aleja Tysiaclecia Panstwa Polskiego. This intersection is a significant part of the road network in the city of Kielce. In the immediate vicinity of the studied site, there is a university, numerous service points, shops, and public transport stops, which generate significant pedestrian traffic across various age groups. The study at this intersection was conducted on March 13, 2023. During 51 signal cycles, 304 people used the crossing, of which 268 began crossing on a green signal, 24 entered on a flashing green signal, and 12 started crossing on a red signal with closed vehicle traffic. None of the pedestrians began crossing on a red signal with open vehicle traffic.

The data collected from the intersection of Warszawska Street and Aleja Tysiaclecia Panstwa Polskiego during 51 signal cycles are presented in Figure 4, which shows the number of pedestrians using the crossing. In addition, Figure 5 illustrates pedestrian behavior at the same intersection, detailing how they responded to traffic signals and their use of mobile devices. These figures provide a comprehensive overview of pedestrian activity and highlight the key behavioral patterns observed during the study.

The data presented in Figure 4 shows that among all the pedestrians using the crossing during the study, 68% did not use any additional devices such as headphones or mobile phones. It was recorded that 51 pedestrians had a phone, 20 people were using headphones, 8 people were talking on the phone, and 14 people were actively using a phone while crossing the street. Additionally, only 4 pedestrians with a bicycle or scooter used the crossing during the study. The average duration of the green signal, based on 20 measurements, was 22.43 seconds, while the average duration of the red signal was 76.65 seconds. The average time it took for a pedestrian to cross the street was 23.43 seconds. It is important to note that the duration of the green signal is shorter than the average time needed to cross the pedestrian crossing, which may impact the pedestrian safety.

Based on the data presented in Figure 5, it is evident that among all the pedestrians who used the crossing, 68% (or 207 people) did not use any additional devices such as headphones or mobile phones. At the same time, 17% of pedestrians (52 people) used a mobile phone while crossing, and 6% (18 people) were using headphones. Additionally, 5% of pedestrians (15 people) were engaged in a phone conversation, and 3% (9 people) were actively using their phone, such as looking at the screen, while crossing the street. It is also noteworthy that only 1% of pedestrians (4 people) used the crossing with a bicycle, scooter, or similar means of

transport. These data indicate that while the majority of pedestrians avoid using electronic devices while crossing the street, a significant portion is still distracted by various devices, which may affect their safety.

4.2 Pedestrian crossing at the intersection of Swietokrzyska Street and Warszawska Street

The next examined site, is a signalized pedestrian crossing located at the intersection of Swietokrzyska Street and Warszawska Street. This intersection is characterized by high vehicle traffic, primarily due to transit traffic heading toward the S74 expressway. The increased pedestrian traffic in this area is associated with the nearby high school, shopping mall, and other facilities that generate high foot traffic among various age groups. The study at this intersection was conducted on May 22, 2023.

During the 51 signal cycles at the analyzed crossing, 326 people used the crossing. Among them, 288 started crossing on a green signal, 29 on a flashing green signal, and 9 decided to cross on a red signal with vehicle traffic stopped. The analysis of pedestrian activity at the intersection of Swietokrzyska Street and Warszawska Street over 51 signal cycles is depicted in Figure 6, which shows the number of pedestrians using the crossing. Figure 7 provides further insights into pedestrian behavior at this intersection, detailing how they interacted with traffic signals and the extent of mobile device use. These figures illustrate key patterns and behaviors observed during the study at this location.

Detailed data on this is presented in Figure 6. It is noteworthy that none of the pedestrians attempted to cross on a red signal with open vehicle traffic, indicating an awareness of the risks associated with such behavior. It should also be noted that the average duration of the green signal, based on 20 measurements, is 36.92 seconds. The average duration of the red signal is 62.80 seconds. The average time it took for a pedestrian to cross the pedestrian crossing was 19.29 seconds. It is also important to note that in this case, the duration of the green signal is longer than the average time needed for a pedestrian to cross.

Based on the data presented in Figure 7 it is evident that among all the pedestrians who used the crossing during the study, 41% (or 134 people) did not use any additional devices such as headphones or mobile phones. On the other hand, 13% of pedestrians (42 people) used a mobile phone, 10% (32 people) were using headphones, 4% (12 people) were engaged in a phone conversation, and 2% (7 people) were actively using their phone, such as looking at the screen, while crossing the street. Additionally, as many as 30% of pedestrians (98 people) used the crossing with a bicycle, scooter, or other similar means of transport. These data highlight that a significant portion of pedestrians are still distracted by various devices or use alternative means of transport, which may affect their safety at the crossing.

4.3 Pedestrian crossing at the intersection of Warszawska Street and Swietokrzyska Street

The third test was carried out at the crossing located at the intersection of Warszawska and Swietokrzyska streets., A significant intensity of both vehicular and pedestrian traffic, especially during the rush hours, was observed in this case, the same as for the previous research facility.. The survey took place on May 22, 2023. During the 51 signal cycles, 326 people used the crossing. Among them, 225 started crossing on a green signal, 4 entered the crossing on a flashing green signal, and 2 attempted to cross on a red signal, but with vehicle traffic stopped. It is noteworthy that none of the pedestrians attempted to cross on a red signal with open vehicle traffic, which may indicate a high level of awareness among pedestrians regarding

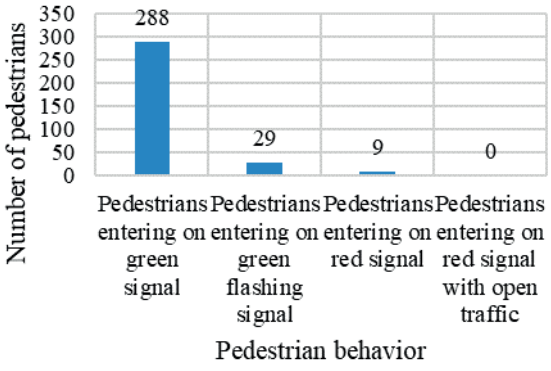

Figure 6 *Number of pedestrians who used the crossing at the intersection of Swietokrzyska Street and Warszawska Street during 51 cycles*

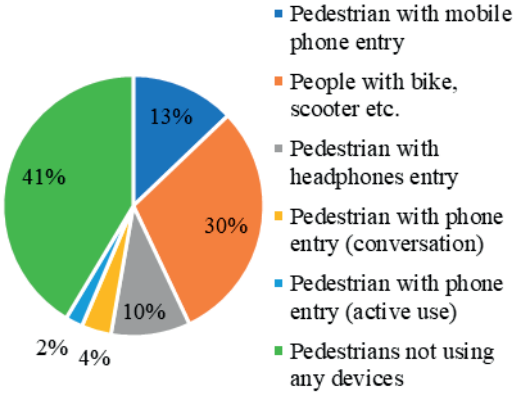

Figure 7 *Behaviour of pedestrians at the intersection of Swietokrzyska Street and Warszawska Street during 51 cycles*

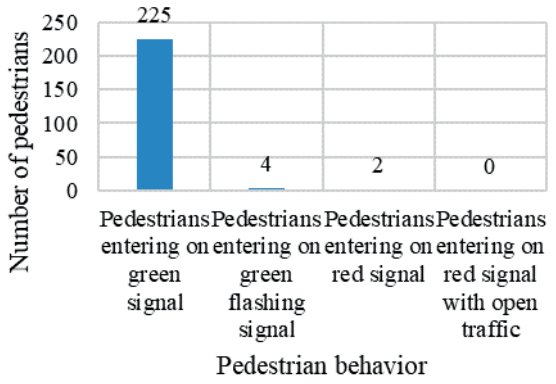

Figure 8 *Number of pedestrians who used the crossing at the intersection of Warszawska Street and Swietokrzyska Street during 51 cycles*

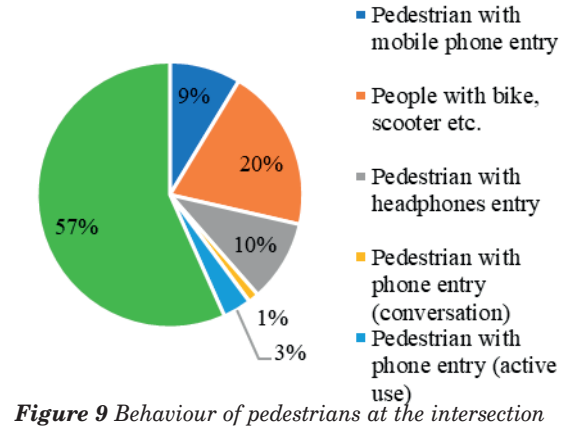

Figure 9 *Behaviour of pedestrians at the intersection of Warszawska Street and Swietokrzyska Street during 51 cycles*

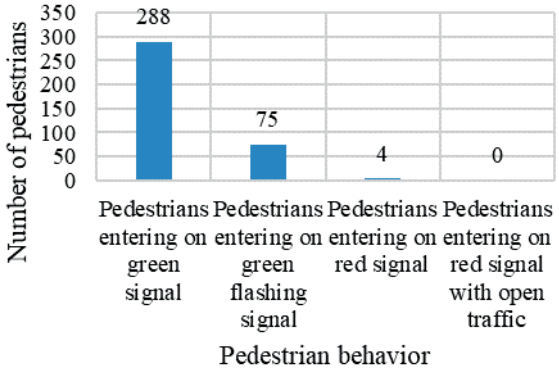

Figure 10 *Number of pedestrians who used the crossing at the intersection of Swietokrzyska Street and Solidarnosci Avenue during 51 cycles*

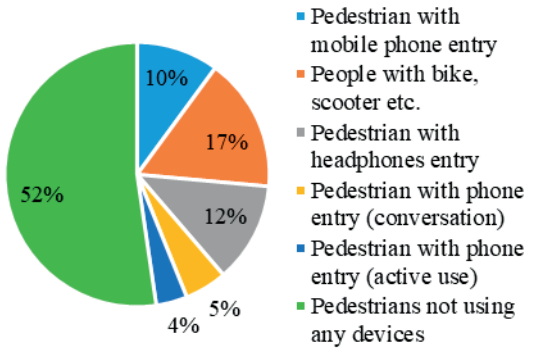

Figure 11 *Behaviour of pedestrians at the intersection of Swietokrzyska Street and Solidarnosci Avenue during 51 cycles*

the road safety rules. Figure 8 presents the number of pedestrians using the crossing at the intersection of Warszawska Street and Swietokrzyska Street during 51 signal cycles. Figure 9 summarizes pedestrian behavior at this intersection, focusing on their responses to traffic signals and mobile device use. These figures highlight key patterns observed during the study.

It should be noted that the average duration of the green signal, based on 20 measurements, is 30.41 seconds. The average duration of the red signal is 69.24 seconds. The average time it took for a pedestrian to cross the pedestrian crossing was 11.24 seconds. It is also important to note that in this case, the duration of the green signal is longer than the average time needed for a pedestrian to cross.

Based on the data presented in Figure 9, it is evident that among all the people who used the crossing during the study, 57% (or 186 people) did not use any additional devices such as headphones or mobile phones. It is also worth noting that 9% of pedestrians (30 people) used a mobile phone, 10% (33 people) were using headphones, 1% (3 people) were engaged in a phone conversation, and 3% (9 people) were actively using their phone, for example, looking at the screen, while crossing the street. Additionally, 20% of pedestrians (65 people) used the crossing with a bicycle, scooter, or other similar means of transport. These data highlight that while the majority of pedestrians avoid using electronic devices while crossing the street, a significant portion is still distracted or uses alternative means of transport, which may affect their safety.

4.4 Pedestrian crossing at the intersection of Swietokrzyska Street and Solidarnosci Avenue

Another survey was conducted on May 25, 2023 at the intersection of Swietokrzyska Street and Solidarnosci Avenue. This crossing plays a vital role in pedestrian traffic in the area due to its strategic location, proximity to large residential areas and the vicinity of a shopping mall, which attracts significant numbers of pedestrians during the day. During the 51 signal cycles, a total of 367 people crossed the street. The vast majority, 288 pedestrians, used the crossing on a green signal. Meanwhile, 75 people chose to cross during the flashing green signal, which may indicate a sense of urgency or

an attempt to save time. Only 4 people took the risk of crossing on a red signal, but only when vehicle traffic was stopped. Importantly, no one attempted to cross on a red signal when vehicle traffic was open, indicating the pedestrians' sense of responsibility in this area.

Figure 10 shows the number of pedestrians using the crossing at the intersection of Swietokrzyska Street and Solidarnosci Avenue during 51 signal cycles. Figure 11 illustrates pedestrian behavior at this intersection, highlighting their responses to traffic signals and use of mobile devices. These figures capture key behavioral trends from the study.

It should be noted that the average duration of the green signal, based on 20 measurements, is 65.30 seconds. The average duration of the red signal is 34.45 seconds. The average time it took for a pedestrian to cross the street was 6.80 seconds. It is also important to note that in this case, the duration of the green signal is longer than the average time needed for a single pedestrian to cross. Based on the data, it is evident that among all the people who used the crossing during the study, 52% (or 191 people) did not use any additional devices such as headphones or mobile phones. However, 10% of pedestrians (37 people) used a mobile phone, 12% (45 people) were using headphones, 4% (14 people) were actively using their phone (for example, looking at the screen), and 5% (19 people) were engaged in a phone conversation while crossing the street. Additionally, 17% of pedestrians (63 people) used the crossing with a bicycle, scooter, or other similar means of transport. These data indicate that while the majority of pedestrians avoid using electronic devices while crossing the road, a significant number of users still engage in activities that may distract them from their surroundings, potentially affecting their safety.

4.5 Pedestrian crossing at the intersection of Solidarnosci Avenue and Swietokrzyska Street

The fifth survey was also carried out on May 25, 2023 and included a pedestrian crossing located at the intersection of Solidarnosci Avenue and Swietokrzyska Street. During the 51 signal cycles, a total of 270 people used the crossing. The vast majority, 261 pedestrians, crossed the street on a green signal. Additionally, 8 people chose to cross during the flashing green signal, which may indicate a sense of urgency or an attempt to save time. Only 1 person attempted to cross on a red signal, but only when vehicle traffic was stopped. It is noteworthy that no one attempted to cross on a red signal with open vehicle traffic, suggesting that pedestrians in this area adhere to safety rules.

Figure 12 presents the number of pedestrians who used the crossing at the intersection of Solidarnosci Avenue and Swietokrzyska Street during 51 signal cycles. Figure 13 highlights pedestrian behavior at this intersection, focusing on their responses to traffic signals and mobile device use. These figures provide key insights into pedestrian activity and behavior observed during the study.

It should be noted that the average duration of the green signal, based on 20 measurements, is 45.64 seconds. The average duration of the red signal is 55.52 seconds. The average time it took for a pedestrian to cross the street was 5.90 seconds. It is also important to note that in this case, the duration of the green signal is longer than the average time needed for a single pedestrian to cross. Based on the data obtained from the study, it is evident that among all the people who used the crossing during the study, 40% (or 108 people) did not use any additional devices such as headphones or mobile phones. On the other hand, 26% of pedestrians (69 people) used a mobile phone, 9% (24 people) were using headphones, 5% (13 people) were engaged in a phone conversation, and 7% (18 people) were actively using their phone, for example, looking at the screen, while crossing the street. Additionally, 13% of pedestrians (36 people) used the crossing with a bicycle, scooter, or other similar means of transport. These data indicate that while a significant portion of pedestrians avoid using electronic devices while crossing the road, a notable number of people still engage in activities that may distract them from their surroundings, potentially affecting their safety.

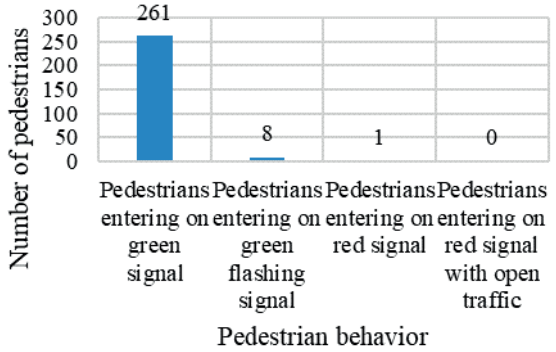

Figure 12 *The number of pedestrians who used the crossing at the intersection of Solidarnosci Avenue and Swietokrzyska Street during 51 cycles*

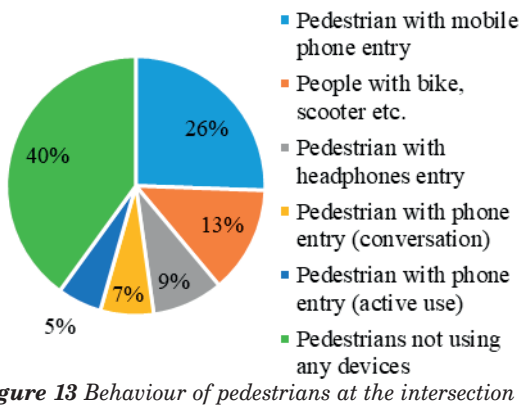

Figure 13 *Behaviour of pedestrians at the intersection of Solidarnosci Avenue and Swietokrzyska Street during 51 cycles*

5 Results of observational studies

The statistical analysis, with a significance level of p = 0.0001 (Table 1), clearly confirms the significant impact of the type of intersection on pedestrian behavior. The study results indicate that at the intersection of Aleja Solidarnosci and Swietokrzyska Street, the highest number of pedestrians used mobile phones - 69 people, accounting for 26% of all pedestrians at this location. This is the highest percentage among all the locations studied. This same intersection also stands out with the highest number of pedestrians actively using their phones 15 people (6%) - and the most people talking on the phone -18 people (7%).

At the intersection of Swietokrzyska and Warszawska Streets, 42 people (15%) were observed using mobile phones, which is also a significant percentage. At this location, 12% of pedestrians used headphones, which is noticeably higher than at other intersections. Conversely, at the intersection of Warszawska and Swietokrzyska Streets, as many as 34% of pedestrians were pushing a bicycle or scooter, the highest percentage of this user group compared to other locations. Additionally, at the intersection of Swietokrzyska Street and Aleja Solidarnosci, 12% of pedestrians used headphones, suggesting greater distraction in this area. This location also recorded the highest percentage of people talking on the phone-5%.

Overall, the analysis of all studied locations reveals that 15% of pedestrians used a mobile phone while crossing. It is also noteworthy that 10% of all pedestrians used headphones, which can significantly limit their ability to respond to their surroundings. One in four pedestrians, or 16% of those surveyed, was pushing a bicycle or scooter, which requires particular attention in the context of road safety.

The most important conclusion from the analysis, however, is that 52% of pedestrians did not use any device that could distract them. This suggests that the majority of pedestrians, despite the widespread availability of mobile devices, try to maintain focus while crossing the road. Nevertheless, the high percentage of pedestrians using mobile devices at certain intersections indicates the need for preventive and educational measures to raise awareness of the risks associated with distraction in road traffic.

The statistical significance coefficient of p = 0.0001 (Table 2), which is lower than the established significance level of 0.05, clearly indicates that the type of intersection has a significant impact on how pedestrians use signalized crosswalks.

The analysis shows that at all the intersections studied, the vast majority of pedestrians crossed the road when the green light was on - 1,330 such instances were recorded, accounting for 89% of all observed situations. The highest percentage of pedestrians adhering to the traffic signal was observed at the intersections of Warszawska Street and Aleja Solidarnosci, where 97% of pedestrians crossed on the green light. Conversely, at the intersection of Swietokrzyska Street and Aleja Solidarnosci, it was noted that 20% of pedestrians (75 people) chose to cross during the flashing green light. This may suggest that pedestrians at this location are inclined to take risks to cross before the light changes to red.

The most instances of crossing on a red light were recorded at the intersection of Warszawska Street and Aleja Tysiaclecia Panstwa Polskiego, where 12 people (4% of all pedestrians at this location) engaged in this risky behavior. This may be due to the short duration of the green light, which could prompt pedestrians to take risks to cross the road more quickly. Importantly,

Table 1 *Summary of pedestrian behaviour at individual intersections*

Crossroads		Pedestrian with a phone	Pedestrian with headphones	Pedestrian with a bike, scooter	Pedestrian talking on the phone	Pedestrian actively using the phone	Pedestrian not using any device
1	n	51	20	4	8	14	207
	%	17	7	1	3	5	68
2	n	42	32	48	12	7	135
	%	15	12	17	4	3	49
3	n	20	23	96	3	8	131
	%	7	8	34	1	3	47
4	n	37	45	60	19	14	192
	%	10	12	16	5	4	52
5	n	69	24	36	18	15	108
	%	26	9	13	7	6	40
Sum	n	219	144	244	60	58	773
	%	15	10	16	4	4	52
Chi-square	$\chi^2 = 188.06$		df = 20		p = 0.0001		

Table 2 *Summary of pedestrian behaviour in terms of compliance with traffic lights*

Crossroads		Pedestrians entering on green signal	Pedestrians entering on green flashing signal	Pedestrians entering on red signal	Pedestrians entering on red signal with open traffic
1	n	268	24	12	0
	%	88%	8%	4%	0%
2	n	288	29	9	0
	%	88%	9%	3%	0%
3	n	225	4	2	0
	%	97%	2%	1%	0%
4	n	288	75	4	0
	%	78%	20%	1%	0%
5	n	261	8	1	0
	%	97%	3%	0%	0%
Sum	n	1330	140	28	0
	%	89%	9%	2%	0%
Chi-square		χ^2 = 97.501	df=12		p=0.0001

Table 3 *Percentage Breakdown of Pedestrian Crossing Behavior, %*

Parameter	Crossroads 1	Crossroads 2	Crossroads 3	Crossroads 4	Crossroads 5
Pedestrian with phone	17	15	7	10	26
Pedestrian with headphones	7	12	8	12	9
Pedestrian with bike, scooter	1	17	34	16	13
Pedestrian talking on phone	3	4	1	5	7
Pedestrian actively using phone	5	3	3	4	6
Pedestrian not using any devices	68	49	47	52	40

Table 4 *Percentage of pedestrian behaviour in terms of compliance with traffic lights, %*

Parameter	Crossroads 1	Crossroads 2	Crossroads 3	Crossroads 4	Crossroads 5
Pedestrians entering on green signal	88	88	97	78	97
Pedestrians entering on green flashing signal	8	9	2	20	3
Pedestrians entering on red signal	4	3	1	1	0
Pedestrians entering on red signal with open traffic	0	0	0	0	0

none of the intersections studied had any cases where pedestrians crossed on a red light with open vehicle traffic, suggesting that pedestrians in Kielce are aware of the dangers associated with such behavior.

The percentage breakdown of pedestrian behavior at crosswalks is presented in Table 3. It is noteworthy that the highest percentage of pedestrians crossing the intersection with a mobile phone in hand was recorded at Intersection 5, where it reached 26%. For pedestrians using headphones, the highest percentage was observed at Intersections 2 and 4, both at 12%. Pedestrians with a bicycle or scooter most frequently crossed at Intersection 3, accounting for 34%. It is important to note that pedestrians using bicycles or scooters made up only 1% of all the pedestrians at Intersection 1. Pedestrians talking on the phone constituted no more than 7% of the total, while those actively using a mobile phone represented no more than 6%. Additionally, it is noteworthy that at Intersection 5, only 40% of all pedestrians observed at the crosswalk were not using any distraction devices.

The percentage breakdown of pedestrian behavior in relation to compliance with the traffic signals is presented in Table 4. It is noteworthy that over 88% of pedestrians crossing at the crosswalks correctly adhered to the traffic signals, crossing only when the green signal was displayed. During the observations, as many as 20% of all the pedestrians at the crosswalk on Intersection 4 entered the crosswalk during the flashing green signal. For the other crosswalks, this percentage did not exceed 9%. In the observational study, none of the pedestrians entered the crosswalk during the red signal with open

vehicle traffic. During the study, only at the crosswalk at Intersection 5 did no pedestrians enter during the red signal. At the other crosswalks, the percentage of such incidents ranged from 1 to 4%.

6 Discussion

The results of the conducted studies in Kielce indicate various pedestrian behaviors at different signalized intersections, as clearly confirmed by the statistical significance coefficient of $p = 0.0001$ (Table 2). This result, which is lower than the accepted significance level of 0.05, suggests a significant impact of the type of intersection on how pedestrians use the crosswalks.

In article [26], the authors analyze a 2018 study on pedestrian safety at crosswalks in Poland, which led to new regulations in 2021 requiring drivers to stop when a pedestrian approaches. The study found that only 45% of drivers yielded to pedestrians at unmarked crossings, while 55% of pedestrians had to wait. Seniors waited longer, and drivers in residential areas were more likely to yield. Risky behaviors like crossing on red lights (7%) and outside crosswalks (8%) were noted, with vehicle speeds often exceeding legal limits, highlighting the need for further safety measures.

Independent research for this study showed a significant rise in pedestrian mobile device use at signalized crosswalks, reaching 14-60% depending on location, with the highest rate at Aleja Solidarnosci and Swietokrzyska in Kielce. The findings underline the need for education and infrastructure changes to reduce risks associated with pedestrian distractions.

In article [27], the authors examine the impact of approaching trams on pedestrian behavior in Wroclaw and Poznan. Pedestrians were more likely to break rules to catch a tram, influencing others to do the same. Predictable traffic signals improved compliance. Similarly, research in Kielce showed traffic intensity influenced risky pedestrian behaviors, with up to 20% crossing during the flashing green lights. In article [28], the authors evaluated behaviors at crosswalks in Poland, identifying factors contributing to pedestrian accidents and proposing infrastructural solutions. Independent research found that 89% of pedestrians in Kielce followed traffic rules, but 15% using phones increased accident risks.

In article [29], a study in Auckland, New Zealand, explored motivations for risky road crossings at undesignated locations, finding habits and attitudes as key factors. Women acted based on personal beliefs, while men were more influenced by peers. Polish research emphasized education on responsible mobile device use, noting distracted pedestrians often took risks like stepping onto the road during the flashing green lights. In article [30], the authors reviewed the eye-tracking studies to understand the pedestrian decision-making during crossings. They highlighted the need for further research on the impact of autonomous vehicles. Polish findings showed that the mobile device use reduced pedestrian attention in 26% of cases at a busy intersection, stressing the importance of education.

In article [31], research in Belgium examined children crossing roads near schools, finding that holding an adult's hand reduced risky behaviors. The study highlights the need for parental education and infrastructural changes like raised crosswalks. Polish research linked mobile device use to decreased attention, especially in younger pedestrians. In article [32], the authors analyzed the pedestrian phone use at signalized intersections, showing that it leads to reduced awareness, slower walking speeds, and risky behaviors. Independent research in Kielce confirmed a rise in phone use, with 26% of pedestrians distracted at the busiest intersections, emphasizing the need for educational initiatives and technological solutions to improve safety.

7 Conclusion

The studies conducted in 2023 at five pedestrian crossings in Kielce showed a significant increase in the number of pedestrians using mobile phones and other electronic devices while crossing the street. Compared to earlier studies conducted by ITS, where the percentage of pedestrians using phones was 7%, the current studies revealed a dramatic increase in this phenomenon. At some crossings, the percentage of pedestrians engaging in risky behaviors related to mobile device use ranged from 14% to as high as 60%, representing a two- to nine-fold increase. This high percentage can be attributed to the growing popularity of smartphones and associated devices such as wireless headphones.

A key finding from the studies is that at the intersection of Aleja Solidarnosci and Swietokrzyska Street, the highest percentage of pedestrians using mobile phones (69 people) and actively using phones while crossing the street (15 people) was recorded. At the intersection of Warszawska Street and Aleja Tysiaclecia Panstwa Polskiego, 12 instances of crossing on a red light were observed, which may be related to the short duration of the green light relative to the time needed to cross the intersection. The analysis results indicate that pedestrians using mobile phones often enter the crossing without proper attention, which can lead to dangerous situations on the road. This phenomenon is consistent with previous studies, which suggest that mobile device use significantly impairs the ability to accurately assess the road conditions.

It is also noteworthy that, compared to previous ITS studies, the percentage of red-light crossings has decreased from 7% to a range of 0.3 to 4%. This indicates a greater awareness of the dangers associated with crossing on a red light. However, there has been an increase in the number of pedestrians entering

the crossing during the flashing green signal, often ending up on a red light. This behavior pattern was observed in 2 to 26% of pedestrians, highlighting the need to continue educational efforts to raise pedestrian awareness.

A new aspect studied in 2023 was the percentage of pedestrians using bicycles, electric scooters, or other personal transport devices while crossing, which ranged from 13% to 30%. Previous ITS studies did not include this aspect, underscoring the need to consider new forms of mobility in the road safety improvement strategies.

Based on the analysis of data from 2020-2023, it was found that the number of pedestrian-involved accidents in Poland has decreased, but the percentage of incidents involving pedestrians stepping onto crosswalks remains stable at around 19-20%. Despite the overall improvement, the issue of inappropriate pedestrian behavior, including mobile phone use, remains a significant challenge. The increase in risky pedestrian behaviors can be partially attributed to the psychological effects of extending pedestrian priority, which may lead to a false sense of security.

Therefore, there is an urgent need to strengthen educational efforts aimed at pedestrians, emphasizing their responsibility for their own safety, especially in the context of mobile device use. Additionally, adapting the road infrastructure, including traffic signals, to the real needs of pedestrians could significantly reduce the risk of accidents and improve overall road safety. Planned further studies focused on unsignalized crossings should aim to better understand pedestrian behavior and assess the risks associated with mobile device use, providing valuable insights for future road safety improvement strategies.

The authors plan further studies on pedestrian behavior, extending the analysis to three European Union countries: Poland, the Czech Republic, and Slovakia. The planned research will include observations of pedestrian behavior at different times of the day, specifically in the morning when people go to work, at midday when most people take lunch breaks, and in the afternoon when many return home. Additionally, the studies will be conducted on both working days and non-working days, allowing for an analysis of how various temporal and social factors influence the pedestrian behavior. This broader scope will provide a more comprehensive understanding of the relationship between the pedestrian behavior and situational context, offering valuable insights for developing effective strategies to improve safety at pedestrian crossings.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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