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EVALUATING AND IDENTIFYING HAZARDS AT PEDESTRIAN CROSSINGS

Summary. Pedestrian crossings are one of the most essential elements of linear infrastructure in road transportation. A crosswalk is a place where a pedestrian should feel safe crossing to the other side of the roadway. Regardless of what means of transportation each road user utilizes, sooner or later, he or she acts as a pedestrian. Thus, he or she becomes a potential victim of accidents that occur on Polish roads. A large proportion of accidents involving pedestrians occur at crosswalks, and proper signage, lighting, and traffic lights cannot always ensure pedestrian safety at a crossing. Many risks affect traffic safety. These include poor judgment on the part of the driver, failure to obey traffic laws, alcohol consumption, and poor weather conditions. Both the pedestrian and the driver of a vehicle can be victims or perpetrators of accidents. In order to prevent traffic hazards at pedestrian crossings, it is necessary to improve the following: the technical conditions of crossings, their markings, lighting, and the use of islands or footbridges. It is also necessary to conduct repeated educational activities among children, adolescents, and adults on the knowledge of traffic regulations. The purpose of the article is to present issues of road transport infrastructure based on the literature and to assess safety at selected pedestrian crossings in the city of Bielsko-Biala.

1. INTRODUCTION

Pedestrian crossings are one of the most important elements of linear infrastructure in road transport. A pedestrian crossing is a place where pedestrians should feel safe when crossing the road. Regardless of the means of transport each road user utilizes, sooner or later, they will be pedestrians and, thus, a potential victim of accidents that occur on Polish roads. Road accidents involving pedestrians evoke very strong emotions and often attract intense media attention, especially when the victims are children or the elderly. Many accidents involving pedestrians occur at crossings, and proper marking, lighting, and traffic lights do not necessarily ensure pedestrian safety. Many threats affect road safety. These include poor judgment of the driver, failure to comply with road traffic regulations, alcohol consumption, and bad weather conditions. Both pedestrians and drivers can be victims or perpetrators of accidents.

To prevent road transport hazards at pedestrian crossings, the following should be improved:

- the technical condition of passages,
- crossing markings,
- passage lighting,
- the use of islands or footbridges,

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- repeated educational activities among children, adolescents, and adults on knowledge regarding road regulations.

In analyzing the causes of accidents at pedestrian crossings, it is important to highlight some key factors contributing to their occurrence. Road traffic accidents are the eighth leading cause of death globally, with vulnerable road users, particularly pedestrians, being the most affected. In 2019, it was reported that 21% of fatalities involved pedestrians [1]. Some of the main issues are that unsignalled pedestrian crossings are arranged in a way that often makes them difficult for drivers to detect, zebra markings are sometimes substantially worn out, and signs cannot always be easily seen in the dark [2]. Pedestrian safety has recently emerged as a public health challenge worldwide [3].

2. REQUIREMENTS FOR PEDESTRIAN TRAFFIC

Pedestrian safety requirements are fundamental for ensuring the well-being of all road users [4]. Road Traffic Law and the Journal of Laws are documents that regulate the requirements for pedestrian traffic. They include pedestrians' obligations regarding both what they should do and what they should not do when entering road traffic.

Pedestrian's obligations on the road

A pedestrian is obliged to [5]:

- Use the sidewalk, or if one is not available, walk along the edge of the roadway.
- A pedestrian can enter the road when there is no shoulder.
- When entering the road, a pedestrian should stay as close to the edge of the road as possible and give way to vehicles.
- Pedestrians are obliged to walk on the left side of the sidewalk/road.
- Pedestrians walking on the road are obliged to walk one behind the other. In case of good visibility and low traffic intensity, two pedestrians can walk side by side.
- Pedestrians may use a bicycle path only when there is no sidewalk or shoulder.
- Pedestrians are obliged to obey road regulations.

It is prohibited to [6]:

- enter the road directly in front of or behind a vehicle,
- cross the road where visibility is limited,
- slow down or stop when crossing the road,
- cross the road in a prohibited place.

Driver responsibilities:

- the driver is obliged to drive on the right,
- the driver should drive as close as possible to the right edge of the road,
- if the lanes on the road are marked with lines, the driver cannot leave his lane,
- the driver is obliged to comply with road regulations.

Pedestrian crossing behavior significantly affects pedestrian safety, especially at uncontrolled mid-block crosswalks [7].

3. SOLUTIONS FOR IMPROVING THE SAFETY OF ROAD USERS

Many solutions can improve road safety. The analysis of the literature on the subject and the causes of road accidents shows that the introduction of modern systems and electronic systems in vehicles can reduce the number of fatalities. In order to increase safety on the roads of the European Union Member States, the European Parliament introduced a project called "Intelligent Car." The "Intelligent Car" initiative is an attempt to create new circumstances in which cars do not have accidents and traffic congestion is radically reduced [8]. Road traffic crashes are the eighth leading cause of death globally. Vulnerable road users, particularly pedestrians, are especially exposed. Pedestrian accidents are more

frequent in urban areas than in rural areas because in the densely populated urban zones walking is a daily routine for most people. The safety level of a pedestrian crossing can be assessed in different ways [9].

An intelligent motor vehicle should be considered a technical object that has the following properties [10]:

- automatically maintains a specific high level of passenger safety,
- reduces the impact of harmful factors (exhaust fumes, noise) on the natural environment,
- automatically adapts to existing traffic conditions,
- ensures a certain high level of driving comfort,
- ensures a high level of operational and diagnostic services.

The framework of an intelligent vehicle includes solutions for both the engine and the chassis and body of the car. The basic electronic systems that increase road safety are installed in the chassis and body of the vehicle. These are advanced driver assistance systems (ADAS), which have "high intelligence" to actively help drivers in the event of fatigue, inattention, or disregard of information important for safety. Advanced driver assistance systems have brought several benefits to the automotive industry, and their widespread use has the potential to reduce the number of road accidents. The reasons for this are mainly attributed to improved perception of the driving environment and reduced human errors [11].

Selected electronic systems that improve safety

The main systems that help improve car safety on the road include [12]:

- **Antilock brake system** – this is a system that prevents the car wheels from locking during braking. Since 2006, this system has been mandatory in all cars sold in Poland. In addition, BAS (i.e., Brake assist system) is increasingly found alongside ABS. This system supports the driver during sudden braking [13].
- **Electronic stability program** – this system eliminates skidding when the car travels along curves. ESP (Electronic stability program) is an automotive active safety system developed based on the automotive anti-lock braking system (ABS) and traction control system (TCS). ESP is an automobile active safety system developed based on an automobile's anti-lock braking system (ABS) and traction control system (TCS) [14].
- **Acceleration slip regulation** – this traction control system allows the driver to optimize traction during acceleration. It belongs to the group of Advanced Vehicle Control Systems (or Automated Highway Systems), whose main task is to prevent excessive slipping of the vehicle's wheels during acceleration, starting, and driving on bends or various surfaces.
- **Adaptive cruise control** – this is a system that adjusts the car's speed to the conditions and condition of the road. It is automatic and allows the driver to maintain a safe distance between other vehicles. It is considered one of the most advanced driving assistance systems available in new smart vehicles. This system is considered one of the most advanced driving assistant systems available in new intelligent vehicles [15].
- **Intelligent headlight control –** this system ensures optimal road lighting, improves lighting, and significantly increases the comfort and safety of traveling at night. The system is based on a camera sensor that measures the ambient brightness and the distance between the vehicle in front and the vehicle approaching from the opposite direction.
- **Adaptive front lighting system –** this adaptive low beam controller system controls the low beam. Its task is to better illuminate the road. An AFS is often used to illuminate corners.
- **Road sign recognition –** road sign recognition systems are one of the main tasks of intelligent transport systems (ITS). These systems use cameras mounted in vehicles to identify road signs while driving. Their primary function is to inform the driver about recent road signs that may have been missed due to distraction or inattention [16].
- **Parking assistance system (PAS)** – this system is responsible for assisting the driver when parking in road traffic. The system uses ultrasonic sensors mounted on the front and rear

bumpers. The system monitors the field of view within a range of approximately 2.5 m and informs the driver about the proximity of obstacles up to approximately 25 cm away.

- **Side view assist** – the vehicle's blind spot mirror monitoring system provides the driver with a visual warning if there are other vehicles in the driver's blind spot by displaying warning lights at the base of the mirrors [17].
- **Fog recognition system** – this system supports driving in difficult weather conditions (e.g., in fog).
- **Lane assist** – this system warns the driver when they leave their lane.
- **Driver alert** – this system emits an audible signal when it detects that the driver is becoming drowsy. It is especially useful for long routes and at night.
- **Night vision assist** – this system improves visibility through night vision. It is especially used at night or in difficult weather conditions.

In addition, important elements are airbags, seat belts, safety seats, headrests, and child car seats. The future is most likely to belong to autonomous and connected vehicles. Vehicle automation technologies open new avenues to improve present transportation networks. It is predicted that autonomous vehicles (AVs) and connected vehicles (CVs) will improve traffic flow by increasing road capacities and significantly reducing travel time and congestion [19]. Pedestrian collision avoidance (PCA) is a crucial task in the development and democratization of autonomous vehicles. This topic represents a critical issue in the improvement and automation of vehicles. Therefore, equipping partially autonomous vehicles with effective and robust PCA systems is a prime solution through which the safety of pedestrians on the road can be enhanced while moving toward the full automation of road traffic. According to Verstraete and Muhammad, the literature on pedestrian collision avoidance systems in autonomous vehicles can be organized into five key categories [20]:

1. **Pedestrian detection methods:**
   - **Line-of-sight (LOS) methods** rely on the autonomous vehicle's onboard perception sensors to detect pedestrians within its field of view. Techniques include wireless communication and probabilistic models to enhance detection accuracy.
   - **Non-line-of-sight (NLOS) methods** address the detection of pedestrians who are not directly visible to the vehicle. They include the use of wireless communication technologies and probabilistic models to predict pedestrian presence and movements in obstructed scenarios.
2. **Collision avoidance approaches:**
   - **Rules-based methods** utilize predefined rules and risk assessment indicators, such as time-to-collision (TTC), to trigger avoidance actions.
   - **Force-field-based methods** include potential field and elastic band approaches, which generate artificial fields of attractive and repulsive forces to plan safe paths.
   - **Model-based methods** employ mathematical modeling of the vehicle and its environment to determine optimal collision avoidance maneuvers.
   - **AI-based methods** incorporate neural networks and fuzzy controllers to adaptively manage collision avoidance based on real-time data and learning algorithms.
3. **Actions triggered by collision avoidance systems:**
   - **Vehicle actions** include longitudinal control (throttle and brake) and lateral control (steering) to navigate safely around pedestrians.
   - **Pedestrian involvement systems** may send warnings to pedestrians via smartphones or other communication devices to alert them of potential collisions.
4. **Computing methods:**
   - **Onboard unit (OBU) computations** are the most common method, performing necessary calculations directly within the vehicle's onboard computer system.
   - **External servers** rely on cloud-based servers for computation, which can introduce latency but offer extensive processing power.

- **Pedestrian smartphones** are used in certain approaches for real-time location and movement data, though this method depends on the quality and battery life of personal devices.

5. **Test methods:**
   - **Real car testing** involves full-scale tests using actual autonomous vehicles to validate system performance in real-world conditions.
   - **Simulators:**
     - ✓ **Custom simulators** include proprietary software and prototype environments created for specific research needs.
     - ✓ **Open-source simulators** include widely used platforms such as CARLA and PreScan that allow for detailed and scalable testing scenarios.

These categories comprehensively cover the various strategies and technologies employed in the development of pedestrian collision avoidance systems, providing a structured overview of the field's current state and future directions.

4. METHODOLOGY

Study area and data collection

The current study was conducted at a pedestrian crossing near the University of Bielsko-Biała, specifically at the intersection of Szeroka and Bystrzańska Streets. This location was chosen due to its high pedestrian traffic and history of accidents involving pedestrians. Data collection took place over two consecutive days in April 2024 (a Friday and a Saturday). Measurements were taken during peak traffic hours, from 7:00 to 9:00 and from 19:00 to 21:00. These times were selected to capture a comprehensive view of pedestrian and vehicle interactions. The pedestrian crossing was evaluated using the following criteria:

- visibility of lanes,
- traffic lights,
- road signs,
- lighting,
- safety islands,
- pedestrian visibility,
- pedestrian traffic intensity,
- car traffic intensity.

The first six criteria were assessed on a scale from 1 to 5, where 1 was the worst and 5 was the best. The ratings assigned to these criteria are the subjective assessments of the authors. Pedestrian and vehicle traffic intensities were recorded to understand the dynamics at the crossing. The collected data were analyzed to identify factors affecting pedestrian safety. This involved calculating average ratings for each assessment criterion and examining the correlation between pedestrian and vehicle traffic intensities and safety conditions. This methodology provided a structured approach to assess the safety of pedestrian crossings and identify key areas that need attention to improve pedestrian safety in urban environments.

5. PEDESTRIAN SAFETY ASSESSMENT

This article focuses on the analysis of the safety of a specific pedestrian crossing located in Bielsko-Biała, near the University of Bielsko-Biała. The choice of this location as the subject of research results from several key factors. First, the proximity of the university area is associated with intense pedestrian traffic, mainly of young people, which increases the risk of road incidents. Additionally, the vicinity of a densely populated housing estate increases the frequency at this crossing, increasing the potential

threats to the safety of residents. Unfortunately, this crossing has been the site of numerous accidents, including those of young people being hit. Incidents from 2018 and 2022 are particularly disturbing, in which young people suffered serious injuries, highlighting the urgent need to take preventive measures and increase safety in the area. This crossing is located at Bystrzańska Street (near the Vienna Hotel and the intersection with Startowa Street).

Fig. 1. Screenshots of road accidents at pedestrian crossings (data from local news websites)

In light of the facts presented above, this analysis aims not only to draw attention to the problem but also to initiate a discussion on possible solutions that can minimize the risk of further tragic events. This analysis is also an attempt to respond to the social responsibility of science to focus on problems that directly affect the lives and health of young people in our society. The assumed evaluation criteria are presented in Tables 1–6. The other two criteria (i.e., the intensity of pedestrian and car traffic), included a scale regarding the number of people and cars crossing the crossing/passing through the crossing in the examined period. The ratings assigned to individual criteria are the subjective assessments of the authors.

Assessment criteria:

Visibility of lanes

Table 1

Assessment criteria for lane visibility

Rating	Assessment criteria
1	Unsatisfactory rating – the pedestrian crossing markings are difficult to notice by the driver driving on the road.
2	Mediocre rating - the pedestrian crossing markings are visible, but not completely. Most of the lanes are not visible, but some are visible to an oncoming car.
3	Satisfactory rating – this grade is between unsatisfactory and very good. Such a lane is visible to the driver from a greater distance, but some defects are still noticeable
4	Good rating - the pedestrian crossing markings are visible to the driver from a distance. There are minimal effects of using the passage (i.e., blurring and a lack of paint).
5	Very good rating - the pedestrian crossing markings are very visible to the driver from a distance. There are no defects on the pedestrian crossing.

Traffic lights

Table 2

Assessment criteria for traffic lights

Rating	Assessment criteria
1	Unsatisfactory rating - no traffic lights at the pedestrian crossing.
3	Satisfactory rating - traffic lights do not work.
5	Very good rating - traffic lights are located at the pedestrian crossing.

Only three aspects could be taken into account when assessing traffic lights.

Road signs

Table 3

Assessment criteria for road signs

Rating	Assessment criteria
1	Unsatisfactory rating - no vertical road sign informing about a pedestrian crossing.
3	Satisfactory rating - the vertical road sign is invisible due to a poor location or is damaged (e.g., painted over).
5	Very good rating - the sign informing about the road crossing is located in a clearly visible place in front of the crossing.

Lighting

Table 4

Assessment criteria for lighting

Rating	Assessment criteria
1	Unsatisfactory rating - lack of lighting at the pedestrian crossing.
2	Mediocre rating - the lighting is located far from the crossing and illuminates the pedestrian crossing very poorly.
3	Satisfactory rating - lighting is visible, away from the passage. The crossing pedestrian is visible.
4	Good rating - lighting is at the pedestrian crossing. Illuminates the entire pedestrian crossing.
5	Very good rating - one or more lamps illuminate the pedestrian crossing. Such a passage is perfectly lit and visible from a distance.

An island in the middle of the road

Table 5

Assessment criteria for an island in the middle of the road

Rating	Assessment criteria
1	Unsatisfactory rating - lack of an island in the middle of the road at a pedestrian crossing.
5	Very good rating - the island is located in the middle of the road, and there are pedestrian crossings, which have a very good impact on road safety.

Pedestrian visibility by the driver

Table 6

Assessment criteria for pedestrian visibility by driver

Rating	Assessment criteria
1	Unsatisfactory rating - the pedestrian crossing is placed in such a place that the pedestrian is not visible to the driver. Such a crossing may be placed behind a building when a pedestrian entering the crossing may endanger his or her own life.
2	Poor rating - pedestrians are poorly visible at the pedestrian crossing due to insufficient lighting and inadequate road surface conditions.
3	Satisfactory rating - the pedestrian is visible at the pedestrian crossing by the driver, but the driver sees him very close to the crossing, which poses a threat.
4	Good rating - the pedestrian is visible at the pedestrian crossing for the driver. The driver has enough time to brake.
5	Very good rating - the pedestrian is very clearly visible to the driver. He notices them at the beginning of the street and has plenty of time to react and brake.

Parameters affecting safety at the tested pedestrian crossing:

Visibility of lanes

Fig. 2. Pedestrian crossing in the examined city area (the authors' photography)

When analyzing photos of pedestrian crossings taken during the day and late in the evening, significant differences in the visibility of the lanes can be noticed. In the case of daytime photos, the first lanes are clearly visible, which promotes pedestrian safety. However, with each subsequent lane, visibility gradually decreases, and the last lane is almost invisible from a distance. At night, this situation worsens due to both limited street lighting and the light-reflecting characteristics of the road markings.

These observations highlight the need for better engineering solutions, such as the use of highly reflective paint or additional crossing lighting, which could significantly improve the visibility of the stripes along the length of the pedestrian crossing, especially after dark. The application of such solutions is crucial to ensuring pedestrian safety and reducing the risk of road accidents.

Traffic lights

There are no traffic lights at the pedestrian crossing in question, which poses a significant threat to pedestrian safety. The absence of traffic lights at this intersection may lead to unpredictable driver behavior and increase the risk of accidents. Although there is no constant supervision by city guards who could regulate pedestrian and vehicle traffic, the introduction of traffic lights could significantly improve the situation.

Installing traffic lights would not only increase safety but also contribute to a more orderly and predictable traffic flow. This type of infrastructure intervention, supported by appropriate traffic flow studies and accident history analysis in the area, could effectively reduce the number of potential hazards while providing better protection for pedestrians.

Road signs

At the pedestrian crossing in question, a strategically placed road sign informs drivers of its presence, which is crucial to increasing pedestrian safety. This sign, located immediately before the crossing, plays an important role in effectively drawing the attention of road users to the need to reduce speed and increase vigilance in this area.

Fig. 3. Road sign on the analyzed pedestrian crossing

Placing a road sign close to a pedestrian crossing is consistent with best practices in designing safe road infrastructure. Its visibility and readability are crucial, especially in places with heavy traffic, which significantly contributes to reducing the risk of accidents. This organization of road space not only improves safety but also increases drivers' awareness of important places on the road where special caution is necessary.

When it comes to potential changes to the positioning of a crosswalk road sign, there are a few suggestions that could improve the visibility and effectiveness of the sign:

- **Moving the sign** - moving the pedestrian crossing warning sign a little earlier before crossing could give drivers more time to react. This change is especially important on high-speed roads or in areas with limited visibility.
- **Additional markings** - additional signs or symbols painted on the road could be added to increase the visibility of the pedestrian crossing. Such symbols can be visible from a distance and draw attention to the upcoming transition.
- **Sign lighting** - installing lighting directed at the sign can significantly improve its visibility at night and in bad weather conditions. This lighting can be activated by a motion sensor, which would further increase the effectiveness of the warning.
- **Higher sign location** - placing a sign on a taller structure can improve its visibility to both drivers and pedestrians, especially in congested urban areas where roadside obstructions may block the view.
- **Multiple signs** - several signs could be placed at different points before a pedestrian crossing, especially on longer sections of the road, to increase drivers' awareness of the approaching crossing.

These changes may contribute to increasing safety and reducing the number of accidents at pedestrian crossings. Each of these changes should be preceded by a detailed analysis and consultation with road safety experts to ensure that the solutions introduced will be effective and appropriate for a given location.

Lighting

The photo in Figure 4 of a pedestrian crossing at night shows that the current lighting does not provide sufficient visibility of the entire crossing. The lighting is mainly concentrated at the beginning of the passage, which means that further parts of the passage remain in the dark.

Fig. 4. Lighting on the analyzed pedestrian crossing (the authors' photography)

Here are some suggested changes that could improve pedestrian crossing lighting, thereby increasing safety at night:

- **Additional lamps above the crossing** - installing additional lamps directly above the pedestrian crossing could provide evenly distributed lighting along its entire length. The use of high-brightness LED lamps is recommended due to their efficiency and durability.
- **Pavement-integrated lighting** - using modern technology such as pavement-integrated lighting that is activated when pedestrians approach could significantly improve visibility without unduly disturbing the surroundings.
- **Motion sensor systems** - installing motion sensors that activate additional lighting only when pedestrians are present can be an effective way to increase safety and energy efficiency.

- **Better synchronization of lighting with road signals** - coordination of lighting with road signals can help inform drivers about the presence of pedestrians at the crossing, especially in the evening and at night.
- **Inspection and adjustment of existing lighting** - regular inspection and appropriate adjustment of the beam angle of existing lamps can improve the overall effectiveness of pedestrian crossing lighting.

These changes could significantly increase pedestrian safety, especially at night, when the risk of accidents is increased due to limited visibility.

An island in the middle of the road

A safety island located in the middle of a pedestrian crossing is an important element of road infrastructure that can significantly increase pedestrian safety. It is a narrow, separated part of the road that allows pedestrians to safely cross the other side of the road in two stages. The island allows pedestrians to stop in the middle of the road and assess traffic conditions before completing the crossing. The safety island has several key benefits:

- **Reduced crossing length** – pedestrians have a shorter distance to cover in one go, which reduces exposure time to vehicles and allows them to focus on one direction of traffic at a time.
- **Observation point** – the island creates a safe point from which pedestrians can observe approaching vehicles, which is especially important on busy streets.
- **Slowing down vehicle traffic** – crossings with islands often result in vehicle traffic slowing down near the crossing, as drivers must maneuver around the island.
- **Better visibility of pedestrians** - the island allows drivers to better see pedestrians, who are more visible standing on the island than on the edge of the sidewalk.

To further increase safety at this crossing, the following improvements could be considered:

- **Additional signage** - placing additional information signs around the island could better inform drivers to slow down before crossing.
- **Island lighting** - installing lighting on the island itself could increase its visibility at night, which is especially important on poorly lit roads.
- **Protective barriers** - installing small protective barriers on the island can provide additional protection for pedestrians, especially children, against accidentally entering the road.
- **Horizontal markings** - strengthening horizontal markings at the crossing can help drivers and pedestrians better orient themselves.

Implementing these changes could significantly improve the functionality of the safety island and the overall effectiveness of the pedestrian crossing, especially in high-traffic areas.

Pedestrian visibility by the driver

In the photos presented, despite the challenges related to lighting, it can be observed that the pedestrian is relatively clearly visible to the oncoming driver, especially when they are directly on the pedestrian crossing. The skillful arrangement of lighting and contrasting crossing stripes can increase visibility, giving the driver enough time to brake and react appropriately, which contributes to increasing the safety of both pedestrians and road users.

Car and pedestrian traffic intensity

Table 7

Car and pedestrian traffic intensity

	Friday	Saturday	Unit
Pedestrian traffic volume	163	15	People/10 minutes
Car traffic intensity	78	32	Cars/10 minutes

Average rating for the road crossing at the intersection of Szeroka and Bystrzańska streets

Table 8

Average rating for the pedestrian crossing on ul. Szeroka – Bystrzańska

Elements included in the criteria	Rating	Car traffic intensity [unit/10 min]	Pedestrian traffic volume [unit/10 min]	
Visibility of lanes	2	78	163	**Friday**
Traffic lights	1	32	15	**Saturday**
Road sign	5			
Lighting	5			
An island in the middle of the road	1			
Pedestrian visibility by the driver	5			
Mean	**3.16**			

Based on the analysis and observations regarding the pedestrian crossing in Bielsko-Biała, the following recommendations can be suggested to improve the safety and comfort of users of this area:

- **Introduction of improved lighting solutions** - lighting of pedestrian crossings is crucial for the visibility of pedestrians in the evening and at night. It is recommended to use high-brightness LED lamps that will ensure the even illumination of the entire length of the crossing. Considering additional lighting in the form of lamps integrated into the surface can further increase pedestrian visibility without unduly disturbing the surroundings.
- **Implementation of advanced traffic light systems** - the absence of traffic lights at the tested pedestrian crossing is a serious threat. The introduction of intelligent traffic light systems that can react to the presence of pedestrians and adapt to traffic conditions can significantly improve safety and traffic flow.
- **Improving road markings and visual warning signals** - current signs are crucial, but their positioning and visibility can be further optimized. It is recommended to add additional warning signs and symbols painted on the road to increase the visibility of the crossing. The ability to install lighting directed at signs will help keep them visible at night.
- **Improving the lighting of the island** - installing additional lighting on the island itself can significantly increase its visibility after dark. Low-intensity lamps that are activated by motion sensors could be used to increase energy efficiency and lighting effectiveness.
- **Improved visibility of the island** - in addition to lighting, additional horizontal or vertical markings around the island can help drivers and pedestrians better orient themselves. Highly reflective paints or lighting elements could be integrated into the surface, which could be particularly effective at night and in bad weather.
- **Protective barriers on the island** - installing small, aesthetic protective barriers can increase the safety of pedestrians, especially children, by preventing them from accidentally entering the road.

Safety in heavily vegetated areas

Pedestrian safety can be compromised by natural elements, such as trees, which obstruct drivers' visibility and obscure pedestrian crossings. The presence of trees and other vegetation near pedestrian crossings can create blind spots for drivers, significantly increasing the risk of accidents. Effective street design should consider the placement of natural elements to ensure they do not interfere with pedestrian visibility at crossings. The safety of pedestrian crossings is a critical aspect of urban traffic management, particularly in areas where natural elements, such as trees and dense vegetation, are present. The images provided in Figure 5 illustrate a pedestrian crossing on Bystrzańska Street, characterized by significant tree coverage and greenery near the roadway [18]. The images show that the trees lining both sides of the road and the central median contribute to potential visibility issues for both drivers and pedestrians.

Fig. 5. Trees around the pedestrian crossing (screenshots from the street view website)

The figure shows the perspective of drivers approaching the pedestrian crossing. The shadows cast by the trees, along with the dense foliage, can obscure pedestrians who are waiting to cross or have already started crossing the road, especially during certain times of the day when the sun's angle exacerbates shadows. This visual obstruction is particularly concerning in scenarios involving high vehicle speeds or poor weather conditions, which further reduce visibility.

The figure provides a broad view of the crossing environment, highlighting the extensive tree coverage in the area. Effective street design should consider the placement of natural elements to ensure they do not interfere with pedestrian visibility at crossings. Implementing measures such as trimming lower branches, installing additional lighting, and using reflective materials on pedestrian signage and crossings can enhance visibility and safety.

In conclusion, while natural elements like trees provide aesthetic and environmental benefits, their presence near pedestrian crossings requires careful management to ensure they do not compromise safety. Urban planners and traffic safety professionals must balance these considerations to create a safe and functional environment for pedestrians.

The application of these recommendations requires an integrated approach that combines technology, infrastructure, and road user education. Cooperation with local authorities, educational institutions, and social organizations will be key in implementing and monitoring the effectiveness of the proposed solutions. In summary, every pedestrian has the right to feel safe at a pedestrian crossing, and any threats they may encounter are related primarily to a lack of caution, inappropriate behavior of car drivers, negligence of appropriate units, lack of islands, vertical markings, and a lack of lighting at road crossings.

6. CONCLUSIONS

The evaluation and identification of hazards at pedestrian crossings have highlighted significant safety concerns requiring immediate attention. The analysis conducted at the pedestrian crossing near the University of Bielsko-Biała, specifically at the intersection of Szeroka and Bystrzańska Streets, revealed several critical areas requiring improvement to enhance pedestrian safety.

The primary findings indicate that the visibility of lanes, traffic lights, road signs, lighting, and the presence of safety islands are crucial factors influencing pedestrian safety. The current state of these elements at the studied crossing is inadequate, contributing to a higher risk of accidents. Pedestrian visibility by drivers, especially during peak hours, is compromised due to insufficient lighting and poorly marked lanes.

Moreover, the intensity of pedestrian and vehicle traffic significantly impacts safety. High pedestrian traffic, coupled with substantial vehicle flow, exacerbates the risk, particularly in poorly lit and inadequately marked crossings. The data reported in this study underscore the need for better infrastructure and systematic improvements.

A multifaceted approach is required to address these issues. Enhanced lighting systems, the introduction of intelligent traffic lights, improved road markings, and the installation of safety islands are imperative. Additionally, managing vegetation to ensure clear visibility and implementing regular maintenance schedules will further mitigate risks.

Future trends in pedestrian safety are likely to be influenced by advancements in technology and urban planning. The integration of smart city technologies, such as automated pedestrian detection systems and real-time traffic management, holds promise for significantly reducing pedestrian accidents. Moreover, the growing emphasis on sustainable urban development will likely lead to increased investment in pedestrian-friendly infrastructure, including the expansion of pedestrian zones and improved crosswalk designs.

Continuous monitoring and adaptive strategies will be essential in creating safer pedestrian environments. This study's findings contribute to the broader understanding of pedestrian safety at crossings, providing a foundation for policymakers, urban planners, and traffic management authorities to develop targeted interventions. Ensuring pedestrian safety not only protects lives but also promotes a more accessible and user-friendly urban infrastructure.

In summary, the evaluation of pedestrian crossings in Bielsko-Biała revealed significant safety concerns that require immediate attention. The primary factors influencing pedestrian safety include the visibility of lanes, traffic lights, road signs, lighting, and the presence of safety islands. The current state of these elements at the studied crossing is inadequate, contributing to a higher risk of accidents.

High pedestrian traffic combined with substantial vehicle flow exacerbates the risk, particularly in poorly lit and inadequately marked crossings. The data reported in this study underscore the need for improved infrastructure and systematic enhancements. The following recommendations are made to address these issues:

- Implementation of advanced lighting systems, including high-brightness LED lamps and integrated pavement lighting.
- Introduction of intelligent traffic light systems that respond to pedestrians' presence and adapt to traffic conditions.
- Enhancement of road markings and visual warning signals, including additional painted symbols and illuminated signs.
- Regular management of vegetation to ensure clear visibility of pedestrian crossings.

Despite the numerous accidents that have occurred at the analyzed road section, no actions have been taken to improve safety at this crossing. It is noteworthy that other crossings on the same road section have implemented traffic lights or safety islands, confirming the effectiveness of these measures. However, this particular crossing remains unchanged and continues to pose a risk. The proposed solutions aim to not only enhance pedestrian safety but also contribute to creating a more user-friendly urban infrastructure. Authorities and relevant bodies should take action to implement these changes to ensure safe conditions for all road users.

This study highlights the need for immediate and targeted interventions. Continuous monitoring and adaptive strategies will be essential in creating safer pedestrian environments. The findings provide a foundation for policymakers, urban planners, and traffic management authorities to develop and implement effective measures. Ensuring pedestrian safety protects lives and promotes a more accessible and user-friendly urban infrastructure.

In conclusion, fostering a collaborative approach between local authorities, urban planners, and the community is crucial for implementing these recommendations effectively. Prioritizing pedestrian safety can pave the way for safer, more resilient urban spaces that cater to the needs of all road users.

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