REVIEW OF SELECTED TECHNICAL SOLUTIONS AFFECTING THE SAFETY OF PEDESTRIANS IN THE ROAD TRAFFIC

Marek Idzior

Summary:

The article presents methods of increasing pedestrian safety in the road traffic. A significant number of different concepts and inventions is systematically appearing on the automotive market to protect pedestrians and support the driver. Through constant analyses, manufacturers have noticed that not only vehicle passengers are at risk of the loss of health or life at the time of an accident, but also unprotected road users (pedestrians and cyclists), of whom there are still more. From year to year, the constructors propose safety devices that protect the driver and passenger, as well as active and passive safety systems. The active and passive safety systems as well as some concepts of creating safe pedestrian crossings have been discussed here.

Key words:

road traffic safety, pedestrian, safety systems, pedestrian crossing

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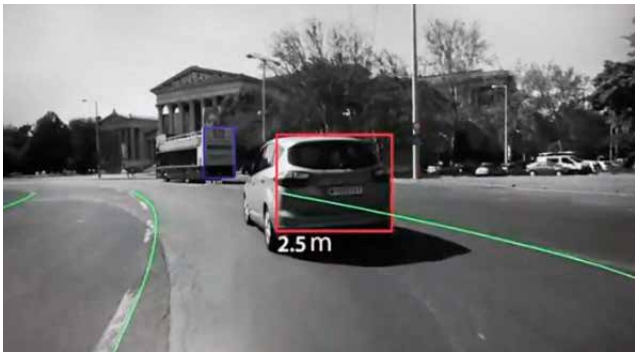
1.1. Mobileye C2-270 system [6]

Mobileye C2-270 is the latest version of the Mobileye C2 series of advanced driver assistance systems. In addition to the standard assistance functions, Mobileye C2-270 offers the world's first system warning of the collision with pedestrians. It is equipped with an "intelligent" camera that is placed inside the car on its windshield. It is a "third eye" that detects vehicles, lanes, speed limits and pedestrians and allows to maintain a safe distance to other vehicles on the road and, if necessary, warns the driver and allows to avoid serious road accidents.

Functions:

- detection of pedestrians and bicycles during the day,
- Forward Collision Warning System in built-up and non-built-up areas, including motorcycle detection,
- Lane Departure Warning System,
- monitoring and warning of a dangerously close proximity to the vehicle ahead,
- high beam control,
- reading speed limit signs (only for integration with external devices),
- optional connectivity to fleet management and telematics systems,
- high intensity visual alerts with eyewatch display, information displayed,

Fig. 1. View from the camera that performs the measurements



This publication presents methods of increasing pedestrian safety in the road traffic. This study is a continuation of the publication on "Analysis of factors influencing pedestrian safety in the road traffic" and includes an analysis of methods of reducing accidents involving pedestrians.

A significant number of different concepts and inventions are systematically appearing on the automotive market to protect pedestrians and support the driver. Through constant analyses, manufacturers have noticed that not only vehicle passengers are exposed to the risk of losing health or life at the time of an accident, but also unprotected road users (pedestrians and cyclists), of whom there are still more.From year to year, the designers propose safety devices that protect the driver and passenger, active and passive safety systems.

1. Active safety systems

Passive safety systems include all devices that control the road and assist the driver in avoiding collisions with pedestrians.

- indication of vehicle detection,
- an audible signal informing about the dangerous distance to the vehicle ahead,
- different coloured alarms for each of the warnings,
- fits all passenger, truck, recreational and fleet cars,
- high sensitivity: day and night operation in virtually any weather.

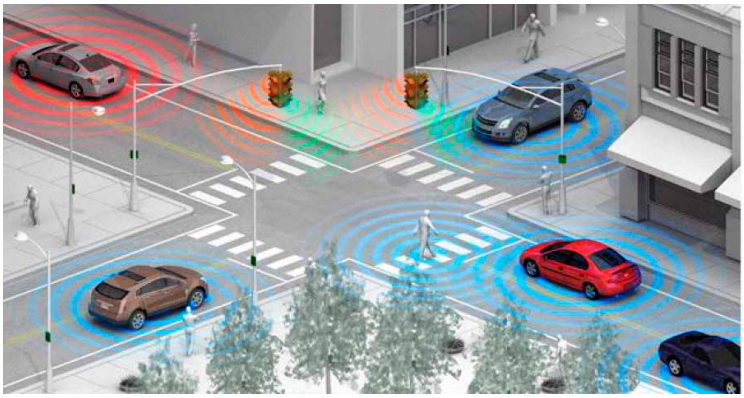
Benefits:

- effective prevention of collisions and bumps,
- increasing the level of safety for drivers, passengers, and the environment,
- safe driving style,
- lower fuel consumption,
- lower accident costs,
- drivers' evaluation and training tool,
- day and night operation in virtually any weather.

1.2. Wi-Fi Direct system [5]

This is a solution that was first introduced by General Motors, designed to protect pedestrians and cyclists from accidents, thanks to their smart phones equipped with WiFi. The most common cause of an accident is the road incursion by a pedestrian and cyclists moving in the dark. This system is designed to warn drivers of the close presence of other road users, including pedestrians and cyclists. The WiFi Direct system would make it possible to detect the devices of other road users (Fig. 2).

Fig. 2. Operating scheme of the WiFi Direct system t



Smart phones with the WiFi Direct function allow the devices to communicate with each other bypassing the access points of the mobile operator. Traditional wireless systems need 7-8 seconds to locate the transmitter, and smart phones within 200 meters could be located in 1 second. WiFi Direct has a chance to soon become a part of driver assistance systems. Such solutions are already in the possession of such firms as General Motors, Chevrolet, Cadillac.

1.3. Volvo's Pedestrian Safety system [9]

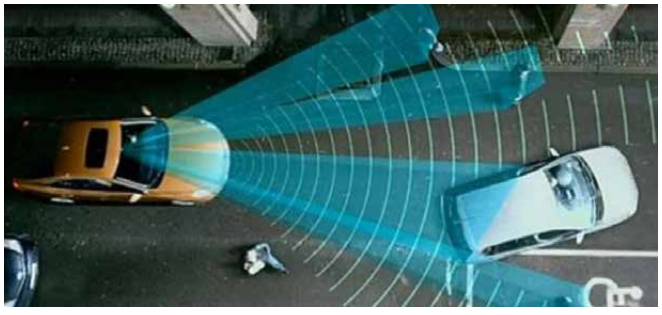
Already in 2010, Volvo Car Corporation presented the new Volvo V60 model equipped with two new active safety systems: Pedestrian Safety and Collision Warning with Full Auto Brake. The Pedestrian Detection System detects pedestrians that could suddenly run onto the road in front of the car. This system automatically applies the brakes with full braking force when it detects a possibility of a collision with pedestrian. The advantage of the system is the ability to detect a pedestrian and automatically brake the vehicle from a speed not exceeding 35 km/h, in the event that the driver does not react. At higher speeds, the task of the system is to maximally decrease the speed and, at the same time, the force of the impact on the pedestrian. A collision with a pedestrian at reduced speed reduces serious injury. When there is no reaction from the driver, the braking system is automatically activated if the object has been defined by both the radar and the camera. The braking system, which is to ensure the fastest possible response and the shortest braking distance, has been designed in such a way that the space between the brake disc and the brake pad is kept to a minimum. Then the system is most efficient.

Collision Warning with Full Auto Brake and Pedestrian Safety systems are based on a dual-mode radar installed in the radiator grille, a camera located at the top of the windshield, next to the rear-view mirror, and supported by a central control unit. The radar and the camera enable constant monitoring of the road (Fig. 8).

The task of the system is to detect objects and measure the distance at which they are. The camera is used to determine what type of object we are dealing with. The system has been programmed to respond to cars standing in front or moving in the same direction as the vehicle. The wide-field radar detects pedestrians who might intrude on the road, and the camera monitors pedestrian traffic patterns. The driver is informed about the danger by means of an audible and visual signal in the form of a brake light on a display located on the windscreen.

The radar in conjunction with a camera enables constant monitoring of the road. Its task is to detect objects and measure the distance at which they are. The camera, on the other hand, is used to determine what types of objects we are dealing with.

Fig. 3. Pedestrian Safety system during road monitoring [17]



The system is programmed to react to cars standing in front or moving in the same direction as the driver's vehicle. Thanks to a modern radar with a wide field of view, the system detects pedestrians who are just about to enter the road. The camera allows to monitor pedestrian traffic patterns. It is also extremely helpful in the event of rear collisions with other vehicles.

According to statistics, half of the drivers who have hit the rear of another vehicle do not brake at all before the collision.

Similar technologies are currently being developed by all major car manufacturers [8]. Mercedes-Benz has a lot to offer to customers, with a large number of collision avoidance systems. The PRE-SAFE technology is an advanced system that launches emergency procedures in the face of impending danger, sensors in the rear bumper monitor the road all the time, the system activates hazard warning lights, warning drivers with rapid flashes. In addition, the PRE-SAFE technology activates the reversible belt tensioner mechanism as a preventive measure. This system closes the side windows, the panoramic sunroof, and sets the seat next to the driver in a more favourable position in case of an accident. In the event of impending danger, PRE-SAFE Sound also emits a short noise signal, which is a kind of warning.

Volvo has always been recognised as a manufacturer of one of the safest cars in the world. This is also confirmed by the company's vision, whose mission is to reduce the number of casualties and seriously injured people travelling in the new Volvo to zero. The new models are equipped with adaptive cruise control, 360-degree camera, active high beam and automatic parking system. There will also be technologies such as blind spot monitoring and lane keeping. At critical moments, the pedestrian airbag is deployed. It is worth mentioning the support system with an application called Volvo On Call, offering driver support 24 hours a day. In case of problems, this system determines the position of the car using GPS and GSM/3G technology.

The Opel OnStar system operates in a similar way to Volvo On Call - it automatically reacts to a collision. The system automatically transmits information about the car, its exact location, direction of travel or even the scale of damage. The assistant speaks to us via a speakerphone in the language of our choice, even when the incident took place abroad. If we do not answer the questions asked by the OnStar staff, the assistant sends us help and thanks to GPS he knows exactly where the accident occurred.

In **BMW**, if the airbag is triggered, the telephone module automatically connects to the BMW hotline. The system also sends information that will be necessary for emergency services. In addition to the exact location of the car, data such as the number of people in the vehicle, possible injuries, as well as the colour and model of the car are sent. The system also works when, for example, we see another accident.

Toyota offers a full range of collision protection systems. We are talking mainly about the early warning system in the event of a risk of a collision and the pedestrian detection system. After detecting a danger, the car starts emitting visual and audible signals, and if the driver does not react, it will start emergency braking. Lexus, on the other hand, competes with European BMW, Mercedes or Audi not only in terms of the offered driving comfort. The Japanese brand has countless safety systems that react in the event of an emergency.

Many additional technologies are used in the latest flagship saloon, the Lexus LS. The Japanese manufacturer boasts the **Lexus Safety System+** system, the task of which is, among the others, pedestrian detection. In case of spotting a pedestrian on the road, the car starts to brake by itself and then bypasses the pedestrian, keeping the vehicle in the lane we were currently following.

1.4. FlirPathFindIR II [7]

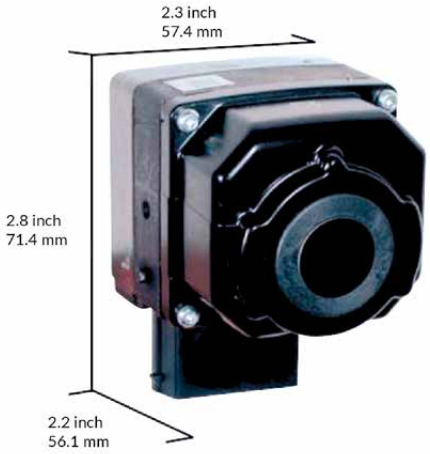
Visibility is a big problem for us when driving at night. The way to reduce accidents outside built-up areas, with roads with the hard shoulder, is the use of thermal imaging cameras in vehicles. There are many places where people now travel on foot between dispersed towns. They are not always visible on the road. The range of the vehicle's headlights is only 20-30 m, at a speed of 70 km/h, the vehicle travels about 20 m/s, and the field of view is limited to 75□. In such a situation, it is difficult to notice the pedestrian blending in with the darkness, in time.

The PathFindIR II system is a thermal imaging system that allows to quickly detect hazards on the road, even in complete darkness. It alerts the driver to approaching vehicles, people or animals. PathFindIR II detects heat without the need for light, allowing to see up to four times farther than traditional vehicle lighting. It allows visibility through dust, smoke or fog. It allows visibility both during the day and at night, in good or bad weather, without being dazzled by the headlights of oncoming cars. Observation of the road at greater distances allows more time to react. More time means more options, more confident driving in an emergency and more room to brake.

Thanks to the thermal imaging camera, the wavelength of which ranges from 0.9-15 km and the power supply from 12-24 volt, it can be easily introduced into the power supply system of each car. A synchronised camera with a GPS navigation monitor can assist the driver in detecting a threat and save many lives. Such an example is the Flir PathFindIR II - a thermal imaging car camera that allows to see much farther and clearer than with standard car lights. The driver can detect pedestrians, animals or other objects on the road in advance thanks to the camera, whose range is 650 meters. Advantages of the system:

- seeing in complete darkness,
- automatic detection and alerting of pedestrians and animals,
- noticing pedestrians and animals through the glare of headlights,
- spotting many threats up to 4 times further than with car headlights,
- seeing through dust and smoke,
- more time to react,
- helps to avoid dangers while remaining safe,
- compact, easy to install,
- hermetically sealed for protection against water, dust and cold.

Fig. 4. PathFindIR II thermal imaging camera



The PathFindIR II camera is built to operate in harsh environments. Well protected against water and moisture, it allows operation in the temperature range from - 40° C to + 80°C. It has an optics defrosting system, which in 15 minutes is able to defrost a 2 mm layer of ice at a temperature of -30° and wind speeds of 100 km/h. The defrosting system activates when a temperature drop below + 4° C is detected and is deactivated at a temperature of + 4° C. Thanks to this, we obtain a thermal image of the highest quality. The size and weight allow to install it inside or outside the vehicle. On the positive side is, that the device's operation does not change with changing weather conditions. This solution enables quick detection and allows the driver to react earlier in the event of danger.

1.5. Sound generators [10]

The increasing number of hybrid and electric vehicles is raising new concerns about pedestrian safety. In urban conditions, driving vehicles with such drives is not accompanied by the characteristic noise, apart from the noise of the wheels and the quiet sound of the electrical system. This can affect the safety of pedestrians who may not hear the approaching car, which may endanger them. This applies not only to carefree pedestrians, often distracted by headphones or looking at the phone, but also, to a much greater extent, to blind pedestrians. The sound emitted by an electric/hybrid car must therefore resemble the sounds made by a traditionally powered vehicle, according to the European Union guidelines. All this to signal your presence in slow city traffic not only to passers-by, but also to the aforementioned blind people.

Fig. 5. Delphi Automotive sound generator

Based on this problem, Delphi company has developed two sound generators, so-called beacons, which enable pedestrians to hear an approaching vehicle. Such cases occurred very often in Japan and for this reason it is recommended to install sound generators over there.
The sound generator is shaped like a horn activated by light magnets. Both devices have been designed to meet the legislative requirements that will define the minimum sound level. The first of the generators is about three times lighter and consumes about 90% less energy than conventional multi-module signalling devices, thanks to the single-module structure of the system. It is much smaller than sound generators. It is designed and built to withstand water, temperature and the conditions prevailing under the bonnet. The device can generate sounds with a frequency of 500 Hz to 10 KHz. However, the second signalling device generates a sound of higher quality. The lower range of the generated sound has been extended to a minimum value of 150 Hz.

The devices are equipped with 32-bit microprocessors with "flash" memory. The Delphi generator is designed to be integrated with other vehicle-mounted systems. For example, it can inform the driver about the need to recharge the battery or when charging, information about the completion of this process.

The sound emitted by an electric/hybrid car must resemble the sounds made by a conventionally powered vehicle, state the guidelines of the European Union. The AVAS system - because this abbreviation stands for a sound generator - will stop working at a speed of about 20 km/h. Then, according to officials, the noise made by the tires and the noise of the wind are loud enough. The sounds of the AVAS system must not resemble a warning beep, but they should indicate the behaviour of the car - whether it is currently accelerating or slowing down.

All this to signal your presence in slow city traffic not only to passers-by, but also to the blind.

The sound of the car may therefore seem as important as its appearance or colour in a few years' time. The system can be found in Jaguar I-Pace, which sounds like a spaceship. A similar solution was also used in the second generation Nissan Leaf.

2. Passive safety systems

Passive safety systems are elements and devices designed to reduce the effects of a collision between a vehicle and a pedestrian.

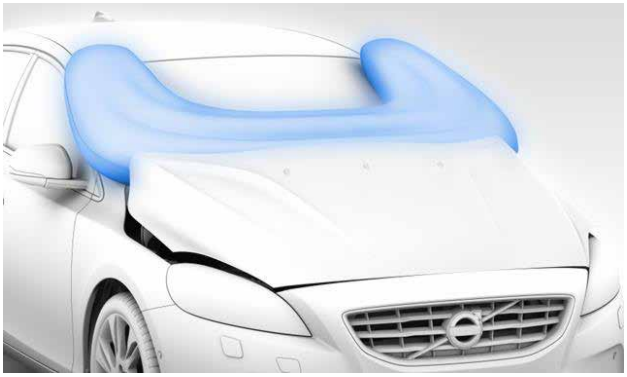
2.1. Pedestrian airbag System Pedestrian Airbag Technology [12, 13]

In 2012, Volvo released the first ever pedestrian airbag. This concept was designed to protect pedestrians in the event of a frontal collision with a car. The Pedestrian Airbag Technology system is a certain type of an airbag. The essence of it is that this pedestrian-specific system is based on seven sensors and a control unit. At the time of an impact, sensors installed in the front of the vehicle send a signal to a connected control unit, which in turn analyses the information to detect the shape of the object. If it is determined that the car is about to hit a pedestrian's legs, the control units will activate the airbag.

The airbag has two functions. The first is to raise the bonnet to create a gap between the bonnet and the engine, to cushion a pedestrian's fall and not to expose them to the impact against engine parts. The second function is to cover hard elements. The airbag covers about 1/3 of the windshield area, and additionally covers the entire windscreen wipers' recess and the lower part of the front pillars. The entire process takes only a few hundredths of a second. This system is designed to prevent or at least reduce injuries to a pedestrian's head in the event of a collision (Fig. 11).

The airbag attached to the bottom of the windscreen, when inflated, can cover not only the area around the wipers, but also a third of the windscreen and the lower part of the pillars. It includes those areas that an adult pedestrian's head could strike in the event of a collision (Fig. 6).

Fig. 6. The way the system works



Like any other airbag, the pedestrian system is based on a bag and a gas hybrid generator that is responsible for filling the bag with gas according to information sent by central units. The system only works at speeds between 20 and 50 km/h, considering that most pedestrian accidents occur at city speeds.

In 2015, Google obtained a patent for a pedestrian airbag approved by the US Patent and Trademark Office. This airbag technology is designed for Google autonomous cars. The Google airbag differs from existing pedestrian airbag models in two main ways. First, the cushion is not under the windscreen, but is placed in the bumper and unfolds at the foot of the pedestrian. Typically, when this happens, the pedestrian 'bounce' effect can cause them to hit the ground or the car, possibly injuring them. Google's latest innovation is in the material of the cussion. Instead of traditional airbag material, Google airbags are made of a special viscoelastic material with a foam-like consistency. The use of silicone coatings is envisaged. This way, pedestrians don't bounce off the cushions, but rather collapse, reducing the risk of injury.

2.2. Flexible BASF plastics [11]

The shapes of motor vehicle bodies have changed continuously over the years. As early as 1937, Claire L. Straith (1891-1958) was the first to suggest reducing injuries to road accident victims through appropriate vehicle design.

BASF and the Opel concern have focused on a joint project in the field of safety. The aim of the project is to use new thermoplastic materials in the construction of the vehicle. The world's largest chemical company, BASF, and the renowned car manufacturer Opel, have developed new technological solutions to increase protection for pedestrians in the event of a collision with a vehicle. B3WG6-CR thermoplastic Ultramid components are already used in the design of the lower bumper stiffener on the new Opel Corsa. As a result of joint work, a new plastic part was designed, which replaced the existing metal part.

The method developed by BASF makes it possible to design the optimal material without the need for costly tests. Such elements meet the EU directives on pedestrian protection. Subassemblies made of LBS can protect road users, and at the same time, thanks to lower production costs, they can be generally available. In this case, the price does not have to go hand in hand with safety.

EuroNCAP (European New Car Assessment Program) also conducts research on pedestrian protection of new vehicles, developing a new concept for the design of the front part of the vehicle based on the optimal use of space, ease of assembly, durability in contact with objects, etc. Ultramid is introduced, which is a stable technical resin with glass filling which provides the appropriate properties to minimize the effects of contact with pedestrians. The lower bumper reinforcement bar weighs just over two pounds, is three feet long, and is mounted behind the front bumper to reduce possible serious injury to the knee in a collision with a pedestrian.

Fig. 7. Lower reinforcement of the LBS bumper

3. Safe crossing

Research shows that good visibility guarantees safety, but it turns out that not always an illuminated crossing guarantees safety. Travelling from town to town after dark distracts the driver and limits visibility. Even if we can see a pedestrian crossing, in many cases marked, not everyone slows down in front of it. When driving at 90 km/h outside built-up areas, the braking distance, excluding the driver's reaction time, is 77 m. Although the speed in front of pedestrian crossings is usually limited to 50-60 km/h, many drivers do not comply with these regulations, putting other road users at risk.

There are frequent cases of blinding a vehicle driver by another vehicle travelling from the opposite direction of traffic. When all these circumstances get superimposed before a pedestrian crossing, it could lead to mishap.

One of the method is through messages that appear on the vehicle's dashboard. Light and sound signals, such as fuel and washer fluid levels, draw the driver's attention. The introduction of messages about pedestrians at the pedestrian crossing may cause the driver to exercise appropriate caution. Here, come in concepts not for smart cars, but for intelligent pedestrian crossings and the roads.

Such a system should detect pedestrian movement in a designated area in front of the pedestrian crossing. The ability to detect the direction of movement makes it impossible to avoid the situation of restarting the alarm by a pedestrian leaving the crossing.

The DEPA system (Distributed Enhanced Processing Architecture) by SONY [14], the so-called intelligent image analysis is capable of alerting about an incident and thoroughly analyse each incident, e.g. vehicle movement on the motorway in the opposite direction to the correct traffic direction. The system uses an IP camera supported by the DEPA platform. The disadvantage of the system is that the alarm can be triggered by flying birds or other animals that are present outside the built-up area. For this purpose, the second element supporting the IP camera is (2) an active infrared receiver (Fig. 8).

This device consists of a transmitter and a receiver facing each other. There is an infrared radiation between the transmitter and the receiver, and the optical path interruption (in the near infrared band) generates an alarm. For the system to function efficiently and not generate false alarms, the signal sent from one device must coincide with the signal from the other device [17, 18].

The built-in transmitter has a limited transmission range of 250 m, because the braking distance from 110 km/h on a dry surface is 90 - 135 m. It is enough to smoothly slow the vehicle down before the pedestrian crossing after receiving a message about the presence of a human being. It is a well-balanced distance taking into account the speeds that drivers achieve despite the various limitations. The system elements are powered in the voltage range 12-24 V, thanks to which the entire system is self-sufficient. The electricity produced by the hybrid system (photovoltaic panels and wind turbine) is stored in batteries. The energy created in this way is enough to power the entire system for a few windless and sunless days.

Fig. 8. Safe crossing: 1 - IP camera, 2 - active infrared barrier, 3 - control module (image recorder, FM radio transmitter), 4 - LED warning sign, 5 - LED lighting

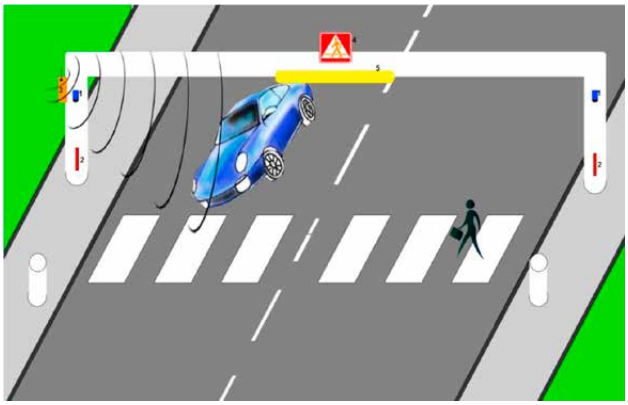
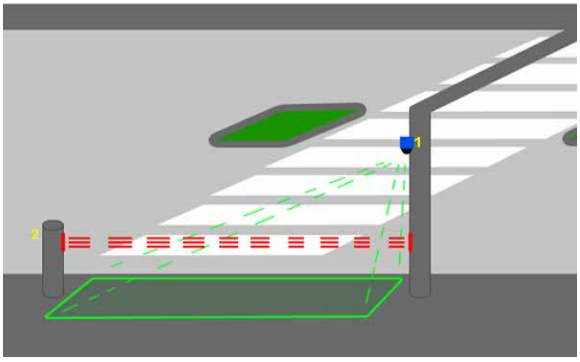


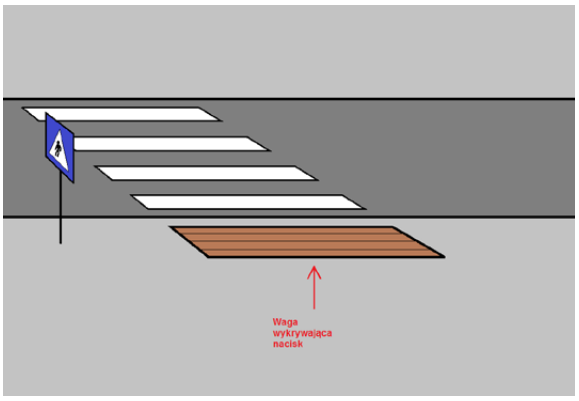
Fig. 9. The area of operation of both sensors



The system presented has a chance to protect drivers against a road accident involving pedestrians, who are ever more frequent on the roads outside built-up areas, where visibility after dark is limited and daring driving does happen.

One of the simplest, and at the same time the cheapest methods of pedestrian protection, known for years thanks to many campaigns devoted to safety, are reflective elements. The visibility of pedestrians after dusk is still a big problem. During limited visibility, pedestrians walking along the

Fig. 10. Pedestrian crossing with a weighing system



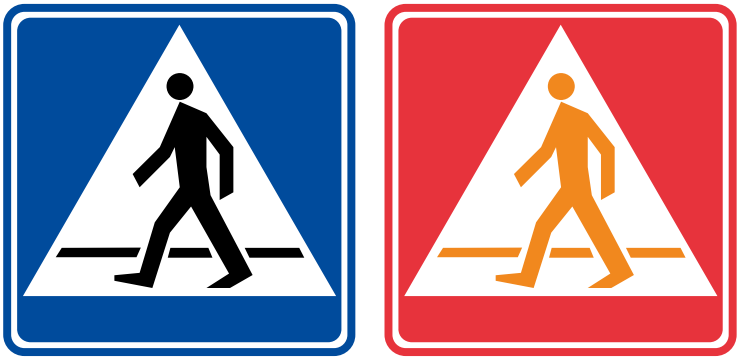
The second [18] example of a system of information about pedestrians using a crossing that is simpler to build is the system based on weight. When approaching a pedestrian crossing, a man stands on the so-called weight. The device measures the weight of a pedestrian on it.

When the weight of the weighed body exceeds 20 kg, the scale sends a signal to the D6 sign, which starts pulsating, informing drivers about the presence of a pedestrian.

road or the hard shoulder are particularly exposed to the risk of being hit. In particular, if they are dressed in shades of gray and black, blending in with the surroundings, they are noticed by drivers with a long delay.

At night, visibility is worse, a pedestrian may notice the car's lights even from a distance of several kilometres, while the driver will see a pedestrian only when his silhouette is within the range of the headlights at a distance of 20-30 m. The vehicle moving outside the built-up area with a permitted

Fig. 11. Sign D6 in the basic version and in the version after activating the pulsating warning



Summary

Based on the solutions presented, it can be concluded that there are many methods of pedestrian protection. Testing devices shows a high percentage of the safety they guarantee. A pedestrian is an unprotected participant in the road traffic, so drivers must remember to give way at pedestrian crossings, and above all, that a pedestrian has little chance of survival in contact with a car. The safety of vulnerable road users largely depends on themselves. The cause of over 60% of all accidents is failure to give way to pedestrians at a pedestrian crossing. In second place is the failure to give way to pedestrians in other circumstances. Thus, a very high percentage of accidents are caused by drivers within the pedestrian crossing. It should be added, however, that pedestrians also contribute to accidents, very often due to careless and dangerous behaviour. The paradox is that the most dangerous places for pedestrians are precisely the places designated for crossing the road.

speed of 90 km/h travels 25 meters in one second. This gives the driver no chance to react. Correctly placed reflective elements such as a vest are visible from both directions of traffic from a distance of up to 300 m. If a pedestrian is equipped with such elements, the driver will easily notice him from a distance of 130-150 m, which is about 5 times earlier.

As early as on July 1, 2020, the regulations were to give pedestrians more rights, because it is at the crossings that 63% of hitting the pedestrian takes place, due to drivers' fault. Most countries have introduced long ago a pedestrian right of way before crossing. The introduction of such a regulation in Poland, especially in the first period, would require great caution of pedestrians and drivers.

Drivers must learn to slow down before crossing the pedestrians, and pedestrians must not lose vigilance when entering the lanes. Otherwise, a change to the law may result in more accidents rather than improvement.

Other causes of hitting the pedestrians are: failure to give way to a pedestrian in other circumstances, incorrect reversing and failure to give way to a pedestrian when turning into a transverse road.

The regulation on road signs and signals states that a driver approaching a pedestrian crossing or a bicycle crossing is obliged to slow down so as not to endanger the safety of people standing in these places and entering them.

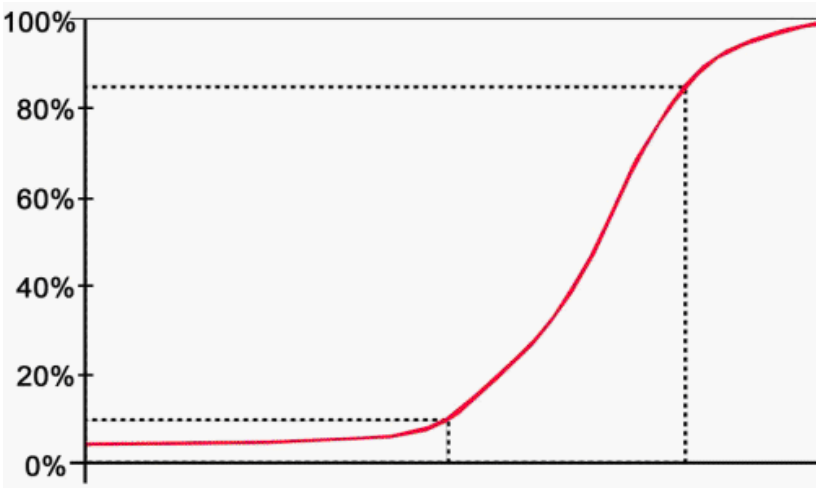
Unfortunately, in places where the speed limit is 50 km/h, 85% of drivers exceed the speed limit 100 meters before the crossing. 40% of drivers are driving too fast 10 m before the crossing [2].

Outside the built-up area it is even worse. If the speed limit is 70 km/h, 90% of drivers drive faster 100 meters before the crossing, and 68% are faster 10 meters before it. The probability of pedestrian death increases sharply with vehicle speed, especially above 30 km/h (Fig. 17).
Another common mistake is for a driver who is driving at a constant speed to overtake next to a slowing down vehicle in the second lane. If this happens before a pedestrian crossing, we are dealing with serious violations of the rules and putting pedestrians at risk.

Turning at the conditional turn arrow also requires attention. The regulation in force here requires the driver using it to stop in front of the signalling device. The observations show that 20 - 25% of the accidents at the crossing result from the driver not stopping in front of the arrow.

In terms of regulations governing the relations between the drivers and pedestrians, we significantly differ from the countries of Western Europe or Scandinavia, where the level of road safety is much higher than in our country. The situation in this country has probably matured to change it, give it the proper rank and improve the unfavourable statistics of pedestrian safety in the road traffic.

Fig. 12. The relationship between the vehicle speed and the probability of pedestrian death



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Marek Idzior
marek.idzior@put.poznan.pl
Poznan University of Technology