Advances in Science and Technology Research Journal

Advances in Science and Technology Research Journal, 2026, 20(1), 477–490
https://doi.org/10.12913/22998624/210934
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Received: 2025.09.03
Accepted: 2025.10.16
Published: 2025.11.21

Analysis and evaluation of the provision of giving precedence to a pedestrian at a crosswalk on a roadway

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ABSTRACT

In the operation of buses, trolleybuses, and streetcars in public transport there are risks of accidents. The highway code is part of the safety system. The rules written should take into account not exposing passengers to accident hazards. Drivers of public transport have a dilemma: either to protect passengers or pedestrians at a pedestrian crossing. The article presents considerations on the analysis of the correctness of the introduced rule giving priority privilege to the pedestrians entering a pedestrian crossing. When crossing a crosswalk on roads, pedestrians are exposed to accidents. The human factor contributes enormously to their occurrence. In particular extreme situations on the road, the regulations to be applied are counter effective. This is indicated by the high number of accidents at pedestrian crossings. The regulations do not take into account the possible situations that often occur on the road. The state of drivers' knowledge of the current law regarding the privileges of pedestrians is unsatisfactory. These are measures from the area of active safety system in the operation of vehicles by road participants. The conclusions point to the need for training drivers, as well as changing the provisions of the current traffic law that take into account the limitations of public transport. There is a need to amend, clarify and specify the provisions of the law in the area under review.

Keywords: bus operation, yielding priority, pedestrians, driving behavior, active safety.

INTRODUCTION

Currently, Europeans have great ease in crossing borders. As a result, there is a large share of foreigners as road users on the roads in the EU [1, 2]. Poland is part of the European Union. The traffic regulations in Poland should be clear, precise, easy to understand as well as apply for Poles and foreigners. The knowledge and skills of driving Poles (who are part of the EU) and the knowledge and skills of driving citizens of other EU countries, affect the road traffic safety system [3–5]. Analysis of the state of knowledge of the Polish driving population allows concluding that it is insufficient [6–8]. Are the regulations correctly formulated, clear, understandable and do not contribute to accidents? This applies to residents of the country, as well as foreigners residing in the country, traveling in their own cars [9–11]. Thus, it is important to have knowledge on the behavior of the drivers in the scope of conduct under study and on the regulations as it relates to a country that is part of the EU [12–14].

In Poland, the principle of giving way to a pedestrian who is in a crosswalk applies. In addition, pedestrians intending to enter a crosswalk (with the exception of streetcars) are given priority. However, accidents do occur at pedestrian crossings. In 2013-2015, the number of accidents was registered in the range of 3400–3550 per year. In 2016–2017, there was an increase in the number of accidents to about 4100 per year. Since 2018,

there has been a steady decline in the number of traffic accidents at pedestrian crossings. In 2022, there was a slight increase [15]. In 2022, 2463 traffic accidents were recorded at pedestrian crossings, or 51.7% of all accidents involving pedestrians. In total, 145 people were killed (31.5% of all pedestrians killed), and 2391 people were injured (54.8% of all pedestrians injured). Pedestrian crossings are dangerous places and pedestrians should be better protected from accidents [16]. Increasing preferential treatment when entering the roadway may worsen accident statistics.

Recent studies indicate that the issues related to pedestrian priority should be analyzed considering actual traffic conditions [17–19]. In the literature, the so-called "yellow light dilemma" can be found, where authors emphasize that drivers often do not know whether they should accelerate or slow down, which may have its equivalent in the decisions regarding stopping before pedestrian crossings [20–22].

Many authors also highlight the difficulties associated with modeling driver behavior under heavy traffic conditions, which is crucial in the context of pedestrian crossing analysis [23–25]. Further studies show comparisons of gap acceptance by car and motorcycle drivers, which is also significant for assessing when drivers decide to stop before a crossing [26–28]. Sudden stops in urban traffic constitute a significant stress factor on both the vehicle structure and the materials used in its construction [29–31]. High decelerations generated during sudden braking result in significant dynamic stresses, particularly in suspension and braking system components, and in the supporting structures of the body [32–34]. Materials with high fatigue strength, such as high-strength steels or fiber composites, exhibit greater resistance to the cyclic loads associated with such events [35–37].

In addition, frequent sudden stops can lead to the accumulation of microcracks, particularly in welded joints and stress concentration zones [38–42]. Therefore, the analysis of the behavior of materials underdynamic conditions – taking into account parameters such as yield strength, impact energy absorption and vibration damping – is crucial for the design of durable and safe structures of vehicles operated in urban conditions [4, 43–45].

Palat and Delhomme conducted simulation studies on driver behavior at intersections with traffic lights, indicating that psychological factors play a significant role in decision-making on the road. The results of these studies confirm that introduced regulations should be adapted to the actual behavior of road users [46].

Figure 1 shows the data on accidents at pedestrian crossings by year from 2013 to 2022. Under the slogan of "improving safety", pedestrians have been given additional privileges in the newly introduced legislation. The Traffic Law was amended to "improve their safety" [47].

The purpose of the research was to analyze and evaluate the relevant provisions of the Traffic Law in the area under consideration in terms of the correctness of the provision and its correctness. The goal was also to obtain information about the correctness of the current law in terms of giving precedence to a pedestrian entering a pedestrian crossing. The thesis is that the drivers are not aware that the Police, the Courts, may

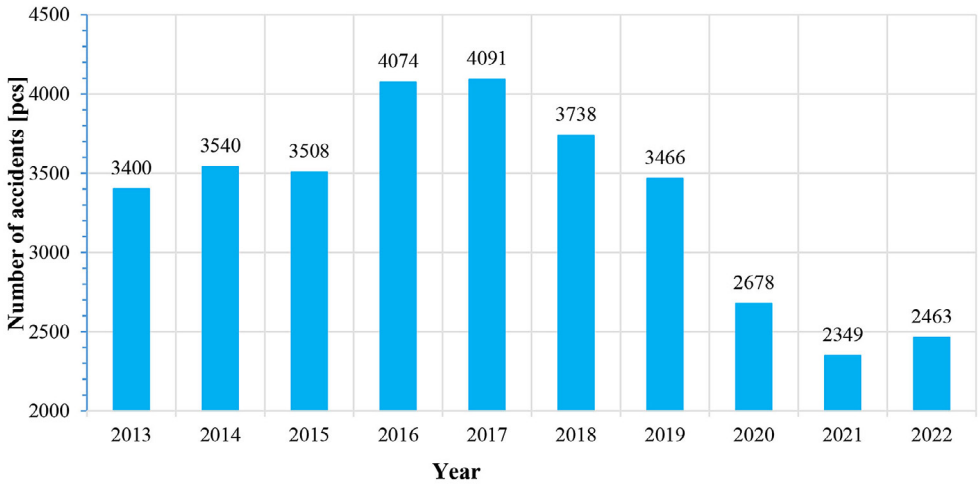

Figure 1. Number of accidents at pedestrian crossings in particular years [24]

interpret differently (differently) the laws in force regarding the preference of the pedestrian. The scope of the covers the legal act [47] in force in Poland. The scope was limited to the analysis of a selected provision on traffic participants, in the area of pedestrian preference.

The subject of the study was the population of traffic participants on roads in Poland. The subject of the analysis were the provisions in the legal regulations (which are part of the safety system) regarding the privileging of pedestrians. The regulations in force in Poland [47] are based on the 1968 Vienna Convention on Road Traffic [48].

The method used in the analysis and evaluation is based on deduction, induction and analysis of possible events during the investigation and passage of a pedestrian at a pedestrian crossing.

The research workshop is based on the analysis and synthesis of the course of possible events arising from the law. In the available literature, analyses of the compatibility and correctness of the national act in the subject area have not been encountered. No publications have been found that show the defects of the provisions in the regulations of the national legislation in the area under consideration. The following questions can be formulated: can legal regulations contain imprecise wording? If such wording is included, are should it be accepted or tolerated? Should there be an obligation to eliminate them from existing legislation? Should imprecise wording, not strictly defined, be clarified or removed from the legal record? What level of irregularity is acceptable, and what level is no longer acceptable?

RESEARCH PROBLEM

Drivers often do not realize they are violating the rules (forcing priority, overtaking, failing to stop in front of a pedestrian crossing – see Figure 2), as this generally does not end in an accident. However, when this happens, the procedure for determining fault begins. If the surveillance (or in-car) cameras did not record the incident, then the police determine the course of the accident and fault, based on the accounts of the participants – the organization of traffic in that place and the damage to the vehicle. There is a problem of (over)interpretation of the current provisions of the traffic law. How to understand the phrase "with special care"?

Pedestrians have been given additional privileges. The Traffic Law [47] was amended as follows in Article 13, paragraph 1. "A pedestrian entering or crossing a roadway or track shall be obliged to exercise extreme caution and, subject to paragraphs 2 and 3, to use a crosswalk", paragraph 1a. "A pedestrian in a pedestrian crossing shall have priority over a vehicle. A pedestrian entering a crosswalk shall have priority over a vehicle, except for a streetcar."

A pedestrian approaching a crosswalk on a carriageway has priority when entering the crosswalk. Even when an individual is already in front of the crosswalk, the driver of the car must give them priority!

The provision is very general and does not specify in detail at what distance from the traffic participant (pedestrian, vehicle) and under what conditions, priority must be given, according to the requirements of the safety system.

Figure 2. Situation where there is a bus in front of a crosswalk

Always, at any distance of a pedestrian from a crosswalk, does a pedestrian have to give way, at what distances is it not necessary to give way and one can enter the lanes? It generally takes a few seconds for a pedestrian to cross a lane.

Under heavy traffic conditions, you need to make a quick decision when there is sufficient distance (how large?) between the pedestrian and the collision point. A missed opportunity may not be repeated quickly. There is generally little time for evaluation, decision and execution [49, 50].

In addition, it may be that the vehicle is traveling at an excessive speed (does not slow down before the crossing). When an accident occurs, will this circumstance matter? In such a situation, what is the practice of the police, the courts? How do the courts interpret it, what is the line of jurisprudence in similar cases? Does the intervening police patrol make a fair analysis of the traffic organization in the area of the collision? Does it correctly and fully document the situation found? Does it not over-interpret the regulations? In this article, the author tries to answer the questions posed and formulates conclusions and proposals for clarifying the provisions of the traffic law.

METHODS

When can a pedestrian enter a crosswalk on a roadway and not run the risk of being run over and when can one not step in front of an oncoming vehicle? (Figure 3). Where is the boundary separating the two distinguished states?

Unfortunately, the regulations do not cover this subject. How is a traffic participant – a pedestrian, supposed to know what is dangerous for them, what are they not allowed to do? Similarly, how is a traffic participant – the driver of a vehicle, supposed to know what they are allowed and not allowed to do in the border states, when to pass and when to stop? When an offense is committed and when it is not. On what basis will the police assign possible fault to the pedestrian or to the driver of the vehicle, recognizing that they violated a provision of the law? Such vague regulations open the door to a great deal of freedom of interpretation up to the point of over-interpretation of the existing law. What rationale will the court follow if such a case comes before it?

The Traffic Law [47] has been amended as follows, in Article 26, paragraph 1. "The driver of a vehicle, when approaching a pedestrian crossing, shall be obliged to exercise special caution, reduce speed so as not to endanger a pedestrian who is on the crossing or entering it, and give way to a pedestrian who is on the crossing or entering it, subject to paragraph 1a." Reduce speed – to what value? The legislator should determine it precisely, for example, as for the area of the residential zone.

Such reasoning can be proposed for a crossing located on a road for cars including buses, trolleybuses.

The meaning of "give way to priority" is as follows – Article 1.1 The Traffic Law defines: "to refrain from movement if the movement could force the driver to change direction or lane or significantly change speed, a pedestrian – to stop, slow down or accelerate his step, and a person moving with the use of an assistive device – to stop, change direction or significantly change speed". No maximum time value is given which would connect the two events.

"If the movement could force the traffic participant to change direction or lane or significantly change speed", after what time from the realization of this movement this forcing would not involve a failure to give priority? E.g. there should be a provision that after t_{up}=3s, then forcing a braking or lane change is not interpreted as not giving way to priority. The limit of the time interval should be fixed, otherwise there is room for any interpretation and over-interpretation of the provision on not giving way to priority.

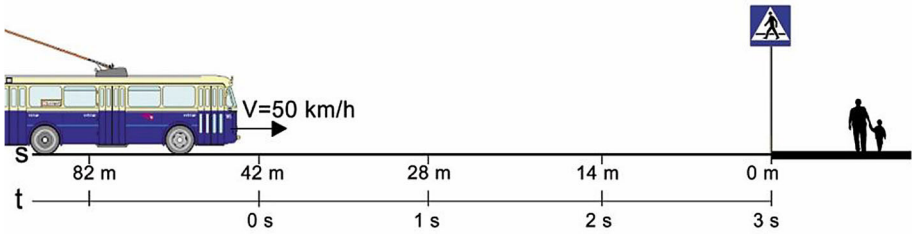

Figure 3. Situation when there is a trolleybus in front of a crosswalk

$$t_{critical} = t_{stop} + t_{up} \quad (1)$$

where: $t_{critical}$ – cut-off time (s), t_{stop} – vehicle stopping time (s), t_{up} – extreme time (3s).

In the Traffic Law in Section 3 of the law, speeding and braking in Article 19 it is written: "The driver of a vehicle is obliged to drive at a speed that ensures control over the vehicle, taking into account the conditions under which the traffic is moving, in particular: the relief of the terrain, the condition and visibility of the road, the condition and load of the vehicle, the atmospheric conditions and the volume of traffic".

A pedestrian enters a pedestrian crossing on a wide two-lane multilane road for cars. When is a driver obliged to stop and give priority to a pedestrian, and when are they allowed to cross the crosswalk without violating the law on giving priority? Citizens have the right to know what they are being punished for. A citizen must know in advance whether their act fulfills the elements of an offense and what the penalty for it will be. The rules must be precise, clear, understandable to all parties evaluating the phenomenon – the event, the traffic participants, the Police, the Courts. Selected two variants of a long crossing on a one-way three-lane roadway will be analyzed (Figure 4).

When can a car enter a pedestrian crossing (on which a pedestrian is walking) and not violate the current legislation? (Figure 4). In a built-up area, the speed limit for a car is V_{dop} = 50 km/h (13.9 m/s), and the pedestrian is moving at a speed of V_{piesz} = 5 km/h (1.39 m/s).

The regulations do not specify the speed limit to which the driver must slow down approaching pedestrian crossings. The car in front of the crossing should necessarily reduce the speed value to no more than the speed limit in the residential zone V_s = 20.0 km/h (5.56 m/s).

In variant A – at what minimum distance from the crosswalk cannot stop and give priority to the pedestrian and still not violate the applicable regulation (the pedestrian will not have time to reach the collision point because the car will pass earlier?) The path needed to move to the collision point of the pedestrian and the car for: S_{pasa} = 3.50 m (lane width on the roadway), n = 1.5 (safety factor), S_{piesz} – the distance traveled by a pedestrian, S_{s1} – the distance traveled by a car, V_{dop} = 50 km/h (13.9 m/s); V_{s1} = 20 km/h (5.56 m/s); V_{piesz} = 5.00 km/h (1.39 m/s); $S_{piesz} = V_{piesz} \cdot t_{piesz}$; $S_s = V_s \cdot t_{piesz}$; $t_{piesz} = S_{piesz} / V_{piesz} = 2 \cdot 3.50$ m/1.39 m/s ≈ 5.00 s.

The distance of the car to the collision point must be much shorter so that the pedestrian does not have time to reach the collision point before the car passes the point (taking into account the safety factor). These are limits, minimum values due to the requirements of the safety system and the evaluation of the correctness of the conduct of the car driver.

The mathematical relationship of the stopping distance S_z has the following form (2) [51]:

$$S_z = S_{rk} + S_{nh} + S_h = V_p \cdot t_{rk} + V_p \cdot \frac{t_{nh}}{2} + \frac{V_p^2}{a \cdot 2} \quad (2)$$

In variant B – if the car starts from a stop, it can enter immediately after the pedestrian passes through the collision point? On the other hand,

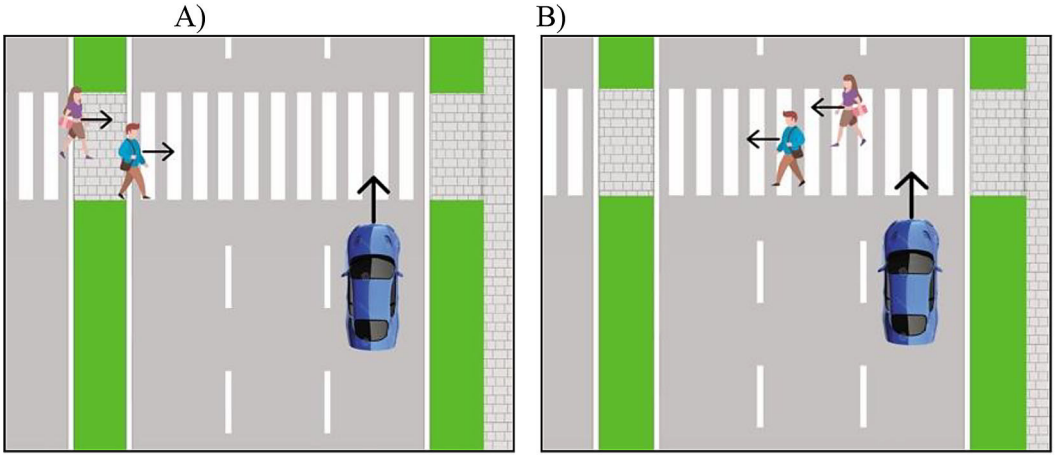

Figure 4. The situation at the pedestrian crossing: A – the car manages to pass the collision spot before the pedestrian reaches it; B – the pedestrian has passed the collision spot before the car reaches it

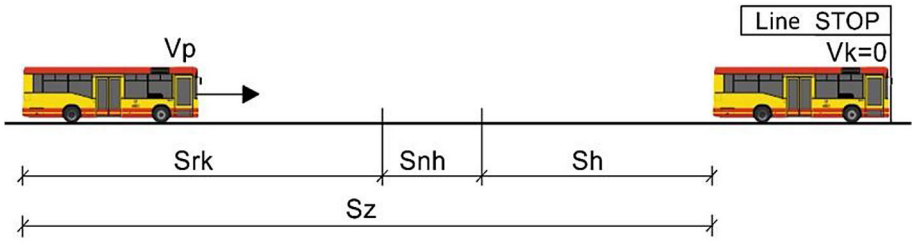

Figure 5. Diagram of the impact of the three quantities making up the stopping distance vehicle: S_z – stop distance; S_{rk} – distance traveled during the driver's response; S_{nh} – distance traveled during braking force build-up; S_h – distance traveled "during braking" with a constant delay; V_p – value of speed at the access to the intersection - permissible, determined by the regulation, t_{rk} – driver response time; t_{nh} – braking force rise time; a – braking permanent delay

if the car is driving (without stopping) then the necessary time interval t for the pedestrian to pass through the lane with a width of s = 3.50 m with a speed of V_{piesz} = 5.00 km/h (1.39 m/s) at the collision spot taking into account the safety factor will be:

$$t = t_{piesz} \bullet n = 2.5\ s \bullet 1.5 = 3.75\ \text{s} \qquad (3)$$

where: n = 1.5 – safety factor.

That is, from the entrance of the pedestrian (and the time needed to pass the collision point), the minimum distance of the car in front of the pedestrian crossing depending on the value of speed, will be at least:

- 3.75 s • 14.0 m/s ≥ 52.5 m for V_p = 50 km/h
- 3.75 s • 830 m/s ≥ 31.1 m for V_p = 30 km/h
- 3.75 s • 5.56 m/s ≥ 20.6 m for V_p = 20 km/h

for the pedestrian to pass the collision spot in time.

These are limits, minimum values due to the requirements of the safety system and the evaluation of the correctness of the conduct of the driver of the car.

Pedestrian crossings are located on roads for vehicular traffic and on streetcar tracks (Figure 6). Some have traffic lights controlling traffic, but a large number of crossings are not equipped with traffic lights. Streetcars travel on streetcar tracks (Figure 6A), while trolleybuses (Figure 6B), buses (Figure 6C, city and other) as well as trucks (Figure 6D) and cars (Figure 6E) travel on roads for vehicular traffic. Trolleybuses, buses, cars, which are elements of the vehicle stream on public roads, have braking systems whose effectiveness is similar and stopping distances in extreme situations are also similar. Streetcars have the braking systems with lower effectiveness and the stopping distance in extreme situations is longer.

Motor vehicles (cars, buses, trolleybuses) are equipped with high-efficiency friction brakes which, as a result of applying with maximum effectiveness on dry pavement, can reach decelerations of up to a_{max} = 8.00 m/s^2. High deceleration during braking is not dangerous for travelers in vehicles other than public transport vehicles: streetcars, trolleybuses, buses. In streetcars, trolleybuses, buses, passengers also travel in a standing position. Long delays when braking, can lead to passengers tipping over and cause fall injuries [Police Headquarters, 2022].

Internal regulations for the operation of vehicles in public transportation, prohibit sudden (with maximum force) braking of the vehicle. The legislator took into account this restriction for streetcars and did not introduce the privilege of priority for a pedestrian entering a crosswalk on the tracks. For the track crossing, the priority of the pedestrian entering the track crossing was excluded. On the other hand, they forgot about the fact that in the stream of vehicles on the road in front of the pedestrian crossing, there may be trolleybuses and buses, which can cause dangerous injuries to passengers when braking sharply [52, 53].

Thus, a major flaw in the new provision is the failure of the legislature to recognize that the composition of the stream on the roadway also includes trolleybuses and public transport buses. Those driving them have been obliged to give way to a pedestrian intending to enter a crosswalk. This will surprise them.

In this case in Figure 7, the driver of the bus, trolleybus about 30.0 m before the crossing notices a pedestrian intending to enter the pedestrian crossing. On such a short stopping distance, the bus deceleration during braking is a_h = 8.00 m/s^2. Such values of deceleration are excessively dangerous for public transport passengers.

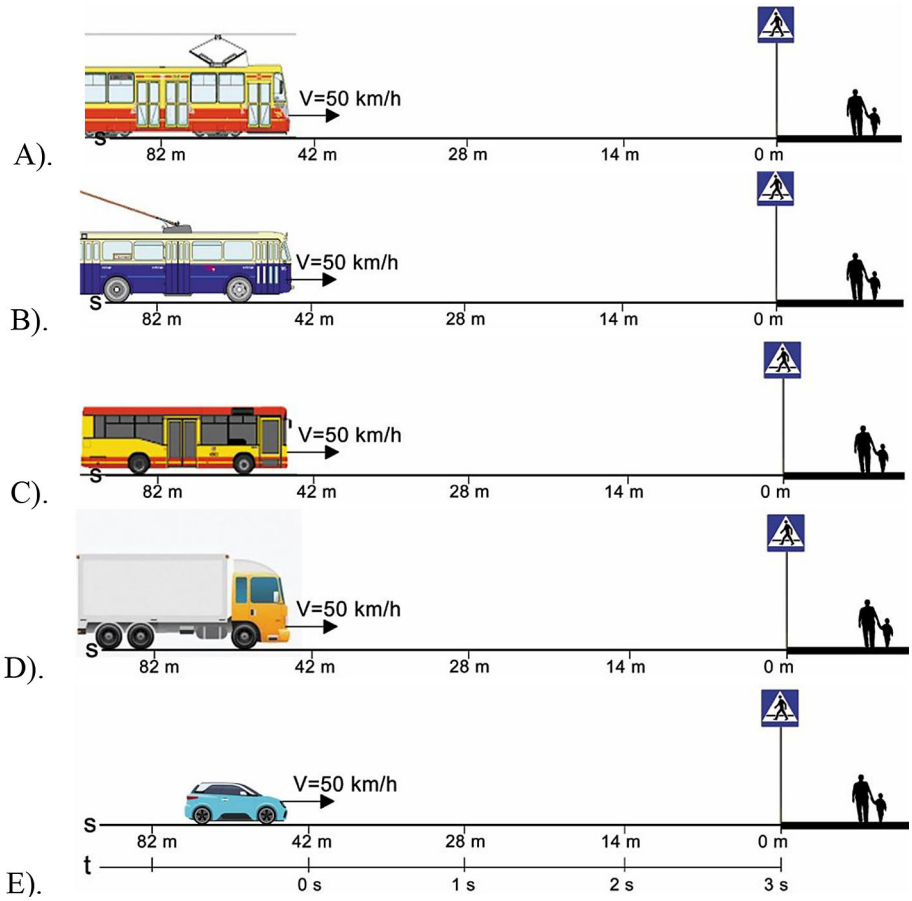

Figure 6. Situation when in front of a crosswalk is: A – tram, B – trolleybus, C – bus, D – truck, E – car

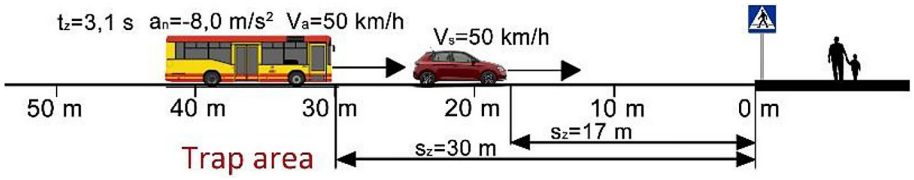

Figure 7. A situation of sudden braking in front of a pedestrian crossing [52, 53]

In this situation, the bus driver is able to stop the bus before the pedestrian crossing, but this involves the possibility of overturning bus passengers and causing injuries. The dilemma of the bus driver, trolley bus driver is whether to protect the passengers of the bus, trolley bus or the pedestrian at the crossing?

Closer to the crosswalk, the driver of a passenger car driving at V_{dop} = 50.0 km/h, perceiving a pedestrian intending to enter the pedestrian crossing at a distance of 17.0 m from the pedestrian lanes, will not manage to stop the car before the crossing.

Proper braking then begins at the pedestrian crossing. It is possible that the car, with its previous speed, drives into the passing pedestrians. The driver's reaction time plus the time it takes for the braking system to fully work causes the car to travel this distance and to not brake.

The study demonstrates that drivers' reaction time to road hazards is highly context-dependent, rather than fixed. Eye-tracking analyses reveal that the required observation of mirrors and surroundings fragments attention into short intervals; for example, during left-turn preparation drivers spent over 2 s checking mirrors, often in multiple glances, leaving the forward scene unmonitored and effectively prolonging hazard detection. Reaction times measured in simulators are systematically shorter than under real-world conditions, where risk awareness and environmental complexity extend the response window.

Distractions such as mobile phone use (≈20% longer reactions) and alcohol consumption further delay responses, while age effects remain inconsistent across studies.

Overall, reaction time should be understood as a distribution shaped by task demands, attention allocation, and external conditions. For traffic safety practice and legal assessment, it is crucial to rely on empirically grounded upper-bound estimates, recognize the impact of mandated mirror checks, and account for distraction and impairment factors that can push drivers into significantly slower reaction regimes.

The same is true when the bus driver sees a pedestrian intending to enter the pedestrian crossing at a distance of 17.0 m. In that case, the bus, with its previous speed, drives into the pedestrians crossing at the crosswalk. On the other hand, when the bus driver sees at a distance of about 30.0 m a pedestrian entering the pedestrian crossing, in order to stop, they had to brake with deceleration a_h = 8.00 m/s^2. A high risk of injury to bus passengers arises [54, 55]. The pedestrian, in his own well-understood interests, in such a situation should not step into the lanes in front of a moving car.

It seems necessary to introduce a marked zone in front of the crossing, giving preference to the pedestrian entering the pedestrian crossing on the roadway. Stopping traffic on the roadway requires time and adequate advance information. This will facilitate the decision to start stopping the vehicle early (Figure 8). A pedestrian approaching the zone will still have 6.00 m to go to enter the crosswalk. This will take them a time of about 4 seconds. During this time, the vehicle approaching the crosswalk will have a chance to stop in front of the crosswalk and give way to the pedestrian.

Reducing the value of the speed of each vehicle at a distance of 20 m before the pedestrian crossing to V_{prz} = 20.0 km/h, (V_{prz} = 5.56 m/s as for the residential zone, Art. 20. paragraph 2. "The permissible speed of a vehicle or combination of vehicles in a residential zone is 20 km/h") reduces the danger of invading a pedestrian. For insubordinate drivers, the provisions in the law are not enough. They break the law until they are caught in the "act" or cause an accident. In order to effectively enforce such behavior (reducing the value of the vehicle speed), speed bumps should be placed on the roadway at a distance of S_{pr} = 20.0 m before the crossing. Such a "barrier"

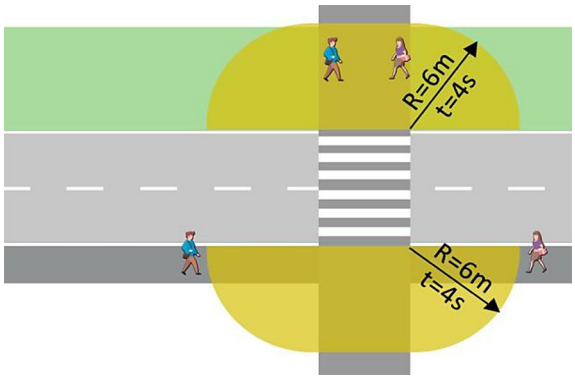

Figure 8. Proposal to designate in front of the crosswalk the zones of preference for a pedestrian entering the pedestrian crossing on the roadway R = 6.00 m, t = 4.00 s being an anticipatory information about the need to stop the vehicle in front of the crossing

will physically force a reduction in speed even for such drivers who notoriously violate traffic regulations. This will reduce the risk of a pedestrian being run over in an accident.

A separate yet serious problem is the misunderstanding by traffic participants of the overtaking maneuver. Driving a vehicle with a higher speed value in one lane next to a vehicle driving with a lower speed value in an adjacent lane ($V_{poj1} > V_{poj2}$), is treated as an overtaking maneuver (Figure 9). Police treat such an occurrence in front of a crosswalk or at a pedestrian crossing as a serious offense that puts a pedestrian at risk of an accident.

RESULTS

The current regulations applied to pedestrian crossings result in a situation where a dilemma zone arises [3]. Drivers of trolley buses and urban public transport buses, will have to strictly comply with the regulations. This may force them to brake the vehicle with delays far in excess of the permissible values. On the other hand, braking with long delays will cause the possibility of injury to passengers traveling in a standing position.

The problem considered here is currently overlooked by those responsible for the safety system in trolleybus and bus operations. Drivers of trolleybuses and buses, surprised by the entry of a pedestrian into the crosswalk, must suddenly brake sharply. This is caused by not noticing such incidents by the creators of the regulations who did not take such behavior into account.

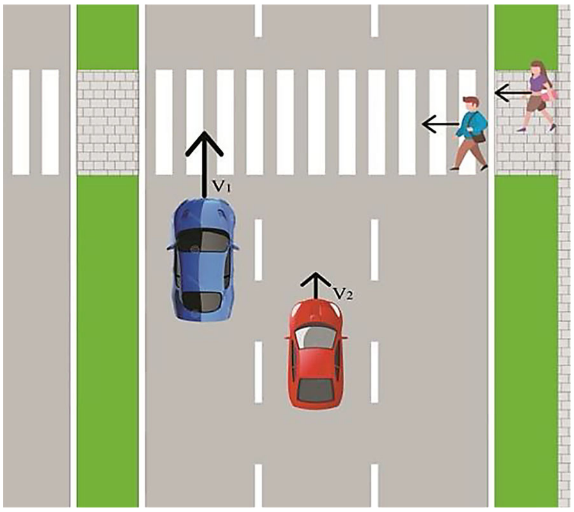

Figure 9. Situation of overtaking vehicles in front of a crosswalk $V_{poj1} > V_{poj2}$ (serious offense)

Consideration should be given to the introduction of a special traffic organization in front of the pedestrian crossing on the roadway for cars. Prior information for traffic participants will make it possible to react earlier to a pedestrian approaching the crossing [46, 56, 57]. Figure 10 shows a proposed traffic organization before a pedestrian crossing on a roadway for vehicular traffic. It should be mandatory and be implemented in the current law. In addition, it is advisable to use the barriers that create a protective zone for the pedestrian – Figure 11 or active traffic organization – Figure 12.

Any misdemeanor can and even should be inevitably punished. The inevitability of punishment is the most effective element of the safety system of road traffic participants, reducing the occurrence of dangers on the road, disciplines them. Laws should be changed so as to give drivers a chance to avoid committing offenses.

Practice shows that the provisions in the Highway Code are (in many cases) "correct" until they have to be used (different interpretation) in a contentious case. It is important to know whether the regulations are correctly worded, precise, clear, understandable and do not contribute to accidents. This applies to residents of a country as well as foreigners residing in that country, traveling in their own cars. It is important to know about: the behavior of the drivers in the studied range of conduct and knowledge of the regulations as it relates to a country that is part of the EU area, as well as analyze the correctness of the regulations and the procedures for their application, to determine whether it is sufficient. The next step is to consider the decision to make changes if they are to improve the safety system of participants in traffic.

Technological advances and the development of equipment provide an opportunity to apply to road infrastructure solutions to help guide trolleybuses and buses in the area under discussion. Legislation should provide a framework for them that takes into account the observations from studies conducted on buses in operation on the road. The transmission of anticipatory information is very necessary and useful in such situations. It helps drivers make the right decision at the right time. It also improves the safety system of traffic participants, especially pedestrians.

Pedestrians suddenly enters the crosswalk, and unfortunately this happens according to the current regulations in this regard. It seems obvious that the current regulations favor causing collisions and accidents. They should be amended, redrafted and enshrined in current law. Drivers, operating trolleybuses and buses in traffic, should be assisted by appropriately adjusted regulations.

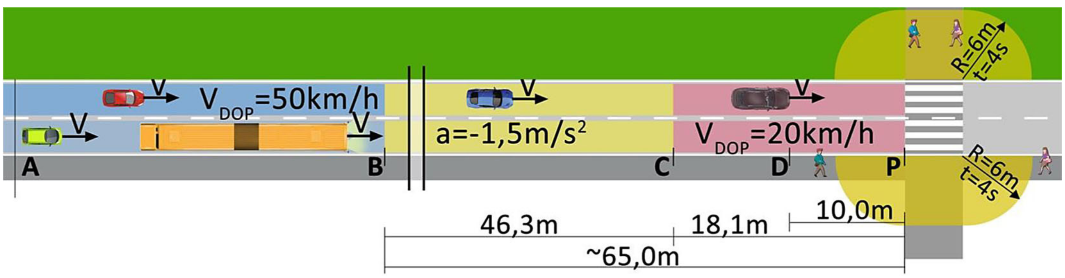

Figure 10. Proposed traffic organization before the pedestrian crossing on the roadway where the area: A-B speed allowed V_p = 50.0 km/h =13.9 m/s, B-C braking with deceleration a = -1.5 m/s^2, reducing speed to V_p = 20.0 km/h, C-P permissible speed V_p = 20.0 km/h = 5.56 m/s, D-P braking with deceleration a = -8.00 m/s^2 and stopping the vehicle before the crossing, V_p = 20.0 km/h, the permissible speed of a vehicle or combination of vehicles in a residential zone

Figure 11. Proposed traffic organization (barriers) to allow vehicle drivers to receive anticipatory information about a pedestrian's intention to enter the lanes

Figure 12. Active traffic organization – a crossing guard stopping vehicle traffic at a pedestrian crossing on a roadway

In addition, it is necessary to use technical devices to provide advance information. The apparent tremendous technical progress and development of equipment makes this possible.

CONCLUSIONS

Traffic regulations should be tested before implementation, similar to computer programs, to detect weaknesses often overlooked by lawmakers. For example, pedestrian-activated traffic lights give priority to pedestrians in a safer way. The study shows that imprecise regulations lead to inconsistent interpretations by drivers and law enforcement, while unclear stopping distances hinder enforcement. Bus and trolleybus drivers must often brake suddenly, risking passenger injuries, and pedestrians may feel overly secure, assuming vehicles can always stop in time. Although accidents at pedestrian crossings in Poland had declined since 2018, their rise in 2022 indicates that current regulations remain insufficient.

This study suggests the necessity of refining regulations concerning minimum stopping distances and pedestrian right-of-way conditions, as well as introducing infrastructure solutions such as designated zones before pedestrian crossings. Another important aspect could be the use of new technologies, such as pedestrian-activated traffic signals, which would allow for smoother and safer street crossings. Additionally, education for both drivers and pedestrians is crucial to raising awareness of the risks at crossings.

Further research should focus on analyzing the effectiveness of various safety improvement strategies and evaluating which proposed solutions yield the best results under real traffic conditions. Particularly important research areas include:

- the impact of education and public awareness campaigns on pedestrian and driver behavior – evaluating the effectiveness of training programs and awareness campaigns on traffic regulations;
- testing different traffic organization systems at pedestrian crossings – analyzing the effectiveness of designated crossing zones and speed bumps in reducing accidents;
- application of smart technologies – research on implementing systems that detect pedestrians and automatically warn drivers about the need to stop;
- effectiveness of modern enforcement methods – assessing the role of speed cameras and other monitoring tools in observing driver behavior near pedestrian crossings;
- the impact of regulatory changes on actual driver behavior – a long-term analysis of accident statistics after the introduction of new regulations to optimize them if necessary.

Conducting further research in these areas will allow for the development of more precise and effective solutions that will contribute to a tangible improvement in pedestrian safety on roads.

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