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Techniques, Methods, Installations and Infrastructure for Protecting Pedestrians in Road Traffic

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Abstract

Road safety is a topic of supreme importance in any modern city, and one of the essential elements for protecting road users, especially pedestrians, is represented by traffic control and command systems, as well as road markings. These play a crucial role in organizing traffic and preventing accidents by clearly demarcating the spaces intended for different categories of road users. Everyday reality has shown that pedestrian vulnerability is determined by several factors, among the most important being: the lack of adequate road infrastructure (such as, for example, the separation of pedestrian and vehicular traffic or the existence of safe pedestrian crossings), or the speed of other traffic participants. This scientific paper was written by the authors in a logical and elegant manner, with the aim of addressing the techniques, methods, installations and infrastructure for protecting pedestrians in road traffic, who are considered the most vulnerable road users, so that readers can understand their place, role, and functional character within the current road infrastructure and traffic. In this way, interested readers can learn about the legislation and specialist literature governing the movement of vehicles and pedestrians on

public roads in Romania, as well as the types of pedestrian crossings currently in use in Europe. The paper also contains a chapter on the braking distance of road vehicles, an essential, defining, and determining factor in road accidents. In this chapter, we presented the definition, constituent elements, influencing factors, braking distances depending on speed, calculation relationships, the two-second rule, and how the braking distance of motor vehicles can be minimized in order to reduce or even stop unwanted road events. In the continuation of the paper, we present a chapter that includes 20 techniques, methods, installations and the infrastructure necessary for the protection of pedestrians when crossing the road or street. The paper also discusses a case study presenting and addressing five serious problems caused by the location of pedestrian crossings in the immediate vicinity of intersections and the need to create buffer zones (spaces) for storing vehicles at intersection access points. At the end of the scientific article, the authors' conclusions and recommendations in the field addressed are presented.

Keywords: Vehicle, Pedestrian, Roadway, Pedestrian Crossing, Protection, Safety, Braking Distance, Buffer zone

1. Introduction

The implementation of effective measures to reduce the number of serious road accidents and, in particular, the number of deaths resulting from such events requires a tool for the national assessment and interpretation of the multiple and complex data that define road traffic. Road traffic is a complex system in which multiple factors at different levels are constantly interdependent. Whether we are talking about the road network, vehicles, drivers, pedestrians, or the relevant legislation and measures taken by the various institutions with responsibilities in this area, all these are interconnected elements of a constantly changing whole that affects both the safety and comfort of travel. Pedestrians in road traffic are people who travel on foot and are required to use sidewalks or, in their absence, the left shoulder of the road. They have the right of way only at crosswalks or when the traffic light is green, and must cross perpendicular to the axis of the road after ensuring that it is safe to do so. A pedestrian crossing is a specially marked and signaled place on the road where pedestrians have priority to cross, and drivers are required to give them priority and stop. These crossings are essential for pedestrian safety, helping to prevent road accidents, especially at intersections. Pedestrians must walk only on pavements or specially designated paths. Outside built-up areas, pedestrians must walk on side paths or the hard shoulder of public roads, and in the absence of these, as close as possible to the left-hand edge of the carriageway, in the direction of travel ^[1]. Protecting pedestrians at crosswalks requires both drivers

and pedestrians to follow certain rules in order to prevent accidents. Drivers are required to give way and stop their vehicles for pedestrians who are crossing or wish to cross at a marked or signalized crosswalk. Pedestrians, on the other hand, must only cross at designated locations and ensure that they can cross safely. Drivers are required to stop their vehicles completely to give way to pedestrians crossing the road at marked and signaled crossings or waiting to cross. They must reduce their speed near pedestrian crossings, especially in areas with poor visibility. Giving way to pedestrians is one of the basic rules of the road. This obligation helps prevent accidents and maintain safety on public roads. Every driver must know clearly when to give way and what consequences await them if they do not follow these rules [2]. Pedestrians must cross the street only at designated and marked locations (crosswalks, underpasses, or overpasses), except in cases where no such locations exist. Before stepping onto a crosswalk, pedestrians must ensure that no vehicles are approaching, even if the traffic light is green. They must not cross when they hear and see acoustic or light signals from emergency vehicles. It is prohibited to cross in front of or behind vehicles parked on the crossing or through intersections. Children, elderly people, and people with disabilities often need more time to cross [3]. When crossing in a group, children must be supervised and walk in single file, and those under 7 years of age must be held by the hand. Pedestrians are one of the most vulnerable categories of road users, given their lack of protection in the event of a traffic accident. In the event of a traffic accident, pedestrians suffer the most severe consequences in collisions with other road users, while injuries to other road users are very rare. [4, p. 73]. According to the latest reliable statistics, in 2023, approximately 20,418 people lost their lives in Europe. In 2023, there were 1,479 serious road accidents on public roads in Romania involving pedestrians (fatalities or serious injuries). These accidents led to the death of 472 pedestrians, serious injuries to 1,021, and minor injuries to 78. In one-third (32.7%) of serious road accidents in 2023, a pedestrian was fatally injured or seriously injured. At the same time, among all road accident victims, pedestrians accounted for 30.6% of fatalities and 28.9% of serious injuries in 2023 [4, p. 74].

2. Legislation and literature review

2.1 Legislation

In Romania, the legislation governing the movement of vehicles and pedestrians on public roads is Government Emergency Ordinance No. 195 of December 12, 2002 (republished) and was published in the Official Monitor of Romania No. 670 of August 3, 2006. [5]. This normative act has suffered subsequent amendments and additions over time in order to adapt road legislation on vehicle and pedestrian traffic to current European legislation.

After its adoption, it was further amended and supplemented by:

- Romanian Government Decision No. 85/2003 approving the Regulations for the implementation of Government Emergency Ordinance No. 195/2002 on traffic on public roads, published in the Official Gazette of Romania, Part I, No. 58 of January 31, 2003;
- Government Emergency Ordinance No. 50/2004 amending and supplementing certain legislative acts with a view to establishing the organizational and

functional framework for the issuance and recording of identity cards, civil status documents, ordinary passports, driving licenses, and vehicle registration certificates, published in the Official Monitor of Romania, Part I, No. 595 of July 1, 2004, approved with amendments and additions by Law No. 520/2004, published in the Official Monitor of Romania, Part I, No. 1,153 of December 7, 2004;

- Government Emergency Ordinance 63/2006 - amending and supplementing Government Emergency Ordinance 195/2002 on traffic on public roads, Official Monitor 792/2006;
- Decision No. 1391/2006 - approving the Regulation for the application of Government Emergency Ordinance No. 195/2002 on traffic on public roads, Official Monitor No. 876/2006;
- Government Emergency Ordinance 69/2007 - amending and supplementing Government Emergency Ordinance 195/2002 on traffic on public roads, Official Monitor 443/2007;
- Law 203/2012 - amending and supplementing Government Emergency Ordinance 195/2002 on traffic on public roads, Official Monitor 760/2012;
- Government Ordinance 21/2014—amending and supplementing Government Emergency Ordinance No. 195/2002 on traffic on public roads, Official Monitor 635/2014;
- Law 93/2016 - amending Article 33(2) of Government Emergency Ordinance 195/2002 on road traffic, Official Monitor 369/2016;
- Government Emergency Ordinance No. 83/May 21, 2020, published in the Official Monitor No. 448/May 27, 2020;
- Government Ordinance No. 1 of 2022, published in the Official Monitor No. 89/2022;

Law No. 168/2023 amending Government Emergency Ordinance No. 195/2002 on traffic on public roads, published in the Official Monitor of Romania No. 521 of June 13, 2023.

NOTE: The republished form of Government Emergency Ordinance No. 195/2002 on traffic on public roads, as approved with amendments and additions by Law No. 49/2006, applies from the date of entry into force of the latter, namely September 20, 2006. The legislative act has been partially amended and supplemented over time, with reference to specific articles, in order to align it with European Union legislation, but also as a result of the unconstitutionality of certain provisions.

2.2 Literature View

With regard to pedestrians, the aforementioned Emergency Ordinance stipulates in Article 73 [5]:

1. Pedestrians are required to walk only on the sidewalk, and in the absence thereof, on the shoulder on the left side of the road, in the direction of their travel. When there is no shoulder, pedestrians are required to walk as close as possible to the left edge of the roadway, in the direction of their travel.
2. Pedestrians have right of way over drivers only when they are crossing public roads at specially designated, marked, and signaled locations, or when the traffic light for pedestrians is green.
3. Pedestrians shall cross public roads perpendicular to their axis, only at specially designated and appropriately

- signaled locations, and in the absence thereof, in built-up areas, at street corners, only after ensuring that they can do so without danger to themselves and other road users;
4. Pedestrians who are caught and injured as a result of crossing at unauthorized locations, when the traffic light for pedestrians is red, or of failing to comply with other obligations established by traffic regulations, bear full responsibility for their injuries, provided that the driver of the vehicle in question has complied with the legal provisions regarding traffic in that sector;
 5. Persons driving specially designed wheelchairs, persons driving vehicles designed exclusively to be pulled or pushed by hand, those traveling on skates or roller devices without self-propulsion, as well as those driving vehicles whose maximum design speed does not exceed 6 km/h and are equipped with an electric motor. (as of February 11, 2020, Paragraph (5) of Article 72, Section 3, Chapter V was amended by Point 8, Article I of Emergency Ordinance No. 13 of February 4, 2020, published in the Official Monitor No. 102 of February 11, 2020);
 6. Traffic police officers and persons who are on the public road platform and are authorized, in the exercise of their duties, to guide or direct traffic, under the conditions established by regulation, are exempt from compliance with the rules established for pedestrians;
 7. It is prohibited to occupy sidewalks with stationary vehicles, and when this is permitted, according to signs or markings, the minimum width of the sidewalk left available to pedestrians must be at least one meter;
 8. The road administrator is required to ensure adequate lighting of marked and signaled crosswalks without traffic lights, with intelligent LED lighting systems with asymmetrical light to create a strong contrast between the pedestrian crossing and the road surface, on sections of international "E" roads, national roads, and county roads located within the built-up areas of localities (as of October 4, 2023, Article 72, Section 3, Chapter V was supplemented by Point 1, Article I of Law No. 278 of October 4, 2022, published in the Official Monitor No. 967 of October 4, 2022).

Other obligations of pedestrians (pedestrian traffic) according to Article 167 of the regulation ^[6]:

1. Pedestrians and persons treated as such are prohibited from:
 - a) crossing the public road when a vehicle with priority traffic rights is approaching with its special light and sound warning signals in operation;
 - b) cross the roadway in front of or behind a vehicle stopped at public transport stops, except where there are appropriately marked pedestrian crossings;
 - c) prolong the time taken to cross the public road, stop or turn around on pedestrian crossings that are not equipped with traffic lights;
 - d) cross the public road in places other than those permitted;
 - e) occupy the carriageway for the purpose of obstructing traffic;
 - f) cross the railway when the barriers or half-barriers are down or when the light or acoustic signal prohibits crossing;
 - g) ride on bicycle lanes, which are properly designed and marked.

2. No person shall engage in commercial activities on the roadway, shoulder, sidewalk, parking lot, or public transportation station.

With regard to drivers of road vehicles, Article 123 of the aforementioned Emergency Ordinance stipulates that ^[7]:

The driver is required to drive at a speed not exceeding 30 km/h in built-up areas or 50 km/h outside built-up areas in the following situations:

- h) at unsignalized pedestrian crossings, marked by signs and markings, when the public road has at most one lane in each direction and pedestrians on the sidewalk, in close proximity to the roadway, intend to cross;

With regard to drivers of road vehicles, Article 135 of Government Emergency Ordinance 195/2002 also stipulates that ^[8]:

- o The driver of a vehicle is obliged to give way in the following situations:

- h) pedestrians crossing the public road at a specially designated, marked, and signaled location or when the traffic light for pedestrians is green, when the pedestrian is in the direction of travel of the vehicle.

3. Types of pedestrian crossings

The most common types of pedestrian crossings in the world are as follows:

- o *Informal pedestrian crossing*: Crossings that give equal priority to both pedestrian and vehicular traffic ^[9];



Fig 1: Pedestrian crossing marked in white and yellow

- o *Zebra crossing*, (Fig 1): Consisting of black and white/yellow and black stripes (similar to a zebra). Pedestrians usually have priority over vehicular traffic. There may be white crosswalks marked in less congested areas, which require drivers to slow down and yield to pedestrians, while pedestrians must be very vigilant, or yellow crosswalks, often associated with traffic signals. They are designed for areas with heavy traffic. In this case, pedestrians must wait for the green light before crossing, while drivers must be prepared to stop immediately.
- o *Traffic light-controlled pedestrian crossing (pelican crossing)*: Crossings with call buttons, pedestrian traffic lights, and traffic lights;
- o *Multi-user pedestrian crossing (toucan crossing)*: Access permitted to users other than pedestrians, such as cyclists or horse riders;
- o *Pedestrian underpass (underground crossing)*: Pedestrian walkway through a tunnel under a road, allowing crossing without interrupting pedestrian or vehicular traffic;
- o *Pedestrian bridge-type crosswalk*: Pedestrian bridge over a road, allowing pedestrians to cross without interrupting vehicle traffic.

In the UK, pedestrian crossings are different from those in Romania or other European countries—they have smart

systems, automatic traffic lights, and specific names, such as [10].



Fig 2: Pelican-type pedestrian crossing (UK) [10]

- *Pelican-type pedestrian crossing*, (Fig 2): (Pedestrian Light Controlled) there is a traffic light that only turns green when a pedestrian presses the button. The traffic light for vehicles changes from green to yellow, then to red. After a few seconds, the yellow light flashes, which means that drivers can only proceed if the crossing is clear. Pelican crossings are the only pedestrian crossings in the UK that have a flashing yellow light. On two-way roads, they can be in line or side by side. If they are side by side, they must be treated separately – you only give way to pedestrians on your side. If they are in line, they are considered a single crossing (even if there is a refuge);
- *Puffin pedestrian crossing*: Pedestrian User-Friendly Intelligent sau Puffin sunt trecerile de pieton similare cu cele Pelican, dar au senzori deasupra semafoarelor. Senzorii detecteaza daca cineva traverseaza mai incet, prelungind astfel culoarea rosie pentru masini. Trecerile de pietoni Puffin nu au galben-intermitent, semafoarele functionand normal;
- *Zebra-type pedestrian crossing*: The most easily recognizable of all, the Zebra crosswalk is marked with black and white stripes stretching across the road. Next to them are poles with yellow lights and zigzag markings on the road. There are no traffic lights for cars at these crossings — drivers must give way to pedestrians who intend to cross. Both pedestrians and drivers must be extremely careful, especially in busy areas;
- *Toucan pedestrian crossing*: (Two Can Cross) allow pedestrians and cyclists to cross. They are often found near parks and bike paths. The traffic light is common for both types of traffic participants, and the light signals function normally, without flashing yellow;



Fig 3: Pegasus-type pedestrian crossing (UK) [10]

- *Pegasus pedestrian crossing*, (Fig 3): Are the least common on the streets of the United Kingdom. They are similar to Toucan crossings, but they also allow cyclists to cross. Pegasus crossings have two sets of buttons for pedestrians, at different heights (for pedestrians and cyclists). They do not have flashing yellow lights; the traffic lights operate normally.



Fig 4: Pedestrian crossings around schools (UK) [10]

- *Pedestrian crossings around schools*, (Fig 4): Usually signaled by a school officer. These crosswalks may be signaled by flashing yellow lights;



Fig 5: Pedestrian shelters (UK). [10]

- *Pedestrian shelters*, (Fig 5): These are crossings where pedestrians can stop in the middle of the road, protected by a refuge. They are very easy to recognize, as they are marked with white lights on a tall pole. Extra caution is required in areas with refuges, as pedestrians may wait in the middle and then cross.

4. Braking distance of road vehicles

In road safety, an essential element that influences accident prevention is braking distance (braking space). The importance of braking distance is crucial for road safety, determining whether a driver can stop the vehicle in time to avoid an accident, a pedestrian, or an obstacle. It is influenced by speed, road conditions (grip, weather), and the technical condition of the vehicle (brakes, tires). Understanding and maintaining an appropriate distance from the car in front is vital in order to have time to react, preventing collisions and sudden maneuvers.

Braking distance or stopping distance is the distance traveled by a vehicle from the moment the driver presses the brake pedal until the vehicle comes to a complete stop. It is influenced by speed, the condition of the braking system,

tires, and road conditions (i.e., wet or dry pavement). The higher the speed, the greater the braking distance.

Most of the time, the need to brake comes suddenly and unexpectedly, but the vehicle does not stop exactly when the driver presses the brake pedal. The vehicle travels a certain distance from the moment the driver detects the danger until the car comes to a complete stop. This portion of the road is called **the total stopping (braking) distance** and is, in turn, composed of the reaction distance and the braking distance. **The reaction distance** is the distance traveled by the car from the moment the driver realizes that they need to stop until the moment they actually brake. In a few fractions of a second, which is how long it takes to react, the vehicle can travel several meters.

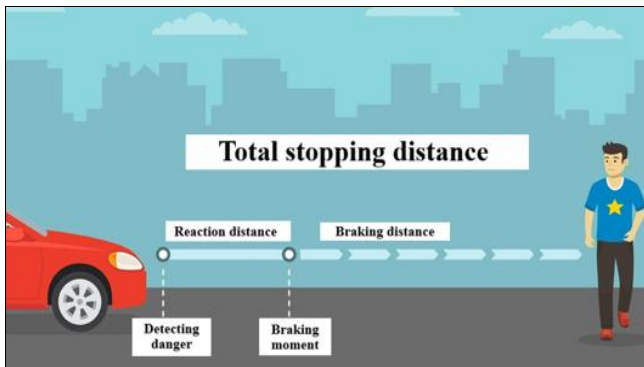


Fig 6: Total stopping distance [11]

Braking distance (braking space) is the distance traveled from the moment the driver presses the brake pedal until the car comes to a complete stop (Fig 6) [11].

Total stopping distance (braking distance) = reaction distance + braking distance.

The main factors influencing braking distance are:

- **Vehicle velocity:** Is the most important factor. Braking distance increases with the square of the speed.
- **Condition of the road surface (roadway):** A dry and clean road surface ensures the best grip and the shortest braking distance. On wet, slippery surfaces (snow, ice) or surfaces covered with dirt, sand, or gravel, traction decreases exponentially and braking distance increases significantly.
- **Condition of the vehicle's braking system:** A good one maintained brakes with pads and discs in good condition ensure maximum efficiency. Problems such as expired brake fluid or air in the brake system compromise performance.
- **Condition and type of tires:** Tires with the appropriate tread pattern (tread without wear, above the maximum wear indicator limit) and correct pressure provide optimal grip. Worn tires or tires that are unsuitable for the season (summer tires on snow, ice, or sleet, or winter tires on hot asphalt) significantly increase braking distance.
- **Vehicle mass (weight):** A heavier vehicle requires more force to brake to a stop, thus increasing the braking distance required. An electric or hybrid vehicle is heavier than a vehicle with an internal combustion engine. For this reason, the braking systems of these types of vehicles are oversized. A truck or bus is much heavier than a passenger car.

- **Slope/ramp of the road:** When going down a slope, gravity helps propel the vehicle, increasing the braking distance, and when going uphill, the braking distance becomes negative, decreasing [4].

It is essential to distinguish between braking distance and total stopping distance. Total stopping distance includes both braking distance and the distance traveled during the driver's reaction time (the interval between the moment the driver perceives a hazard and the moment he or she applies the brakes). According to the data presented in Fig 7, it appears that the braking distance differs depending on the condition of the road surface (dry or wet) and increases exponentially with speed. Observing the speed limit and maintaining a safe distance from the vehicle in front are the most effective measures to prevent accidents, providing sufficient space to stop in an emergency.

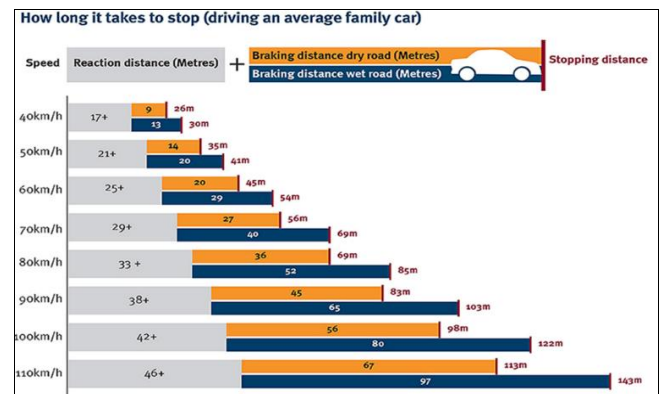


Fig 7: The combined effects of reaction and braking times on both wet and dry conditions [18]

The main factors influencing a driver's reaction distance are:

- **Driver inattention** – using the phone, talking to passengers, or other distractions.
- **Fatigue** – significantly reduces response time.
- **Use of prohibited substances** – alcohol, drugs, or certain medications can significantly impair concentration and reaction time.

When driving a vehicle, it is important to maintain an optimal distance between our vehicle and the one in front of us at all times, or to anticipate obstacles or pedestrians on the side of the road or who are crossing a road/street, whether legally or illegally, because this way:

- We will have a better view (visibility) of the road/street;
- We will have time to react and stop in time if the vehicle in front brakes suddenly, or if a pedestrian suddenly appears on the road or is crossing it;
- We will save fuel because we will drive preventively and will not have to brake every time the vehicle in front slows down or pedestrians cross the road.

To avoid collisions between vehicles during emergency braking, the Highway Code specifies that: "the driver of a vehicle traveling behind another vehicle is required to maintain a sufficient distance from it to avoid collision" [11], but the exact distance is not mentioned.

In practice, approximations are used or additional factors are taken into account to obtain a calculation close to reality using a much simpler method. This method is applied to maintain a safe distance between vehicles and is called the **two-second rule**, which evaluates the distance traveled in that time interval. This rule defines the braking distance and can also define the impact of a vehicle with an obstacle or a

vehicle with a pedestrian on the road (Fig 8).



Fig 8: The two-second rule in preventive/defensive driving for safe distance [12]

However, to avoid a collision with the vehicle in front of us, the two-second rule must be observed. The two-second rule is a simple and effective method for maintaining a safe distance: keep a distance from the vehicle in front of you that is equivalent to the distance traveled in at least two seconds [12].

The two-second rule is applied as follows:

- o Choose a fixed landmark on the side of the road (a tree, a sign, etc);
- o When the vehicle in front passes that landmark, we start counting "one thousand one, one thousand two";
- o If we reach that reference poin before finishing counting, it means that we are not keeping a safe distance and we must reduce the speed of the vehicle.

The mathematical relationship from which it is started to calculate braking distance is as follows:

$$s = \frac{v^2}{2 \cdot \mu \cdot g} \tag{1}$$

Where,

- v is velocity;
- μ - coefficient of friction;
- g - ravitational acceleration (9,81 m/s²).

Applying mathematical equation (1) for a speed of 72 km/h, which is equivalent to 20 m/s, and a friction coefficient μ = 1, the braking distance becomes:

$$s = \frac{20^2}{2 \cdot 1 \cdot 9.81} = \frac{400}{19.62} = 20.39 \text{ (meters)} \tag{2}$$

Dacă coeficientul de aderență al anvelopelor la calea de rulare (alunecarea roților) scade, coeficientul de frecare μ = 0.8, spațiul de frânare crește, astfel:

$$s = \frac{20^2}{2 \cdot 0.8 \cdot 9.81} = \frac{400}{15.7} = 25.48 \text{ (meters)} \tag{3}$$

We note that the calculation of braking distance using mathematical relations (1), (2), and (3) does not include reaction distance (*D_{reaction}*), i.e. the distance traveled by the vehicle from the moment the driver notices the obstacle (danger) until he decides to press the brake pedal (m/sec).

Adding reaction distance to these relationships increases the total braking distance. Finally, the total braking distance (*D_{TOTAL}*) (in Romanian), or Total Brake Distance (TBD) (in English) of a motor vehicle is calculated using the fundamental mathematical relationship as follows:

$$TBD = D_{reaction} + D_{braking} = v \cdot t_{reaction} + \frac{v^2}{2 \cdot \mu \cdot g} \tag{4}$$

Where,

- TBD is the total braking distance of the vehicle (includes *D_{reaction}* + *D_{braking}*), (meters);
- D_{reaction}* - the distance traveled by the vehicle from the moment the driver notices the obstacle (danger) until he decides to press the brake pedal (m/sec);
- D_{braking}* - the distance traveled by the vehicle from the moment the brake pedal is pressed until it comes to a stop (m/sec);
- v - initial velocity of the vehicle (km/h);
- t_{reaction}* - driver reaction time (1–1.5 seconds for experienced drivers). This interval is the time needed to perceive a danger and initiate braking action. Braking reaction time decreases with the experience gained by drivers behind the wheel. It is added to the actual braking distance (the time it takes for the vehicle to stop after the brakes have been applied). Reaction time can vary depending on factors such as fatigue, driver experience, and concentration level. Table 1 shows the values indicated by specialists regarding the total braking distance, depending on the speed of the vehicle.

Table 1: Values indicated by specialists regarding the total braking distance, depending on the speed of the vehicle [11]

Speed (km/h)	50	70	90	100	110	120	130	140
Reaction distance (m/sec)	13.8	19.4	25	27.8	30.55	33.3	36.1	38.8
Braking distance (m/sec)	19	37	61	78	90	108	130	147
Total Braking Distance (m)	32.8	56.48	86	105.8	120.16	141.3	166.1	185.8

Analyzing the data presented in Table 1, we can say that every second of inattention, in which we delay pressing the brake pedal, causes the car to travel an extra distance, which can be fatal for us, but also for other road users.

Minimizing braking distance can be achieved by applying the following methods:

- o **Respect speed limits** - Reducing speed is the most effective way to shorten braking distance. Observing speed limits and adapting speed to weather, traffic, and road conditions are the best measures we can take to travel safely;
- o **Brake system maintenance** - Regular inspection and maintenance of the braking system ensures its optimal functioning;
- o **Choosing and maintaining the right tires** - Investing in quality tires and maintaining them in good condition throughout the year is crucial for effective grip and braking. Regularly check tire pressure and ensure that tires are replaced before they reach the minimum wear and grip limit (summer tires should be used in summer and winter tires in winter when the ambient temperature drops below 7° C). In addition, there are tires specially designed for various weather conditions. Winter tires offer superior grip on snow and ice, while summer tires are optimized for dry and warm road conditions;

- **Preventive driving of motor vehicles** - Anticipating traffic situations, maintaining an appropriate distance from the vehicle in front, and attention to traffic signals can significantly contribute to safety and reduce braking distance.

5. Techniques, methods, installations and infrastructure for protecting people at pedestrian crossings

Many traffic and road infrastructure specialists believe that sustainable infrastructure forgives human error, and that those who build and design roads can dictate the subsequent behavior of road users. Life is considered the most precious good of human beings. It always takes priority, regardless of the context. For this reason, people's lives must be protected in their capacity as road users, i.e. pedestrians, so that they have priority. The priority of life can be created, provided, and ensured through techniques, methods, installations, and adequate road transport infrastructure. All of these, when correctly applied to the two essential components of the road transport system, infrastructure and traffic, will ensure the smooth flow of motor vehicles and the safety and comfort of all road users.

The 21 most important and effective techniques, methods, installations, and infrastructures that ensure the protection of people at pedestrian crossings, are:



Fig 9: Zebra-type pedestrian crossing, elevated

5.1 Elevated pedestrian crossings (crosswalks "zebra"), (Fig 9), up to sidewalk level. These cannot be bypassed, and drivers are forced to slow down. Such crossings are also much more resistant, but also accessible to people with disabilities, the elderly, and children in strollers. They are built at pedestrian crossings and are mainly used at pedestrian crossings in localities that are not located near an intersection;



Fig 10: Chicanes built at the entrance to localities

5.2 Road infrastructure obstacles (traffic islands), (Fig 10) are obstacles of various shapes installed on the road to force drivers to zigzag. This method of protecting pedestrians forces drivers to reduce their speed and drive carefully. They are usually built at the entrance to towns. Traffic islands are physical structures, usually island-shaped, located on roads or in urban areas to separate traffic flows and guide vehicles onto the correct lanes. They help reduce the risk of collisions and improve road safety. There are several types of traffic islands, including curved, rectangular, or round islands, depending on the specific needs of the area and design characteristics. They can be made of concrete, plastic, or other durable materials. Traffic islands are used in high-traffic areas, such as busy intersections, pedestrian crossings, residential or commercial areas, and construction sites, to improve traffic management and road safety;



Fig 11: Safety islands for pedestrians

- **Pedestrian safety islands,** (Fig 11) are built on wide roads (such as boulevards) with high pedestrian traffic. Pedestrian refuge islands serve to increase road safety and improve traffic management, especially in congested areas. They help to separate traffic flows, create safe areas for pedestrians, protecting them while crossing, and can facilitate traffic organization at intersections. They are designed with the following objectives in mind:
 - **Increased road safety:** Provides pedestrians with an intermediate safety space where they can wait before crossing the remaining lanes;
 - **Organization of road traffic:** Helps to clearly separate traffic lanes, directing vehicles onto the appropriate routes and reducing confusion, especially at intersections;
 - **Improved traffic management:** In areas with heavy traffic, busy intersections, or construction sites, they help to ease traffic flow and prevent accidents;



Fig 12: Adequate lighting of pedestrian crossings

5.3 Adequate lighting of pedestrian crossings, (Fig 12) is designed to ensure increased visibility and safety by using light sources that focus specifically on crossings and pedestrians, while complying with safety standards. This type of lighting requires a higher level of luminance (light intensity) than that of the road, but without causing visual shock or glare to drivers. The basic conditions that proper lighting of pedestrian crossings must meet are as follows:

1. *High luminance:* The light level is higher than on the rest of the road to highlight the pedestrian crossing area.
2. *Focus:* The light is focused directly on the crossing and pedestrians, often using elliptical focus LED lamps to illuminate them properly.
3. *Avoiding visual shocks:* Lighting must be consistent and must not produce sudden changes in color or intensity that could distract drivers.
4. *Reducing the blinding effect:* Attention is given to the placement of lighting fixtures to minimize glare for drivers, even in bright light conditions.
5. *Smart lighting systems:* The use of new solutions that include sensors to detect the presence of pedestrians and specifically light up the crossing.

Implementation: lighting fixtures shall be placed near pedestrian crossings so as to ensure that pedestrians are illuminated in both directions;

Standards: reference is made to specific standards (such as SR 13433) to ensure that lighting complies with safety regulations;

Technology: modern light sources, such as LEDs, are predominantly used, allowing precise control of the light beam;

Compliance: the systems comply with protection requirements for outdoor operation (IP protection class) and varying temperatures;



Fig 13: Speed limit indicator for vehicles at 30 km/h in built-up areas

5.4 Speed limit of 30 km/h in areas with heavy pedestrian traffic, (Fig 13). There is no specific speed limit for pedestrian crossings in the traffic codes of countries around the world. In Romanian traffic legislation, drivers are required to reduce their speed and give priority to pedestrians who are crossing or are on the crossing. This obligation is stipulated and regulated in each country's specific traffic code, and failure to comply with it results in penalties. It is necessary to set up several sections of road where the maximum speed is 30 km/h (a requirement of the World Health Organization) ^[13]. Experience in the United Kingdom shows that after large cities doubled the number of areas with a speed limit of 30 km/h in 1996, accidents

resulting in injuries fell by 60%. More than that, according to a study by the European Federation of Road Traffic Victims, if a pedestrian is hit at 50 km/h, there's a 70% chance the accident will be fatal, but if the impact speed is reduced to 30 km/h, the risk of death drops to 10%.

However, the speed limit of 30 km/h applies in certain situations regulated by law, such as when passing through uncontrolled intersections, on certain sections of road marked accordingly (by road sign C27), in sensitive areas (such as residential areas, with a maximum speed of 5 km/h, or in areas with heavy traffic) and when visibility is reduced. According to the Romanian Highway Code, the traffic regulations specify the situations in which the speed limit of 30 km/h applies, as follows:

- *Uncontrolled intersections:* when crossing intersections where traffic is not controlled by traffic lights or other signs;
- *Dangerous curves:* on curves marked as dangerous or where visibility is less than 50 m;
- *Signaled areas:* on road sections where road sign C27 "Speed limit 30 km/h" imposes this restriction;
- *Sensitive areas:* in certain sensitive areas, such as residential areas, where a maximum speed of 5 km/h applies;
- *Heavy traffic:* In very heavy traffic, in order to maintain a safe distance, speed must be reduced and may be limited to 30-40 km/h in traffic jams;

Other situations: when passing organized groups of pedestrians or military columns.

The aim of limiting vehicle speeds to 30 km/h in areas with high pedestrian traffic is as follows:

- *Road safety:* Reducing speed increases safety, especially in congested areas;
- *Reducing pollution:* Lower speed limits help reduce gas emissions and noise;
- *Improving quality of life:* Contributes to a more pleasant and safer environment for residents.



Fig 14: Traffic circles (miniroundabout)

5.5 Traffic circles (mini-roundabouts), (Fig 14), used to calm and even out traffic flow. These are small circular islands, installed mainly at unmarked intersections. They are a kind of small roundabout (mini-roundabout), which helps to create a constant flow of traffic and reduce speed. These circles require drivers to slow down and pay attention to their surroundings in order to maneuver around them. According to the literature, a mini-roundabout is a small roundabout with a small inner diameter (approximately 3 meters), which serves to calm and even out traffic in areas

with higher density (residential or commercial). Although it has a similar role to a regular roundabout, it is distinguished by its smaller size and the fact that it is not intended for heavy traffic arterials. It is located in residential or commercial areas. It is not suitable for arterials with heavy traffic exceeding 10%;



Fig 15: Lanes specially designed for pedestrian or bicycle traffic

5.6 Lanes specially designed for pedestrian or bicycle traffic, (Fig 15), are spaces dedicated exclusively to either pedestrians or cyclists, or they can be shared lanes (for pedestrians, cyclists, and other slow-moving vehicles). They are marked accordingly and serve to separate bicycle and pedestrian traffic from motor vehicle traffic, thereby increasing traffic safety and flow.

Bicycle lanes: these are roads or lanes dedicated to cyclists, marked as such, where cyclists are required to ride; they are usually located on the right-hand side of the road; other traffic participants are prohibited from using the bicycle lane.

Pedestrian lanes: These are sidewalks or pedestrian areas specially designed for walking.

Shared lanes: These are traffic lanes shared by both pedestrians and cyclists (along with other slow vehicles such as scooters), and are marked correspondingly;



Fig 16: Diagonal barriers

5.7 Diagonal barriers, (Fig 16) are obstacles installed at four-way intersections. The role of diagonal barriers, in the context of security and safety, is to protect the perimeter by delimiting spaces and controlling access, acting as a first line of defense against intrusions. They can be used in various situations, such as traffic control or delimiting work areas, to maintain safety in various contexts.

They are installed for the following purposes:

- **Role in security:** Perimeter barriers, including diagonal ones, are essential for protecting an area, acting as a physical barrier against unauthorized entry;
- **Role in public safety:** They can be used to control traffic and delimit access areas, helping to maintain safety in communities or workspaces;

- **Role in delimitation:** Diagonal barriers serve to clearly delimit access or work areas, helping to organize space and prevent accidents;



Fig 17: Narrowing of the roadway

5.8 Narrowing of the roadway, (Fig 17). In some areas with an increased risk of accidents, it can make the road infrastructure much safer. These narrowings force drivers to reduce their speed substantially and sometimes even stop to give way to other cars or pedestrians;



Fig 18: Artificial bumps of the roadway

5.9 Artificial bumps, (Fig 18), Placed transversely across the entire width of the road, preventing drivers from bypassing them in the opposite lane, are a method of calming vehicle traffic, forcing them to reduce their speed and preventing unwanted road incidents. The unofficial term "sleeping policeman" or "speed bump" – sleeping policeman, is a device for forcibly reducing the speed of motor vehicles and one of the measures for calming road traffic. Artificial road bumps were first used in the US in the early 20th century to forcibly limit the speed of cars on dangerous sections of the road. At that time, the US was undergoing a period of rapid mass motorization, which greatly concerned farmers, whose farms were located along highways, regarding the protection of animals. At that time, the US was undergoing a period of rapid mass motorisation, which was a cause of great concern to farmers whose farms were located near motorways, as they were worried about the safety of their domestic animals, which were often hit by moving cars. In Europe, speed bumps appeared after World War I and varied in shape and size, as well as in the signs that indicated their presence [14];



Fig 19: Resonator bands

5.10 Resonator strips, (Fig 19) are mainly used in road safety to alert drivers to imminent dangers through vibration and noise, being placed before pedestrian crossings, roundabouts, dangerous curves, or on the side of the road. Their purpose is to reduce vehicle speed, signal lane departure, and warn drivers to be more careful. They can be marked near pedestrian crossings, alternating with grip strips ("red carpets"), in order to force drivers to reduce the speed of their vehicles (resonator strips produce vibrations, and grip strips increase the grip of vehicle tires on the road surface).

They have the following utilities:

- *Before danger spots (areas)*: Used to warn drivers to slow down before reaching intersections, roundabouts, pedestrian crossings, or dangerous areas;
- *On the side of the road*: They mark the boundaries of traffic lanes, drawing drivers' attention when they leave the lane (e.g., due to fatigue);
- *At the entrance to towns*: They can be used as signage to encourage drivers to slow down at the entrance to towns;

They work by:

- *Vibration and noise*: Rumble strips, either in the form of grooves or bumps, create loud noise and vibration when a vehicle drives over them;
- *Warning for drivers*: These vibrations and noises pass through the tires, suspension, and chassis, alerting the driver and signaling the presence of an obstacle or danger zone.

The effectiveness of resonator strips along road shoulders depends largely on a wide and stable shoulder for successful recovery. Resonator strips were first used in the Netherlands in the early 1990s, reducing the number of traffic fatalities caused by inattention by about one-third by 2007. There are basically two ways to install resonator strips on the road: applying a road marking with an appropriate layer thickness and/or surface structure (rough) or milling grooves into the road surface. A resonator strip is applied along the direction of travel, following the edge line at the right-hand edge of the carriageway or a center line, to warn drivers when they leave their lane. Rumble strips can also be placed in series, transversely to the direction of travel, to warn drivers of a stop or slowdown ahead or of an approaching hazard (pedestrian crossing, other obstacle, or important road infrastructure feature).

In practice, countries that use rumble strips have found them to be extremely effective in improving road safety. In Japan, for example, the number of accidents has been reduced by about 50%, and the number of deaths caused by collisions, accidents involving people crossing the street at crosswalks, and vehicles leaving the lane has been reduced by about 70% [15];



Fig 20: Tread strips (red carpets) placed at pedestrian crossings

5.11 Tread strips (red carpets) placed at pedestrian crossings, (Fig 20). These markings are applied to the road surface in front of pedestrian crossings in order to increase pedestrian safety. "Red carpets" are distinguished by their bright color, designed to attract the attention of drivers well before they reach the pedestrian crossing. The markings are made of a special material with an abrasive (non-slip) surface, which helps reduce braking distance, thus giving drivers extra reaction time and very high tire grip on the road surface. In addition to their warning role, "red carpets" are recommended for use at busy intersections and in areas with heavy pedestrian traffic to ensure increased visibility and reduce the risk of accidents. This type of carpet can only be used in accordance with the standards set by the norm, and for operating speeds of up to 50 km/h, it must be at least 17 m long. Of course, to be effective, simply applying this marking material is not enough. It must be accompanied by other traffic calming measures, such as narrowing lanes in the vicinity, perfect visibility, and other actions, depending on the alignment. The marking is applied to the road surface in accordance with standard SM SR 1848-7:2015. They are applied in areas with heavy pedestrian traffic (especially near schools, kindergartens, nurseries, and playgrounds);

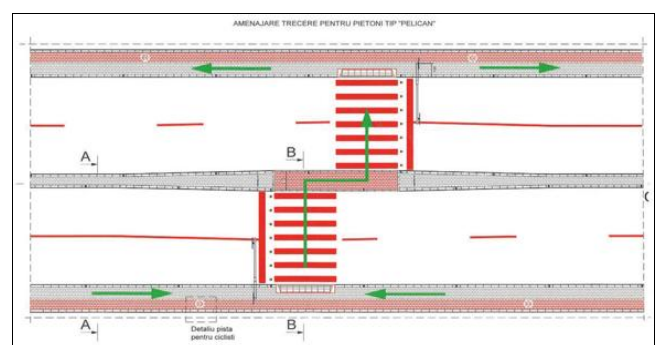


Fig 21: Pedestrian crossings equipped with "chicanes" and refuge islands between lanes for pedestrian safety (arranged for a pelican-style crosswalk)

5.12 Pedestrian crossings equipped with "chicanes" and refuge islands between lanes for pedestrian safety, (Fig 21). Pedestrian traffic islands are physical structures, usually in the form of elevated islands, located on streets with more than two lanes in each direction, on roads or in urban areas to separate pedestrian and vehicular traffic flows and guide pedestrians and vehicles along the correct routes. Pedestrian routes are protected by metal fences (grilles) arranged transversely and longitudinally on the central island, or protective posts, in order to increase the safety and protection of pedestrians, but also to compel them to follow

the route of the street crossing exactly, by facing the flow of vehicles traveling on the road to be crossed (note the route marked with a green arrow in Fig 21). They also help reduce vehicle-pedestrian conflict points by creating real "chicanes" for pedestrians crossing the road or street at pedestrian crossings, increasing their safety by establishing distinct, well-defined and determined routes (the route marked in green);



Fig 22: Pedestrian traffic lights

5.13 Pedestrian traffic lights, (Fig 22). They are located at marked pedestrian crossings equipped with such traffic control and command systems and usually work in conjunction with the operating program of all traffic lights for pedestrians and vehicles at an intersection, if the pedestrian crossing is located near the intersection. The main role of the pedestrian traffic light is to regulate safe crossing of the street by giving alternating priority to pedestrians. The green signal allows pedestrians to cross, while the red signal prohibits crossing. The flashing green signal indicates that the crossing time is coming to an end, and pedestrians already on the road must complete the crossing safely, while those waiting must remain in place.

The traffic light signals for pedestrians are:

- **Green light:** Allows pedestrians to cross the street. Even when the light is green, it is important for pedestrians to look both ways before starting to cross.
- **Flashing green light:** Indicates that the crossing time is ending and the red light will appear soon. Pedestrians who have already started crossing must finish quickly. Pedestrians who have not started crossing are not allowed to enter the roadway and must wait for the green light.
- **Red light:** Prohibits pedestrians from crossing the street. During this time, vehicles have the right of way.
- **Audible signals:** Some traffic lights may be equipped with audible signals to help blind people cross safely.

Pedestrian traffic lights play an essential role in regulating street crossings, ensuring pedestrian safety and keeping traffic flowing smoothly.

Its main functions and roles are:

- **Indicating when it is safe to cross:** By displaying a green light (or a symbol of a pedestrian walking), the traffic light indicates to pedestrians that they have priority and can safely cross the road.
- **Warning to stop:** A red light (or a symbol of a stationary pedestrian) signals that crossing is prohibited,

indicating that vehicle traffic has priority or that crossing is unsafe at that moment;

- **Accident prevention:** The main role is to minimize the risk of road accidents by temporarily separating pedestrian and vehicle flows;
- **Coordination with vehicle traffic:** Pedestrian traffic lights are synchronized with vehicle traffic lights, optimizing the overall flow of traffic at intersections;
- **Legal regulation:** Compliance with traffic light signals is mandatory under the Highway Code, and failure to comply (crossing on red) constitutes a misdemeanor and involves major risks;

5.14 Smart traffic lights that anticipate pedestrians' intentions to cross. Waiting at traffic lights can be difficult for pedestrians who want to cross the street during rush hour. Most of the time, the wait lasts from a few seconds to a few minutes, and this can cause congestion or frustration among passers-by. There are smart traffic lights that anticipate the pedestrian's intention to cross. Austrian researchers have found a solution to the needs of crossing streets by designing a smart traffic light capable of anticipating pedestrians' intentions to cross. These traffic lights are equipped with video cameras and are designed to detect people who want to cross, giving them a green light, which could lead to smoother traffic flow. The system continuously scans a 9x3-meter area and transmits the information to the traffic light, which gives pedestrians the green light, all in just a few seconds. The new technology is up to 4 seconds faster than other smart traffic lights, where pedestrians press a button and wait for the green light [16]. They can be equipped with photovoltaic panels to ensure a higher degree of autonomy in terms of the power supply on which they operate.



Fig 23: Traffic light with radar

5.15 Radar traffic lights that detect the speed of vehicles, (Fig 23). This advanced technology allows for dynamic and automatic traffic adaptation, ensuring fluidity without unnecessarily blocking traffic.

In Romania, the municipality of Braşov is testing smart traffic lights that detect vehicles exceeding the legal speed limit. The traffic lights automatically switch to red to stop drivers at pedestrian crossings. The traffic lights have been equipped with radar detectors connected to the traffic light systems for pedestrian crossings. If drivers exceed the legal speed limit, the traffic light switches to red for road traffic in order to slow down traffic and protect pedestrians in the area. The installation of these systems does not affect the operation of pedestrian traffic lights. Pedestrians will continue to request a green light by pressing the button [17]. They can be equipped with photovoltaic panels to ensure a higher degree of autonomy in terms of the power supply on which they operate.

The operation of these traffic lights consists of:

- **Radar sensors:** A built-in radar device instantly detects the speed of an approaching vehicle;
- **Automatic switching:** If the speed exceeds the preset threshold, i.e., the legal speed limit of 50 km/h (the regulatory speed for vehicles in built-up areas), the traffic light changes to red;
- **Increased safety:** The red light forces the driver to slow down, giving pedestrians extra time to cross safely;



Fig 24: Traffic light with pedestrian button

5.16 Pedestrian push-button traffic signals, (Fig 24). A push-button pedestrian signal operates by activating a crossing cycle, in which the traffic signal system responds to the pedestrian pressing the button. When the button is pressed, the traffic light registers the request and, at the appropriate time, will change the traffic lights to allow pedestrians to cross safely, either by giving pedestrians a green light or by allowing them to cross while the traffic lights for vehicles display a red light.

The basic algorithms governing the operation of a pedestrian push-button traffic light are:

- Request:** when a pedestrian presses the button, it sends a request to the traffic light control system;
- Prioritization:** the traffic light control system processes the request based on current vehicle traffic.
- Activation:** the system will change the pedestrian signals at the next opportunity allowed by the overall traffic signal cycle, often by shortening the cycle for vehicles and activating the pedestrian signal;
- Pedestrian signal:** the pedestrian signal will display green to indicate safe crossing of the street;
- Safety:** at the same time, the vehicle signals will turn red to stop traffic and allow pedestrians to cross safely;



Fig 25: Radar speed with indicators

5.17 Radar speed indicators, (Fig 25), are systems that monitor vehicle speed using Doppler radar and display information to road users, encouraging them to reduce their speed and drive within the legal limit. They have a psychological effect on drivers and combine advanced technology with adaptable design to provide effective speed monitoring solutions in residential areas, schools, and communities (especially in urban environments), speed-sensitive locations in neighborhoods or where pedestrians may walk on streets alongside vehicles, making drivers aware and responsible for their speed in a dynamic way. They can be installed with the option to transmit messages to road users by displaying additional messages such as:

"Thank you" (for the limit) or "Slow down" for those who have exceeded the legal speed limit, or alternatively, a "smiling" or "frowning" face (smiley);



Fig 26: Illuminated pedestrian crossings [18]

5.18 Illuminated pedestrian crossings, (Fig 26). These special white stripes illuminate both the crossing and pedestrian traffic to improve safety. Smart crosswalks can be effectively combined with smart street lighting solutions and connected traffic lights, enhancing road safety while promoting the inclusion of people with visual and mobility impairments [18];



Fig 27: 3D pedestrian crossing

5.19 3D pedestrian crossings, (Fig 27). There are innovative solutions in the field of road safety, including road markings. In many cities in Europe, but also in cities in Romania, 3D pedestrian crossings are currently being implemented, creating an optical illusion designed to attract the attention of drivers, forcing them to slow down in dangerous areas. These markings are a creative and effective solution, having a positive impact on driver behavior without the need to install additional road signs or traffic lights, by creating the optical illusion of a raised obstacle placed across the roadway.

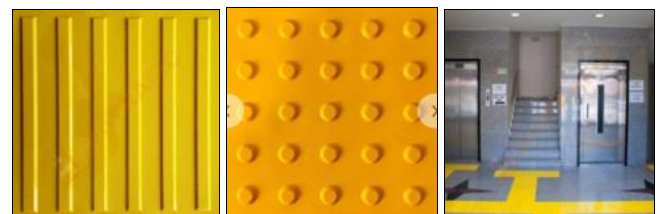


Fig 28: Tactile markings for blind people

5.20 Tactile stop/guidance road markings, (Fig 28). These are road markings that help people with visual impairments cross safely, representing another important step towards pedestrian safety. These markings are made with special surfaces that can be felt under the soles of shoes or with a

cane, thus providing clear guidance for blind or visually impaired people. They can be either stop or guide markings. The tactile stop marking for the blind is a special product that is applied to sidewalks or public spaces designed to warn visually impaired people of dangerous areas or changes in route, such as train platforms, subways, or trams, or stairs or crosswalks. This product is made of durable material with a texture that varies depending on the model. The role of tactile markings, such as stop or guide markings, is to enable blind people to orient themselves in an open space. This type of marking is applied in the form of longitudinal strips and has a special profile that allows the cane to be directed in the direction to be followed. The special profile of the tactile markings also allows the direction indicated by them to be followed by shoes with normal soles.

5.21 Underground passages (tunnels) or overpasses (footbridge) for pedestrians, (Fig 29). Underground passages (tunnels) and overpasses (footbridge) for pedestrians are infrastructures separated from the road level, created for the safety of pedestrians, allowing them to cross busy roads without interrupting vehicle traffic and without risking accidents, either by walking under the street (underground) or over the street (above ground/footbridge).



Fig 29: Underground passages (tunnels) or overpasses (footbridge) for pedestrians. Equipping them with a horizontal elevator and ramp for people with disabilities

Types and functions:

- *Underpass (pedestrian tunnel):* A tunnel built under the road, connecting two parts of the sidewalk, providing a completely safe crossing, completely separated from cars;
- *Pedestrian bridge (footbridge):* A structure raised (a bridge) over a street or highway, allowing pedestrians to cross over, supported by pillars, maintaining the flow of vehicles at ground level.

Benefits:

- *Safety:* Eliminates the risk of collisions between pedestrians and vehicles, especially on busy roads;
- *Fluidity:* Contributes to smoother traffic flow, as pedestrians no longer stop cars;
- *Comfort:* Provides a comfortable crossing regardless of weather conditions (especially underground passages, which protect from rain/sun).

Underground passages can be equipped with horizontal elevators or sloped ramps for people with disabilities. Similarly, overground passages can be equipped with vertical elevators for people (Fig 29).

These structures are essential in congested urban areas, schools, hospitals, and shopping centers, where pedestrian safety is a priority.

6. Creating buffer zones for vehicles at intersections with pedestrian crossings: Case study

Statistics show that road markings in Romania cause more than half of all road accidents.

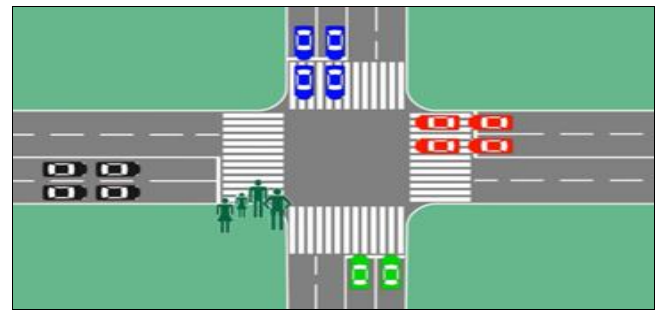


Fig 30: Incorrect positioning of pedestrian crossings at an intersection

In Fig 30, we have identified five serious problems caused by incorrect positioning of pedestrian crossings at an intersection, situations that can lead to serious accidents involving people crossing the road legally at permitted locations. All five problems cause insecurity, traffic jams, and an increased risk of accidents. It is possible that some more skilled minds may identify other problems, but we will only analyze the five identified, which are overwhelmingly serious in terms of causing casualties when crossing.

Below we present the serious problems identified, as well as solutions for identifying them:

A. The danger of crossing the street: Article 72 of Romanian Government Ordinance No. 195/2002, as well as the traffic laws of European countries, state that pedestrians must cross public roads perpendicular to their axis, only at specially designated and appropriately marked locations, and in the absence of such places, in built-up areas, at the corner of roads (streets), only after ensuring that they can do so without danger to themselves and other road users. We do not know how correct it is to cross the street properly at the corner of intersections under the conditions described above. Parents, schools, and traffic police educate people from a young age to cross the street according to the rules, telling them that before stepping onto a crosswalk, and not only there, they should first look carefully both left and right.

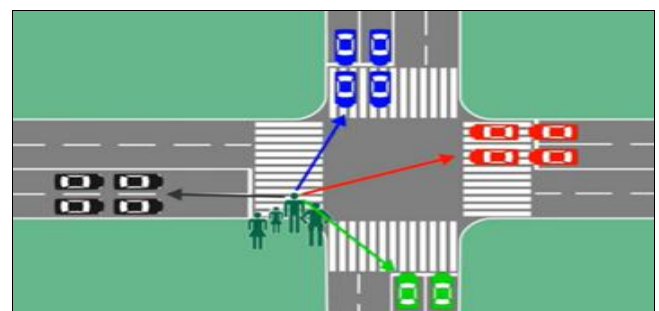


Fig 31: Ensuring pedestrian safety when crossing a street from all four directions



Fig 32: Giving priority to pedestrians crossing the street

No one tells pedestrians that if they cross the street properly at the corner of intersections, even on a crosswalk, they should look both ways, as mentioned above, and also in front and behind them (Fig 31). This is important because one of the blue vehicles could turn right, as it does, and one of the green vehicles could turn left, and in this way they could surprise pedestrians crossing the street at the crosswalk. If the drivers of these vehicles are attentive and skilled, there should be no problem. They should stop and give way to pedestrians crossing the road (Fig 32), but things sometimes get more complicated, especially for less experienced drivers, because turning involves several operations such as: checking, signaling, changing gears, sometimes braking, changing direction, and distributing attention. This is where the problem of *field of vision* arises, especially *peripheral vision*.

In many cases, there are blind spots at the pillars between the windshield and the car doors, generically referred to as the *A-pillar*, which could prevent the driver from noticing pedestrians crossing the road properly in time, or at all. If pedestrians are not noticed in time and the speed of the vehicle is not adjusted, a collision between the vehicle and the pedestrian is inevitable. Some vehicles, depending on their design, have a double *A-pillar* (minibuses, buses, SUVs), and in this case, their drivers have a blind spot of 15-20 degrees.

The recommended solution: the placement of pedestrian crossings at a considerable distance from the corner of the intersection by creating *buffer zones (spaces)* for storing vehicles between the corner of the intersection and the pedestrian crossing, thus ensuring a different dynamic and perspective for traffic through the intersection. In this case, pedestrians will only need to look left and right, as there are no other dangers from other directions. In this case, pedestrians are seen in advance, as they are in the field of vision of all drivers traveling on that street. (Fig 33).

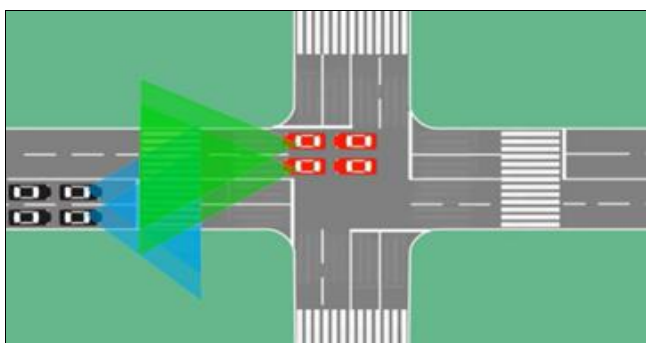


Fig 33: The field of vision of drivers

B. Blocking intersections: Most often, this happens when drivers "force" the yellow light at an intersection, reaching the crosswalk when pedestrians have the green light and begin to cross the street according to the rules. In this case, drivers stop to give way to pedestrians, but block all traffic on the intersecting street. There is no need for a traffic light intersection, because when pedestrians cross the street at a crosswalk, regardless of the direction of traffic, vehicles are required to stop in the path of other vehicles, thus causing traffic jams by blocking intersections (Fig 34). This is the consequence of the inability of vehicles to move beyond the corner of the intersection, with vehicles blocking traffic at that intersection.



Fig 34: Creating traffic jams at intersections

The recommended solution: Lacing pedestrian crossings at a considerable distance from the corner of the intersection by creating *buffer zones (spaces)* for storage vehicles between the corner of the intersection and the pedestrian crossing. This creates sufficient space for storing vehicles entering the intersection on this section of the street. Leaving the center of the intersection free allows traffic to flow freely on the intersecting streets (Fig 35).

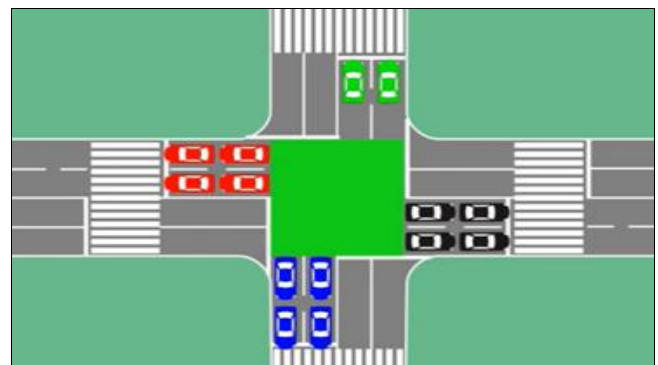


Fig 35: Eliminating congestion by providing a storage area for vehicles at a road intersection

C. Blockage in granting intermittent priority: This case is specific to entering an intersection from a road without right of way. Before entering the intersection, there is a pedestrian crossing, and traffic laws require us to give priority to pedestrians who are crossing the street in accordance with the rules. However, priority must also be given immediately to vehicles traveling on the main road or on the road with priority (intermittent priority) (Fig 36).



Fig 36: Priority for pedestrians and vehicles traveling on the principal roadway

Even in conditions of maximum visibility, it is possible to enter the intersection easily. It is possible to enter the intersection because there are no vehicles on the priority road, but there are pedestrians crossing, then there is a

pedestrian crossing and you advance towards the corner of the intersection, but there are vehicles on the priority road. While waiting for them to cross, other pedestrians start crossing, and again we miss the moment to enter the intersection from the non-priority road, and this can go on forever at busy intersections. This hesitation can become fatal when we have just made sure that the intersection is clear and other pedestrians or vehicles appear on the main road (with priority).

The recommended solution: Placing pedestrian crossings at a considerable distance from the corner of the intersection by creating buffer zones (spaces) for storing vehicles between the corner of the intersection and the pedestrian crossing. If we mark pedestrian crossings at a distance from the corner of intersections, we create a buffer zone (space) for vehicles entering the intersection. Now, pedestrians are given priority to cross first, then vehicles advance to the entrance of the intersection, where priority is given to all vehicles traveling on the main road (with priority), and when the intersection is clear, they enter it from the road that loses priority without any problems. This eliminates risks, points of conflict (vehicle-vehicle, vehicle-vehicle, vehicle-pedestrian, and vehicle-pedestrian), or possible accidents (Fig 37).

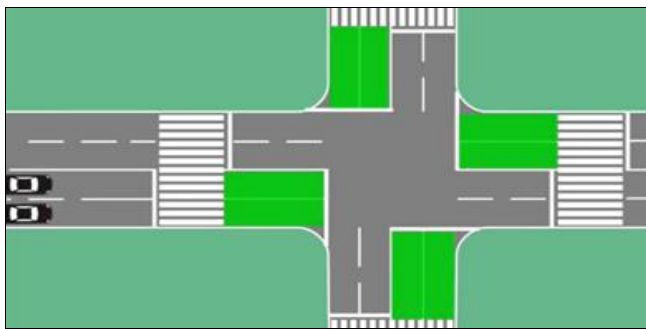


Fig 37: Creating buffer zones for vehicles approaching intersections

D. Ignoring particularly important markings: The lack of "stop" or "yield" markings on the road surface (asphalt) is one of the main causes of road accidents, increasing the risk of vehicle traffic. In this case, if there is a car in lane 1 of a road and a truck, bus, or other taller vehicle in lane 2, the drivers of the larger vehicles will be able to easily see the stop or yield sign at the intersection (Fig 38). The lack of markings on the road surface is also specific to Romania, a country that has adapted its road legislation to European legislation, but it seems that this has not been fully implemented on some roads or streets.

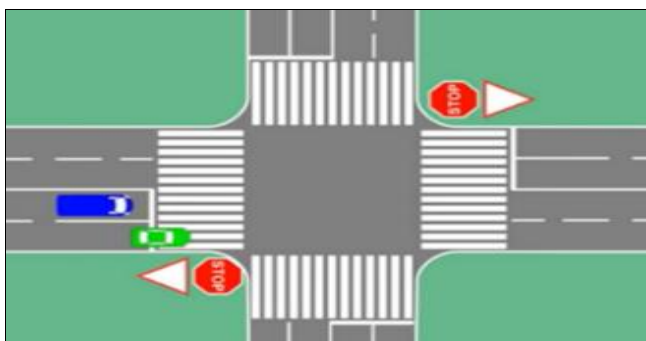


Fig 38: Optimal visibility of indicators at intersections on lane 2 of a road

In reality, the situation shown in Fig 38 only occurs when taller vehicles turn left and have entered lane 2 of the road (street). In all other situations, the taller vehicle will be in lane 1 of the road or street, and the car will be in lane 2. In this case, the driver of the car (or other lower vehicles) does not have a clear view (Fig 39) of the stop sign or yield sign located at an intersection of streets or roads, and there is a possibility that they will enter the intersection without slowing down or stopping to ensure.

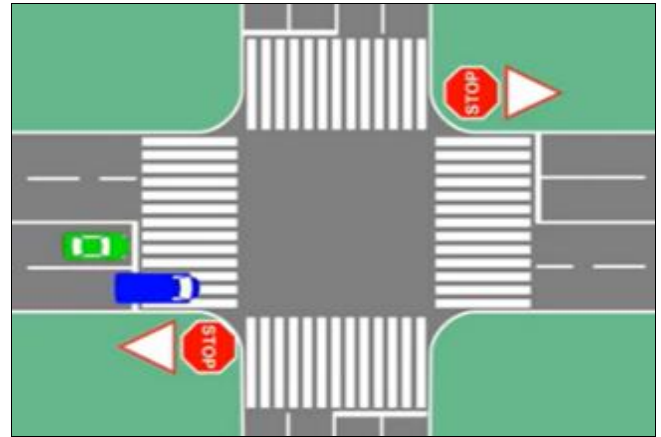


Fig 39: Obstruction of the field of vision by large vehicles on two-lane roads

The same situation occurs when stop or yield signs are covered by vegetation or dense trees. It makes no sense to paint stop or yield markings on the asphalt as shown in Fig 40, i.e., before pedestrian crossings. It can be interpreted by drivers as a stop or yield sign at the pedestrian crossing and not for vehicles or motor vehicles. The marking in this case is meaningless. These types of markings should be made at intersections and should be permanently in the drivers' field of vision (thick fog, sun reflections, snow covering the asphalt, etc).

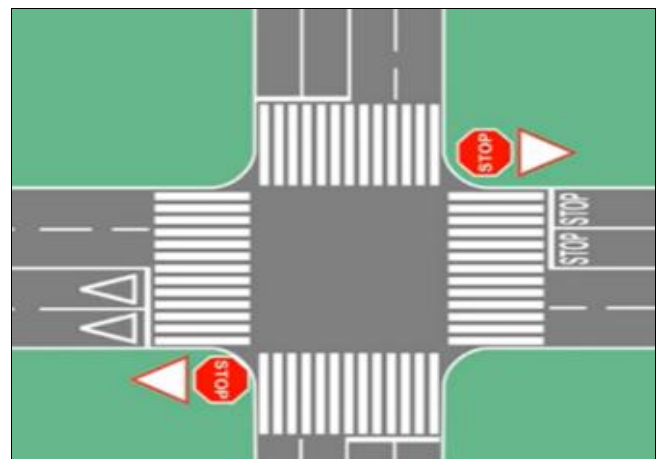


Fig 40: Incorrect marking of stop signs or yield signs

The recommended solution: placing pedestrian crossings at a considerable distance from the corner of the intersection by creating buffer zones (spaces) for storing vehicles between the corner of the intersection and the pedestrian crossing. This creates a storage area (space) for vehicles entering the intersection, where both preselection (directional) markings and stop or yield markings can be made (Fig 41). This way,

there is no possibility of failing to comply with the meaning of road markings.

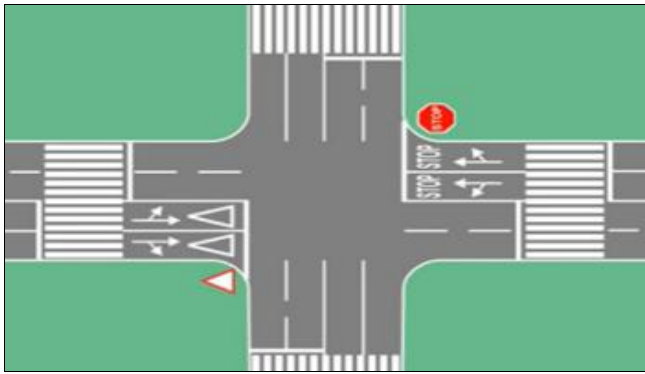


Fig 41: Correct marking of stop or yield signs and directional signs

E. Lack of reflectivity of road markings (lack of visibility of road markings). This is a problem encountered by drivers in Romania. Compared to other road markings in Western Europe, even the oldest ones are easily visible both during the day and at night, in heavy rain or dense fog. This can be easily detected using a reflectometer, a device that is not currently available to the Romanian police.



Fig 42: Reflectometer

The recommended solution: equipping all institutions responsible for roads in Romania with *reflectometers*, (Fig 42) and using them to detect all areas where the reflectivity of road markings is poor; using high-quality reflective paints when applying road markings; tightening legislation to determine and mobilise the public authorities responsible for carrying out road marking works in Romania.

7. Conclusions and recommendations from the authors

Pedestrian crossings protect pedestrians from potential accidents, making them the ideal solution for crossing roads safely.

Marked crosswalks are commonly found near intersections but may also be located at other points on busy roads that would otherwise be too dangerous to cross due to the number, speed, or width of the roads. They are often installed in areas with a high number of pedestrians attempting to cross (such as shopping areas) or where vulnerable users (such as children) frequently cross. There are rules governing the use of crosswalks to ensure safety; for example, in some areas, drivers may only proceed after the pedestrian has crossed halfway, and in other areas there are laws against jaywalking, which restrict pedestrians from crossing outside of marked areas.

A zebra crossing without other safety measures can increase pedestrian accidents by 28% compared to locations without crossings. However, if it is located on a raised platform, it reduces accidents by 80%.

On multi-lane roads with traffic exceeding 12,000 vehicles/day, marked crossings are more dangerous than unmarked ones if there are no median refuges or pedestrian beacons.

On roads with more than 15,000 vehicles per day, marked crossings are more dangerous than unmarked ones, even with median refuges.

Pedestrians shall cross public roads perpendicular to their axis, only at specially designated and appropriately marked locations, and in the absence of such places, in built-up areas, at street corners, only after ensuring that they can do so without danger to themselves and other road users," according to Article 72 (3) of Government Emergency Ordinance No. 195/2002. Therefore, people who are about to cross the street at a pedestrian crossing must take precautions. Otherwise, they may be held responsible for causing a traffic accident.

Pedestrians who are caught and injured as a result of crossing in prohibited areas, at a red light intended for them, or failing to comply with other obligations established by traffic regulations bear full responsibility for their injuries, provided that the driver of the vehicle in question complied with the legal provisions regarding traffic in that area," as established by Art. 72 (4) of the traffic law.

At a traffic light-controlled pedestrian crossing, pedestrians may only cross when the light is green. At a simple pedestrian crossing, pedestrians may only cross the road after checking that it is safe to do so, and drivers are required to stop.

Situations in which people crossing the street at a pedestrian crossing do not have priority are regulated. According to the updated legislation, Article 167 prohibits pedestrians and persons assimilated to them from:

- To cross the public road when a vehicle with priority traffic rights is approaching with its special light and sound warning signals in operation;
- Cross the roadway in front of or behind a vehicle stopped at public transport stops, except where there are properly marked pedestrian crossings;
- Prolong the time taken to cross the public road, stop or turn back on pedestrian crossings that are not equipped with traffic lights;
- Cross the public road in places other than those permitted;

- Occupy the roadway for the purpose of obstructing traffic.

In the case of roads with two or more lanes, as well as those with a single lane in each direction, pedestrian refuges may be installed halfway across the road. In this situation, drivers must give priority to pedestrians only when they are in their direction of travel. It is an offense and is punishable by a fine provided for in class III penalties and the application of the complementary penalty of suspension of the right to drive for a period of 60 days [...] Failure to give way to pedestrians who are crossing the public road in a regulated manner at specially designated and signaled locations, located in the direction of travel of the motor vehicle, agricultural or forestry tractor, or tram," establishes Art. 101 (3-e) of the traffic law.

The kinetic energy of a vehicle increases exponentially with speed. In other words, the faster the vehicle is traveling, the more effort the brakes must exert to bring it to a complete stop.

Worn or seasonally inappropriate tires reduce traction, which means that the brakes are unable to stop the vehicle in time.

Maintaining a safe distance is not just a recommendation, but a necessity for road safety. It helps you react effectively in an emergency, avoid collisions, and maintain smooth traffic flow.

Braking distance is an essential concept for road safety, influenced by numerous factors such as speed, weather conditions, and the technical condition of the vehicle. Understanding this aspect and following safety rules, such as the 2-second rule, can save lives and prevent accidents.

Our own safety and that of other road users depends largely on our ability to react as drivers when we identify an imminent danger and on the braking distance of the vehicle we are driving. This is where factors that influence the reaction distance of the driver of a road vehicle come into play, as well as those that affect the braking distance.

Excessive speed and incorrect assessment of the optimal braking distance are among the most common causes of road accidents. When driving, it is essential to know how to adapt to traffic conditions, maintain an appropriate distance between vehicles, and stay focused on the road to avoid accidents or unpleasant events.

An attentive and rested driver can react more quickly to obstacles, reducing the total stopping distance. That is why it is important to get behind the wheel well-rested, to always focus on the road, and to avoid distractions.

In winter, snow and ice can double or even triple the stopping (braking) distance.

In spring and autumn, water and wet leaves also create difficult conditions for stopping the vehicle.

In summer, hot asphalt can affect tire performance, especially if they are used.

The advantages of using traffic islands include reducing vehicle speed, guiding traffic flows, improving road safety, reducing the risk of accidents, and improving traffic organization in congested areas.

Smart pedestrian traffic lights offer more flexibility and high potential for smoothing the flow of vehicle and pedestrian traffic. Through this type of traffic control and command system in Romania, as well as at the European level, authorities are making significant efforts to increase road safety, both through the implementation of new technologies and through road safety and prevention campaigns.

Smart traffic lights with pedestrian buttons eliminate the risks of unsafe crossings, give pedestrians direct control over crossings, and increase the visibility and priority of pedestrians in traffic.

Technology saves lives and promotes responsible behavior in traffic, adapted to the needs of modern and safe cities.

By combining smart technologies with renewable energy sources, smart traffic lights with photovoltaic panels represent a significant step towards more efficient, sustainable, and adaptable road traffic management in urban areas. Investing in smart solutions is essential for preventing tragedies.

Speed signs with radar not only improve safety, but also promote a safer environment for all road users. They are easy to install and maintain, use energy-efficient LEDs to display data, raise awareness among drivers, and encourage preventive and responsible driving.

The distance at which a pedestrian crossing can be marked from the corner of an intersection is determined based on measured or known traffic flows.

Prevention implies creating the optimal environment for all traffic participants to correctly and timely identify the situations they will encounter or find themselves in and the correct choices they will make.

Prevention also implies finding and applying solutions that eliminate points of conflict and risks as much as possible. The solutions must be clear and understandable to all traffic participants. It is useless to have authorities doing their job on public roads if the general framework is flawed.

It is not enough to develop rules, they must be harmonized with logic, the laws of physics, or those of mathematics.

Road markings are much more than just lines painted on asphalt; they are a vital element for the safety of all road users, especially pedestrians. A well-designed and well-maintained road infrastructure can save lives by reducing the risk of accidents and creating a safer and more organized environment. Modern cities need to invest in innovative and sustainable solutions to protect pedestrians and ensure smooth and safe traffic flow.

It can be observed that in four of the five cases presented in the case study, the creation of buffer zones (spaces) for storing vehicles on traffic flows is more than necessary. In order to create these storage areas (spaces), it is necessary that pedestrian crossings are not marked immediately at the corner of the street or intersection, but at a regulatory distance from it.

The buffer zone between intersections and pedestrian crossings should be at least 6 m for intersections with low traffic volume so that this area (space) can accommodate at least one car per lane, and at least 10-20 m for intersections with heavy traffic volume. The average length of a car is approximately 4.5 m, so two cars could fit in the buffer zone (space) on a 10 m lane, and if the intersection is used by long vehicles, then the buffer zone (space) should be at least 20 m long.

Finally, we present one particularly interesting aspect of child safety in Japanese road traffic is the way children cross the street at crosswalks. Here, children cross the street in a special way. First, the child should stand at a marked spot on the sidewalk and wait until the passing vehicle has come to a complete stop. Then the child lifts his or her hand and begins to cross the street safely, thanking the driver once he or she reaches the other side of the road or street. These aspects are presented in Fig 43.



Fig 43: The rule regarding children crossing the street at crosswalks in Japan

Road safety means trust and respect, and people trust professionals.

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