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The influence of insufficient road visibility on road hazards in urban traffic

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Abstract

In urban traffic, there are situations where cars parked on the road shoulder or part of the roadway obstruct the view to other road users. That situation can lead to a road incident with various consequences. This article presents sample consequences of a road incident that occurred due to one driver failing to give way by moving his or her car too far forward to make sure they could continue the drive. A total of four scenarios were analysed, assuming two different car positions before the accident and two different driving speeds. The reconstruction of road incidents was conducted with the use of the V-SIM 6.0 software licensed by CYBID Kraków, Poland. In addition, the number of road incidents at five selected crossroads in the consecutive quarters of the year was forecast using the grey system theory.

The simulation results demonstrated that moving the front of the car that gave way by up to 1.25 m beyond the roadway centre line and the other car's driving speed of 60 km/h will lead to the most serious consequences of the accident. The maximum volume of car silhouette coverage in that case will be 0.38 m^3. The forecast of the number of road incidents at the four crossroads in the next four quarters will demonstrate an increase in the number of accidents if relevant procedures are not implemented to improve visibility of the situation on the road at these locations.

Keywords: road traffic, road incident, V-SIM software, transport, grey system theory

1. Introduction

Road infrastructure develops rapidly in both developed and developing countries (Hermawan, Firdausy, Rambe, Zuhdi, Erwidodo, Nugraheni, Malisan, Isnasari, Marpaung, Asshagab, 2024; Mamo, Abebe, Beyene, Alemu, Bereka, 2023). The development of motorisation and the society's transport needs result in more and more cars on the roads. As a consequence, that development brings with it increasing congestion, as well as the growing risk of a road incident (Guo, Xu, Jin, 2024). Road accidents pose a serious risk to both public safety and infrastructure (Aati, Houda, Alotaibi, Khan, Alselami, Benjeddou, 2024), therefore as the number of vehicles on the road increases, concomitant efforts should be made to minimise the accident risk through appropriate education of the public and through research aimed at proposals for changes in traffic management. The need for road safety is directly correlated with the rapidly increasing impact of urbanisation on infrastructure and on daily life (Berhanu, Schröder, Wodajo, Alemayehu, 2024). That situation is particularly true for cities due to the constraints associated with the expansion of road infrastructure and the lack of options to adapt such infrastructure to the current situation.

The increasing number of vehicles means that there is a shortage of parking spaces in towns and cities for safe car parking. Drivers use any available space to park their cars, unfortunately very often breaking traffic regulations in the process. That situation can lead to a road incident, the consequences of which will depend on current road and environmental conditions. In the best case scenario, a minor bump may occur, but a more dangerous situation may also develop, such as hitting a pedestrian or a road accident causing damage to the people's health (Abdulrahman, Almoshaogeh, Haider, Alharbi, Jamal, 2025; Yahia, Mohammed, Eissa, Albrka, Ladin, Jashami, 2024). Therefore, traffic accidents are one of the most important public health safety issues of concern to both the public and city managers (Cui, Yang, Abdel-Aty, Zhang, Yan, 2024), primarily because of the costs, which represent a significant physical and economic burden (Kpe, Otoo, Owusu, Bawua, 2024). The costs of accidents include (Jaspers, 2023): costs of fatalities in road accidents, costs of slightly injured in road accidents, costs of seriously injured in road accidents, and material damage costs (incurred in accidents involving injuries and/or fatalities).

In the case of a two-lane one-way road, it can often be noted that drivers take advantage of the entire one part of the road to park their cars. In the light of the regulations, that situation is acceptable unless forbidden by prohibition signs. However, some drivers do not consider whether such parking will not obstruct the view to other road users and thus create a traffic hazard. It can often be noted that drivers want to make use of every piece of the road and leave their cars in the immediate vicinity of a crossroads, and do not remember about keeping a ten-metre distance from the crossroads. Parking a car in that way poses a real road traffic hazard. Drivers who want to join the traffic by entering from a minor street from the side of parked cars then have reduced visibility and are unable to make a proper decision as to whether they can join the traffic. In order to make sure that they can safely use the entryway, they drive forward looking for a convenient position to watch the traffic. The problem arises when the car front has been moved too far forward and the car is therefore in a collision position.

An enormous problem is caused by drivers who lack imagination and, in addition to parking too close to the crossroads, do it at a distance from the kerb, paying no attention to the regulations that require parking a vehicle as close to the road edge as possible. The combination of those two factors makes visibility even poorer and puts other road users at a greater risk of a traffic accident.

Incorrect parking carries a fine of an appropriate amount, but nevertheless some drivers are willing to break the rules and leave their cars at a place which is convenient to them. Interviews with such drivers most often show that they are aware of breaking traffic regulations, but explain that they are in a hurry and

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park their car only for a moment needed to resolve a matter in an office or deliver documents to an appropriate place, counting on not being stopped by the police during that time and fined. What drives do not realise, however, is that for that "moment" another person could lose their health or even their life.

One of the disadvantageous aspects of a traffic accident is disruptions to traffic causing traffic jams. The issue appears in the case of road accidents as the more serious they are, the more traffic congestion is concentrated in space (Mou, Jin, Wang, Chen, Li, Chen, 2022). In the present times, when reaching the destination is important, that aspect is becoming of special importance. Even a very minor collision may hold up road traffic for a longer time. Road users become frustrated, which is due to the thought that they are unable, for example, to provide services on time. The phenomenon becomes more intense when the incident occurs on a one-way road, as in that case it is not possible to do a U-turn or find a diversion route to bypass the scene of the accident.

The next disadvantageous consequence of a road accident is mechanical injuries in humans (Sufian, Varadarajan, Niu, 2024), which occur almost always, and which may be transitional, long-term or permanent. Returning to normal life may then be hindered and associated with the costs of therapy or rehabilitation.

Another disadvantageous aspect of a road incident, particularly of the one with serious consequences, is the occurrence of the mental implications of the accident in its participants. In such a situation, the post-traumatic stress syndrome may occur in some persons. In extreme situations, a similar trauma may also be suffered by witnesses to the accident. The consequences of the mental post-accident trauma may persist in a person throughout their life thus causing the person to be unable to function correctly in the social environment.

When analysing road accident causes and consequences mentioned above, it should be noted that they are a huge problem and ought to be minimised. This should be the case even more so that, as it follows from statistical data disclosed by the Police Headquarters, 20,936 road accidents and 365,991 road collisions were recorded in Poland in 2023. The data include 6,522 side collisions, i.e. those which will be reviewed further in this article. In those collisions, 343 people were killed, and 7,660 injured. In the first six months of 2024, 10,092 road accidents and 194,379 road collisions were recorded.

Road safety improvement through better understanding of the drivers' behaviour is a realistic approach to the reduction of the number of road collisions (Moslem, Farooq, Esztergar-Kiss, Yaseen, Senapati, Deveci, 2024), that is why the campaign promoting road safety should continue. The campaign ought to be aimed not only at drivers, but also at other road users. This article becomes part of that trend and may be one of the elements of education supporting road safety improvement awareness.

In the article, the analysis was conducted of the influence of driver insufficient visibility and the related lack of the option to take an appropriate decision on the possible consequences related to failure to give way on the road. Subjected to the analysis was the crossroads which the author believes is representative, and a similar assessment of other crossroads can be undertaken using that crossroads as an example. Detailed information on the crossroads under analysis is presented under the next item.

2. Description of simulation conditions

To define the assumptions necessary for the simulation, traffic management was watched at five selected crossroads, at which a road incident could have happened or did happen because it was not possible to evaluate the situation at a given time or the option possibility to do so was limited.

The intersections in question were designed in accordance with (Patterns and standards recommended by the Minister responsible for transport. WR-D--31-2. Road intersection design guidelines. Part 2: Standard and channelized intersections.). The lack of sufficient visibility is caused by cars parked on the left side of the one-way road, which is the main one. Drivers wishing to join the traffic from the minor road are forced to position the vehicle so that traffic at the crossroads can be visible well enough from their perspective to evaluate the situation, and that position may be hazardous to road safety. Fig. 1 shows an example of precisely such road visibility from the perspective of a driver joining the traffic, both during the day and at night.

a)

b)

Fig. 1. Road visibility by a driver joining the traffic from a minor road a) during the day, b) at night (photo by author)

In the case in which the driver stops the vehicle at the stop line, his or her view is obscured by cars parked too close to the crossroads and by the power pole. It is only when the car reaches the centre lane of the main road that visibility improves enough to assess the situation. Such a car position causes a problem particularly in the case of vehicles with a long front as this is located in a collision position with oncoming cars on the right. A sample collision at one of the crossroads under analysis is shown in Fig. 2. As it follows from media reports, one person suffered injuries in that accident and had to stay in hospital for more than seven days.

Fig. 2. A sample collision at one of the crossroads under analysis (source: www.sadeczanin.info)

The simulation of a collision of two cars due to insufficient visibility was conducted with the use of V-SIM 6.0 software, the licence for which is owned by CYBID (Kraków, Poland). That piece of software is a special computer programme enabling, in compliance with the principles of dynamics, the analysis of the movement and performance of vehicles, the simulation of collisions and

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the analysis of the pedestrian's, passenger's and vehicle driver's behaviour. The programme enables the reconstruction of various road incident scenarios with complex interactions in the environment/man/vehicle configuration taken into account.

As part of the simulations, two scenarios for the collision position of a car joining the traffic (the grey car) and two driving speeds of the car on a one-way road (the green car) are allowed for. Fig. 3 presents the car location and road situation visibility from the position of the car driver joining the traffic.

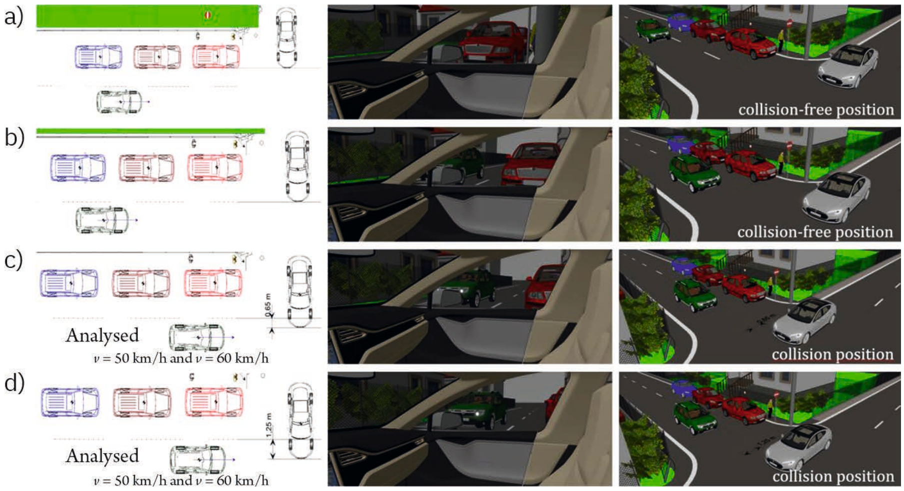


Fig. 3. The diagram showing the car location and road situation visibility from the position of the grey car driver (own elaboration)

The first two grey car positions (Fig. 3a and 3b), i.e. the situation where the car front is at the side line of the cars parked on the roadway and the car front is at the one-way road centre line, are not a collision position, however, that position considerably limits the visibility of the situation on the road, and the driver is not sure whether he or she may join the traffic safely.

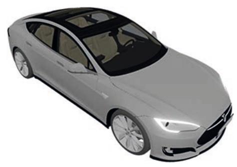
The driver wishing to be certain that he or she will join the traffic safely, approaches the one-way road centre line and puts the vehicle's front wheels at the centre line, but the car front protrudes by 0.65 m beyond the roadway centre line (Figure 3c). That situation causes the grey car to be in the collision position with the green car, which the driver is not aware of. The green car driver is also certain that he or she is not in a collision position with the other car and does not slow down, but continues the drive at a predetermined speed. Unfortunately, a road incident, i.e. a collision, occurs at that point.

The grey car driver came to the conclusion that he or she still did not have appropriate road visibility to take the correct decision because the driver's view was obscured by the car window pillar and, to some extent, by the cars parked on the road shoulder. Therefore, the driver decides to move the car slightly forward so that the front wheels are immediately beyond the one-way road centre line. Thus, the car front protrudes by as much as 1.25 m beyond the roadway centre line (Figure 3d). The driver is aware that he or she may have moved too far and be in a collision position, but the green car is too close for its driver to slow down safely. Before the driver had time to react and actuate the brakes, a collision occurs, whose consequences are analysed further in the article.

In the road accident simulation, two cars were used of the total permissible laden weight of 1,800 kg (the green one) and 2,694 kg (the grey one). The remaining technical parameters of the cars are summarised in Table 1.

The simulation scenario assumed two green car driving speeds i.e. 50 km/h and 60 km/h. During each simulation, the grey car was motionless and awaited the opportunity to joint the traffic. It is also appropriate to emphasize that only the drivers were present in the cars, and they did not transport cargo of a considerable weight. That information is of key importance in the evaluation of the consequences of road incidents.

Table 1. Car basic technical parameters

Parameter	Unit	Value	Silhouette
Green car			
Power source	Combustion engine		
Maximum power	kW	77	
Maximum torque	Nm	148	
Length	mm	4315	
Width	mm	1822	
Height	mm	1625	
Wheel base	mm	2673	
Brake efficiency	kN	16.6	
Grey car			
Power source	Electric motor		
Maximum power	kW	515	
Maximum torque	Nm	931	
Length	mm	4980	
Width	mm	1964	
Height	mm	1440	
Wheel base	mm	2960	
Brake efficiency	kN	28.9	

3. Grey system theory

In the final part of this article provided was a forecast of the number of road incidents which may happen in 2025 and 2026 if road conditions and visibility are not improved. For that purpose, the grey system theory was used as the tool.

The grey system theory was postulated by Prof. Julong Deng for the purposes of statistical analysis, where the sample size is insignificant (Liang, Tang, Qi, Jiang, Lao, Miao, Tang, Liu, Bao, 2023; Kokocińska, Nowak, Łopatka, 2020; Jalali, Heidari, Boriskov, 2023). This theory expresses that most systems cannot be divided into only two white and black categories (the category with known and unknown information). In fact, information related to most of the systems is grey (a combination of black and white) (Zhou, Wang, Nezhad, Maroufpoorf, Band, 2023). This means that part of information about the system is known through the isolation of useful information from whatever is available (Qian, Fu, Chen, Marengo, Zhang, Xu, 2022). The theory was first postulated in 1982 (Zha, Zheng, Li, Chen, Yuan, 2021) and is one of the most popular uncertainty testing methods (Wang, Qi, Chen, Tang, Jiang, 2014) A model of a system with a single observed output is conveniently constructed as a sequence of seven steps, which are discussed in detail in (Cempel, 2014). A mathematical model known as the grey model GM(1,1) yields accurate and highly repeatable predictions, characterized by high reliability and efficiency (Mao, Chirwa, 2006).

Due to low requirements concerning the volume of data, the grey system theory has been widely accepted in various disciplines for the forecasting of various phenomena (Mao, Chirwa, 2006). For example, the authors of (Wang, Wang, Zhang, 2020) used the grey system theory to predict contaminants on the insulator surface in power systems.

The maintenance system is a key system ensuring the continuity and safety of operation of production systems and affecting the safety of people working in those systems, that is why the aim of the article (Qiao, Zhang, Jiang, He, Li, 2019) was to identify the main management factors influencing work safety and arrange those factors in terms of their efficiency in ensuring safe maintenance, by using the grey system theory.

The authors of (Tabor, 2021) used the grey system theory to forecast motorway traffic parameters. Knowing that road traffic changes suddenly due to various factors such as weather, accidents, driving performance as well as increases in demand, which adversely affect forecasting model efficiency, the authors made an attempt to consider the options for the use and the accuracy levels of various grey system theory models for short-term traffic speed and travel time forecasts.

The grey system theory model is also defined by differential equation (1). The presentation of the formula and equation below is based on (Bezuglov, Comert, 2016; Opoka, 2020).

$$\frac{dX^{1}(t)}{dt}+aX^{(1)}(t)=u \tag{1}$$

Parameters a and u are determined through the determination of model $X^{(1)}(k)$, which is presented as the sum of the sizes of input models $X^{(0)}(t)$ for $i=1,2,\ldots,k$ (2).

$$X^{(n)}(k)=\sum\nolimits_{i=1}^{k}X^{(n-1)}(i) \tag{2}$$

The grey system model is created by data obtained by observation, and the response takes the form of prediction equation (3).

$$X^{(1)}(t+1)=\left(X^{(1)}(0)-\frac{u}{a}\right)\cdot e^{-at}+\frac{u}{a} \tag{3}$$

Parameters a and u are determined from equation (4).

$$\hat{a}=(a,u)^{T}=(B^{T}B)^{-1}B^{T}Y_{n} \tag{4}$$

where B and Y_n are established from formulas (5) and (6).

$$\begin{bmatrix} -\frac{1}{2}[X^{(1)}(1)+X^{(1)}(2) & 1 \\ -\frac{1}{2}[X^{(1)}(2)+X^{(1)}(3) & 1 \\ \cdots & \cdots \\ \cdots & \cdots \\ \cdots & \cdots \\ -\frac{1}{2}[X^{(1)}(n-1)+X^{(1)}(n) & 1 \end{bmatrix} \tag{5}$$

$$Y_{n}=[X^{(0)}(2)\quad X^{(0)}(3)\quad X^{(0)}(n)]^{T} \tag{6}$$

Where the model does not reach necessary precision, there is an option to correct it through the identification of the "data reminder" of the model. Then data sequences sets determined in equation (3) are described by equation (7).

$$\hat{X}^{(1)}(t)=[\hat{X}^{(1)}(t)\quad \hat{X}^{(1)}(2)\quad \cdots\quad \hat{X}^{(1)}(n)]^{T} \tag{7}$$

Predicted data is calculated from formula (8):

$$\hat{X}^{(0)}(t+1)=\left[X^{(0)}(1)-\frac{u}{a}\right]\cdot e^{-a(t-1)}\cdot(e^{-1}-1) \tag{8}$$

The remaining predicted data is calculated from equation (3). The process mentioned above may be repeated many times until model precision has been obtained.

Determining the accuracy of the method requires calculating the value of the discrepancy ratio C using formula (9) and comparing the result with the reference values of the minimum error P presented in Table 2.

$$C=\frac{S_1}{S_2} \tag{9}$$

where:

$$S_1^2=\frac{1}{n}\sum_{t=1}^{n}[(X_o(t)-\bar{X})^2];\quad \bar{X}=\frac{1}{n}\sum_{k=1}^{n}X_o(t)$$

$$S_2^2=\frac{1}{n}\sum_{t=1}^{n}[(q(t)-\bar{q})^2];\quad \bar{q}=\frac{1}{n}\sum_{k=1}^{n'}[X_o(t)-\hat{X}(t)];\quad n'<n$$

Table 2. Prediction of method accuracy (Mingfei, Kuhnell, 1991)

Forecast accuracy	P	C
Good	>0.95	<0.35
Satisfactory	0.8–0.9	0.35–0.5
Unsatisfactory	0.7–0.8	0.5–0.65
Poor	<0.7	>0.65

This study attempts to apply grey system theory to the forecasting of road incidents at five different intersections, where there is a significant risk of occurrence due to insufficient visibility of oncoming traffic for drivers merging from secondary roads.

It follows from statistical data that a total of one hundred collisions and accidents occurred at the crossroads under analysis during the last two years. The detailed number of road incidents by year is shown in Fig. 4.

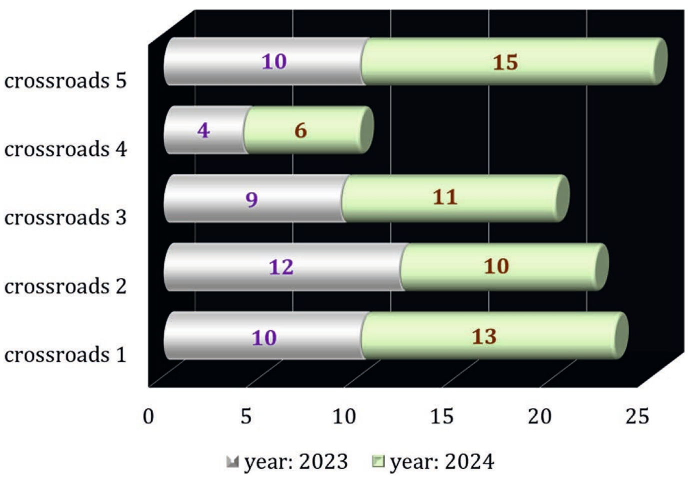


Fig. 4. The number of road incidents at the crossroads in question in 2023–2024 (own elaboration)

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It follows from the diagram that a decrease in the number of road incidents was noted at two crossroads only. This may be related to drivers' better vigilance at those crossroads or to a smaller number of vehicles driven in the area. A more detailed breakdown of road incidents by quarters is presented in Table 3. That data will be used for road incident forecasts in the next two years.

Table 3. The number of road incidents at the crossroads in question

	year: 2023				year: 2024			
	quarter I	quarter II	quarter III	quarter IV	quarter I	quarter II	quarter III	quarter IV
crossroads 1	2	3	2	3	3	2	4	4
crossroads 2	3	4	3	2	2	3	1	4
crossroads 3	2	0	3	4	2	4	2	3
crossroads 4	0	2	1	1	0	2	1	3
crossroads 5	3	3	1	3	3	4	3	5

It follows from the data shown above that road incidents happened at most crossroads in the fourth quarter. This may be due to the fact that that quarter comprises the months of unfavourable weather conditions and quick nightfall. Road visibility at that time is considerably reduced, and white frost on the roadway may occur, so a collision situation may happen despite the drivers' vigilance.

4. Results of the accident simulation analysis

The first two road incident scenarios assumed that the grey car front was 0.65 m beyond the one-way road centre line, and the green car was moving along the one-way road first at 50 km/h (the first scenario) and then at 60 km/h (the second scenario). The results for those incident scenarios are shown in Fig. 5 and 6.

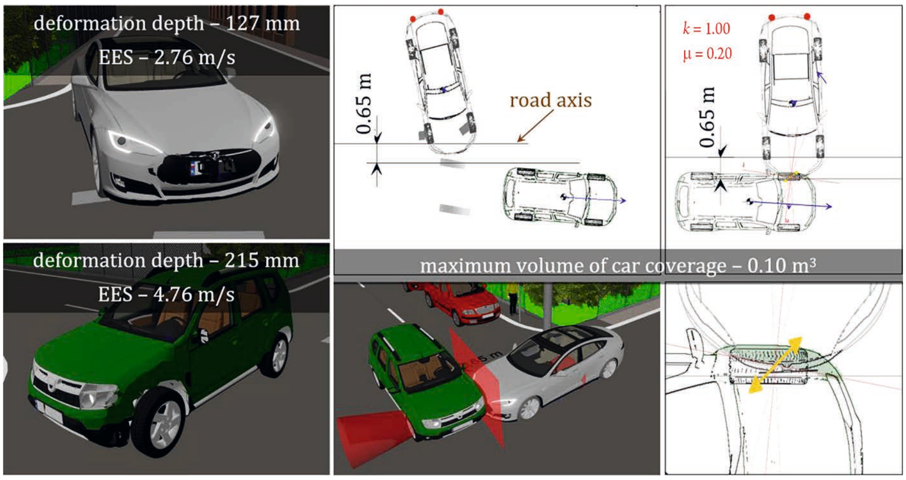

Fig. 5. The consequences of the collision of two cars for the first scenario (own elaboration)

The consequences of the car collision in both scenarios are very similar. The difference lies mainly in the extent of damage and in the angle of the car path change following the collision.

As a result of the road collision, the cars involved in the incident were slightly damaged. In the case of the green car, the areas of the left wheel arch were destroyed, and the front, mainly its central part, was destroyed in the grey car. The grey car deformation depth in the first scenario is 127 mm; in the second scenario that depth is greater by approximately 7 per cent and is

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137 mm. The difference in the deformation depth of the green car has a similar distribution. The increased deformation depth was noted there, too, this time by approximately ten per cent.

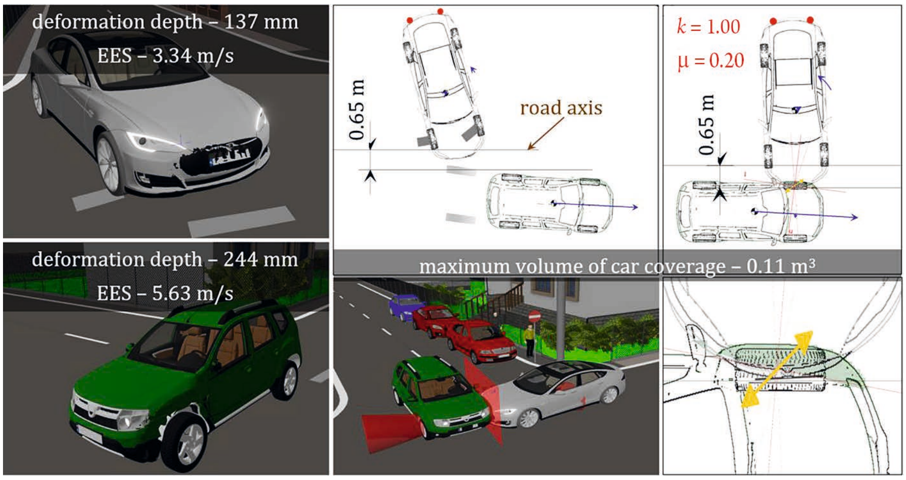

Fig. 6. The consequences of the collision of two cars for the second scenario (own elaboration)

By assessing the damage to cars after the accident simulation, it can be concluded that they may continue the ride because there is no visible damage preventing their further use.

In road accident reconstruction, energy methods are often used to determine the energy equivalent speed (EES) pertaining to energy consumed to deform the body. The EES value results from the amount of work performed during the deformation of the body, that amount being estimated on the basis of the extent of body deformation.

The energy equivalent speed is determined from formula (9).

$$\mathrm{EES} = \sqrt{\frac{2E}{m}} \tag{9}$$

where: E – kinetic energy, m – vehicle weight (total).

The energy equivalent speed allows us to understand how much kinetic energy a body has by comparing that energy to the energy a body moving at a certain speed would have. That speed also depends on the weight of the object. For an object with a large weight, the equivalent speed will be lower because, given the same kinetic energy, a larger weight means a lower speed.

The value of equivalent energy speed considered in the context of car accidents can indicate which speeds are critical for the safety of road users. Collisions at 50–60 km/h and higher are known to cause serious injuries or deaths.

A simulation using V-SIM 6.0 software demonstrated that that speed for the green car was 17.1 km/h (the driving speed of 50 km/h) and 20.3 km/h (at the driving speed of 60 km/h), and for the grey car that speed was 10 and 12 km/h respectively. Fig. 7 shows the speed and kinetic energy values of the cars at the point of the collision.

As a result of the collision, the grey car, which had stopped to give way, was given the speed of 3.4 km/h with its vector directed at 29.4° to the driving direction (for the first simulation scenario) and the speed of 3.7 km/h with its vector directed at 29.7° (for the second simulation scenario). At the same time, the impact force caused the green car to decelerate to a speed that was approximately 6 km/h lower than its pre-collision speed. For the green car, the driving speed vector was directed at 3.8° to the driving direction (for the first simulation scenario) and 3.5° (for the second simulation scenario).

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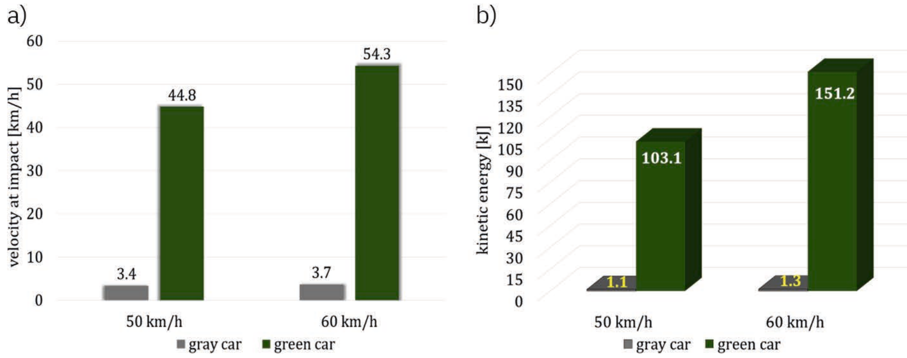

Fig. 7. The speed and kinetic energy values of the cars at the point of the collision (own elaboration)

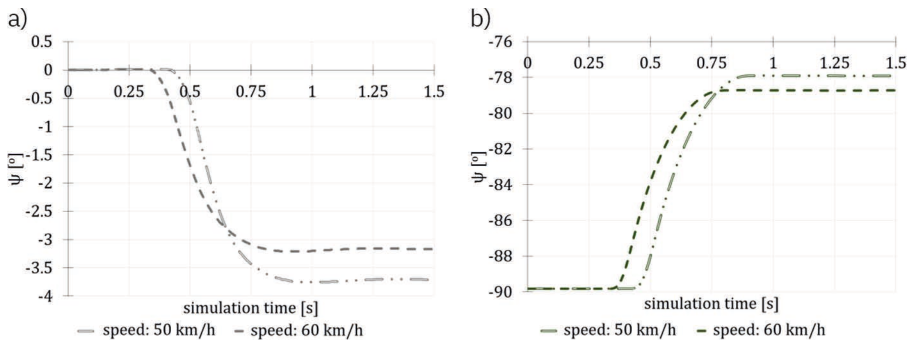

Fig. 8. The change of the angle of car rotation during the collision depending on the simulation time, a) the grey car, b) the green car (own elaboration)

Fig. 8 shows the change of the angle of car rotation during the collision depending on the simulation time. The grey car, when hit by the green one at 50 km/h, turned by 3.71°, and that rotation was 3.17° at 60 km/h. At the same time, the green car hitting the grey one changed its driving path by 12.10° and 11.28° respectively.

Several factors influence the extent of damage and body deformation. One of those factors is the speed at which the vehicles are moving immediately before the incident, which directly translates to the value of kinetic energy transferred by the vehicles. As can be seen in Figure 7, a 10 km/h change in the driving speed of the green car increases the value of kinetic energy by approximately 48%.

Another factor influencing the amount of deformation of the car bodies is the weight of the vehicles and their acceleration, the values of which are shown in Fig. 9, and the resulting value of the impact force. Fig. 10 shows the change in the force acting on the car body at the point of impact as a function of the simulation time.

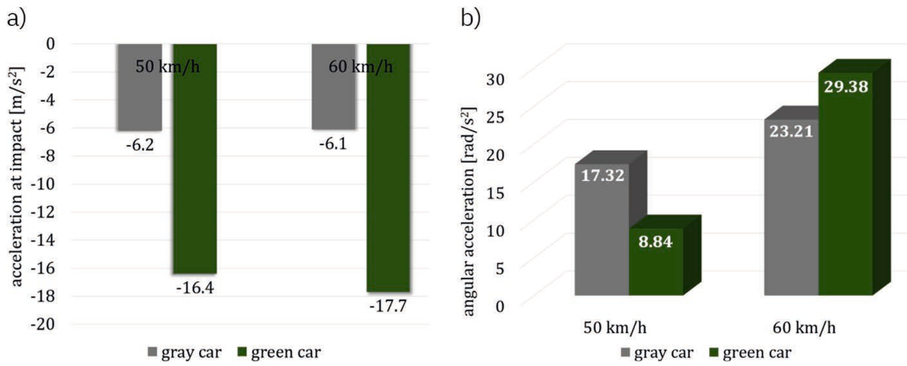

Fig. 9. The car linear and angular acceleration values at the point of the collision (own elaboration)

In the case of the green car travelling at 50 km/h, the maximum value of the force acting on the car body is 47.06 kN, and in the case of the grey car that value is 30.1 kN. In the case in which the green car travelled at 60 km/h, those forces would increase to 48.3 kN for the green car and 33.2 kN for the grey car respectively.

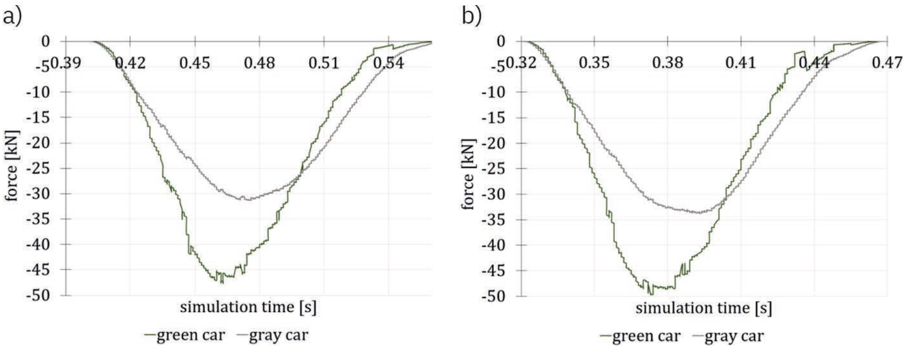

Fig. 10. A change of the force acting on the car body at the point of impact as a function of the simulation time, a) for the driving speed of 50 km/h, b) for the driving speed of 60 km/h (own elaboration)

Figure 9 shows the maximum car linear and angular acceleration values at the point of the collision.

The cone of friction is also analysed during road incident reconstruction. The cone of friction has several applications, but mainly helps to assess how the vehicles behaved after the collision. Cone geometry makes it possible to determine whether the vehicle was able to regain control after the accident, or rather, whether the vehicle lost its stability. Cone geometry also enables the prediction of how quickly a vehicle will lose its speed after a collision. When a vehicle begins to skid, frictional forces act on the vehicle within the cone, and the greater the cone angle, the more difficult it is for the vehicle to return to stable motion.

By analysing the images of the collision situation, it can be seen that the plane of the friction forces covers the entire length of the grey car front and half the length of the green car. The axis direction of the cone of friction coincides with the front axle is of the green car and, in the case of the grey car, the cone axis runs at an angle towards the driver. That distribution means that the green car, under impulse, will be pushed to the right towards the kerb. The grey car, on the other hand, will be turned towards the centre axis of the roadway at which the car was waiting to drive onto the road.

The car positions prior to the collision situation, which were assumed in the scenarios, resulted in the maximum car coverage volume of 0.10 m^3 following the road incident. It can therefore be concluded that the cars rubbed against each other without causing major financial damage. If a similar collision occurred in reality, the removal of the consequences of the collision would be quick and would not require the emergency services to be called. Drivers would have been able to make relevant statements at the road shoulder and therefore without causing disruptions to traffic.

The next two scenarios (the third and fourth) assumed that the grey car front was 1.25 m beyond the one-way roadway centre line and the green car was travelling along the one-way road at 50 km/h and 60 km/h. The results of the incidents for those scenarios are presented in Fig. 11 and 12.

In the case of the pre-accident car position described in the third and fourth scenarios, the consequences of the road incident will be more severe than in the case of the first two scenarios. The difference in the extent of damage and the post-accident position of the cars will be noticeable.

Substantial damage has been caused as a result of the road incident. In the case of the green car, the areas of its left wheel arch and the left-side front were destroyed. In the grey car, its right-side front was destroyed. The grey car deformation depth in the third scenario is 273 mm; in the fourth scenario that depth increased by approximately 12% and is 322 mm. The difference in the deformation depth of the green car has a similar distribution. An approximately twelve per cent increase in the deformation depth was noted there, too.

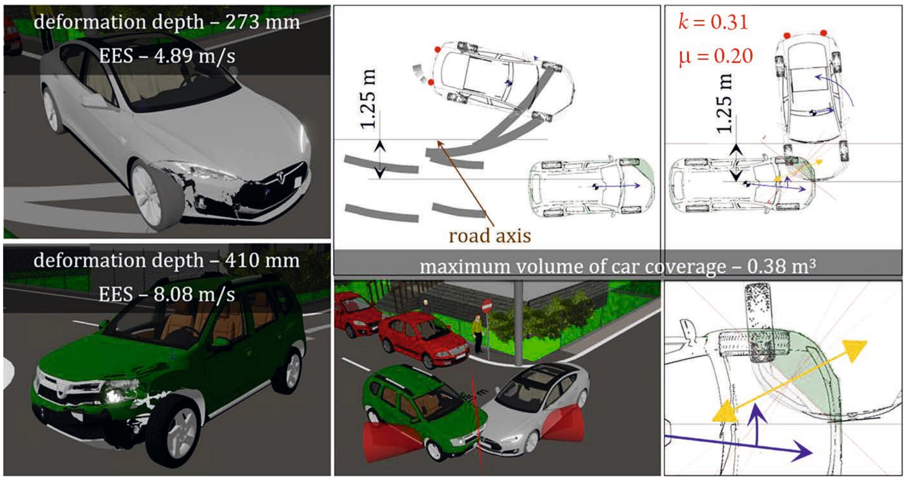

Fig. 11. The consequences of the collision of two cars for the third scenario (own elaboration)

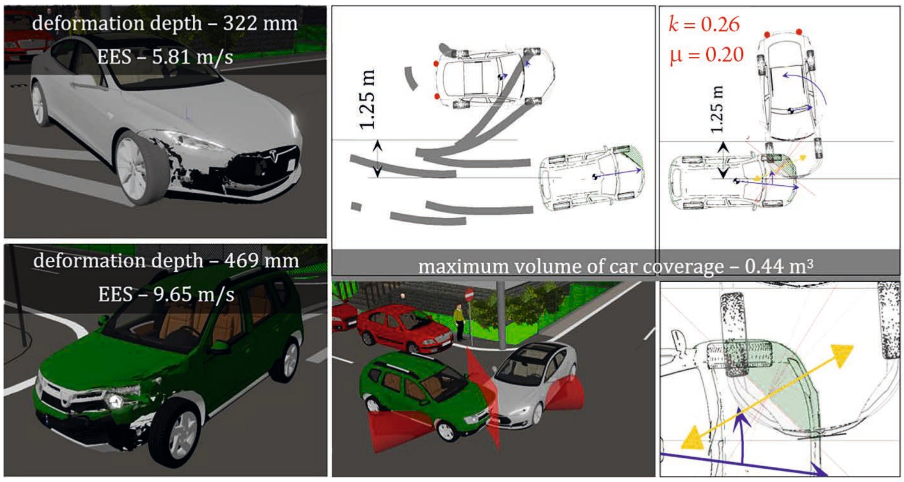

Fig. 12. The consequences of the collision of two cars for the fourth scenario (own elaboration)

By assessing the damage to the cars after the accident simulation, it may be concluded that the cars have suffered enough damage that their condition will prevent further driving. It will be necessary to call the breakdown recovery service.

A simulation using V-SIM 6.0 software demonstrated that that speed for the green car was 29.1 km/h (the driving speed of 50 km/h) and 34.8 km/h (at the driving speed of 60 km/h), and for the grey car that speed was 17.6 and 21.0 km/h respectively. Fig. 13 shows the speed and kinetic energy values of the cars at the point of the collision.

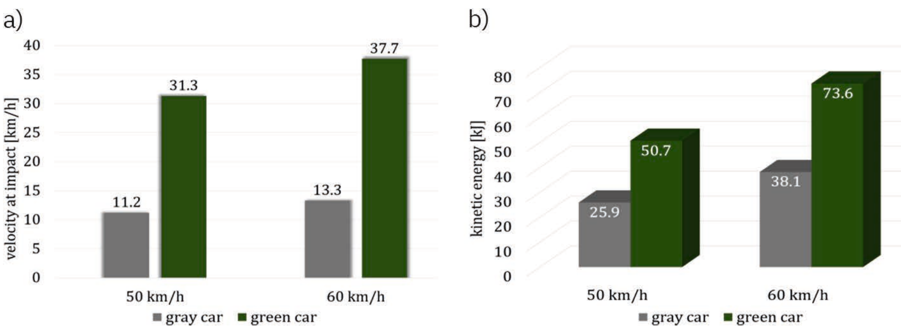

Fig. 13. The speed and kinetic energy values of the cars at the point of the collision (own elaboration)

As a result of the collision, the grey car, which had stopped to give way, was given the speed of 11.2 km/h with its vector directed at 10.7° to the driving direction (for the third simulation scenario) and the speed of 13.3 km/h with its vector directed at 10.3° (for the fourth simulation scenario). At that time, the impact force caused green car deceleration to 31.3 km/h (for the third simulation scenario) and 37.7 km/h (for the fourth simulation scenario). The speed vectors for that car were directed at an angle of – 6.2° and –5.9° respectively.

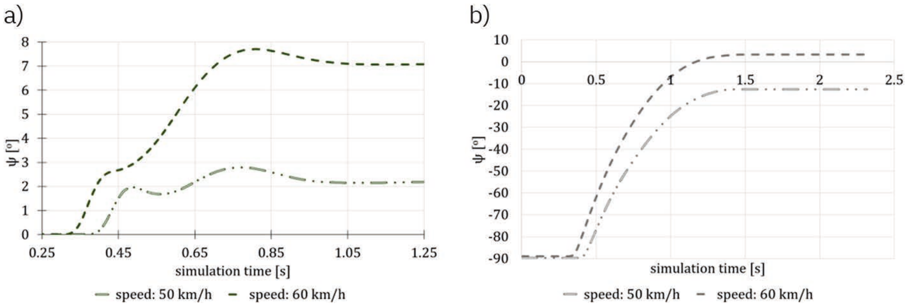

Fig. 14. The change of the angle of car rotation during the collision depending on the simulation time, a) the grey car, b) the green car (own elaboration)

Fig. 14 shows the change of the angle of car rotation immediately after the collision depending on the simulation time. The grey car, when hit by the green one at 50 km/h, turned by 77.37°, and that rotation was 104.3° at 60 km/h. At the same time, the green car hitting the grey one changed its driving path by 2.71° and 7.58° respectively.

As it was mentioned before, the body deformation size depends on many factors. One of them is the vehicle speed immediately before the collision, and kinetic energy depending on that speed. As can be seen in Figure 13, a 10 km/h change in the driving speed of the green car increases the value of kinetic energy by approximately 41%.

Fig. 15 presents car linear and angular acceleration values at the point of the collision. The squares of the resulting acceleration values multiplied by the vehicle weight will enable the determination of the force acting on the cars at the point of impact. The pattern of the changes in those forces as a function of simulation time is shown in Fig. 16.

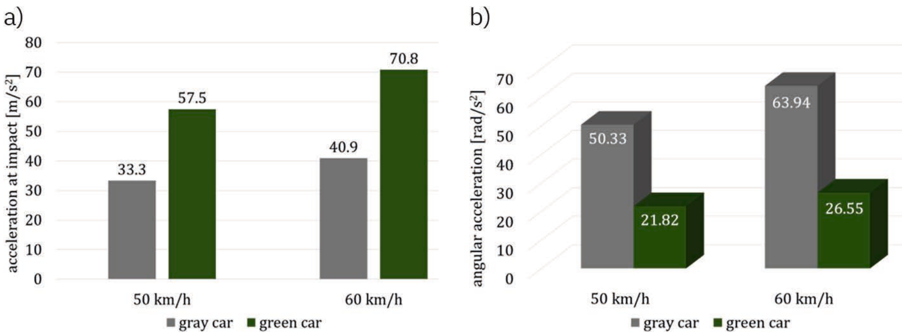

Fig. 15. The car linear and angular acceleration values at the point of the collision (own elaboration)

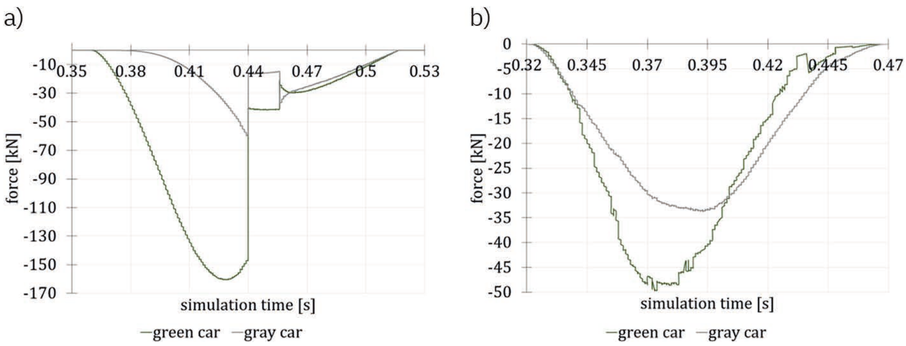

Fig. 16. A change of the force acting on the car body at the point of impact as a function of the simulation time, a) for the driving speed of 50 km/h, b) for the driving speed of 60 km/h (own elaboration)

In the case of the green car travelling at 50 km/h, the maximum value of the force acting on the car body is 147 kN, and in the case of the grey car that

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value is 57.8 kN. In the case in which the green car travelled at 60 km/h, those forces would increase to 180 kN for the green car and 66.8 kN for the grey car respectively.

The car positions prior to the collision situation, which were assumed in the scenarios, resulted in the maximum car coverage volume of 0.44 m^3 following the road incident. It cannot therefore be stated that the cars rubbed against each other without causing major financial damage, as was the case in the first two simulations. If a similar collision occurred in reality, the removal of the consequences of the collision might require calling the rescue services. Medical assistance for the drivers of both cars and car towing by the breakdown recovery service might be required.

5. Forecasting the number of road accidents at the crossroads under review

Using the formulae and input data presented in Chapter 3, the equations needed to forecast road incidents (both accidents and collisions) in accordance with the grey system theory were determined for the various crossroads analysed in this article.

The common feature of all the five crossroads to which special attention was paid and which also became the inspiration to address the forecasting of the number of road incidents in the near future is the traffic management in their vicinity. As emphasized several times before, the main issue at those locations is the lack of or reduced visibility of road traffic which, with the increasing number of cars in operation, can be conducive to further road incidents with unpredictable consequences.

The equations to specify the predicted quantitative data are presented below, and Fig. 17 presents diagrams showing the predicted number of road incidents in the next eight quarters.

First crossroads

$$\hat{X}^{(0)}(t+1)=2.33511\cdot e^{0.0783095(t-1)}$$

Second crossroads

$$\hat{X}^{(0)}(t+1)=3.12964\cdot e^{-0.049738(t-1)}$$

Third crossroads

$$\hat{X}^{(0)}(t+1)=2.029626\cdot e^{0.0774194(t-1)}$$

Fourth crossroads

$$\hat{X}^{(0)}(t+1)=0.81798\cdot e^{0.1515152(t-1)}$$

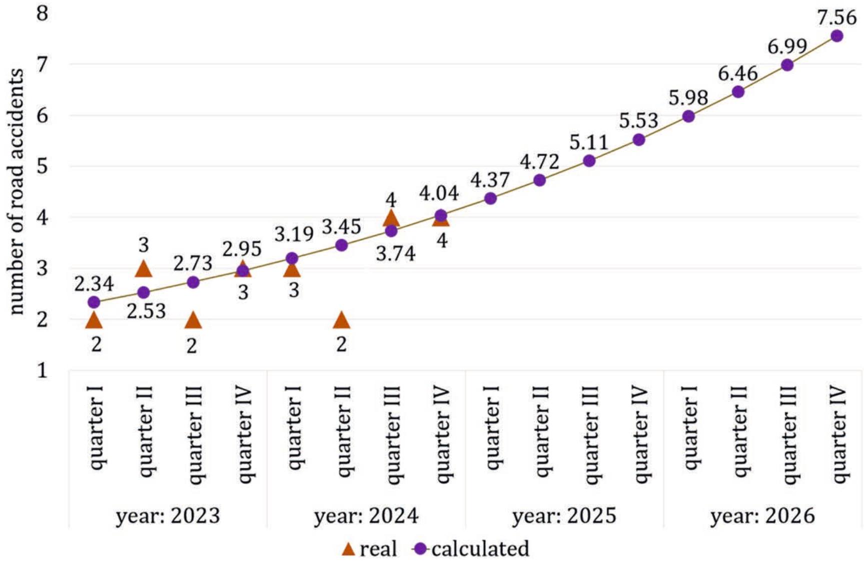
Fifth crossroads

$$\hat{X}^{(0)}(t+1)=2.016874\cdot e^{0.1333701(t-1)}$$

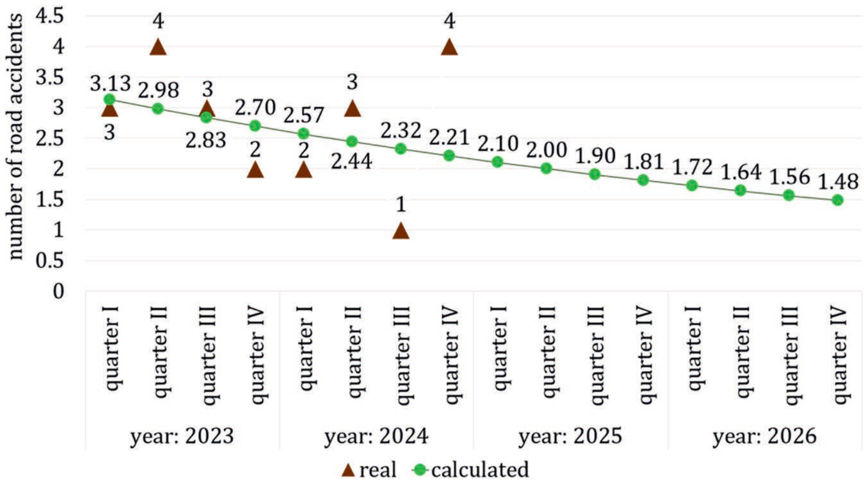
It follows from the data in the diagrams that there is a risk of an increase of the number of road incidents at as many as four crossroads. At three of them (Fig. 17a, 17c and 17d), road traffic is light, therefore the forecast predicts an insignificant increase in the number of incidents; the forecast assumes that approximately 7-8 road incidents will take place in the fourth quarter of 2026.

At the fourth crossroads, road traffic is significantly busier (Fig. 17e), as that crossroads is within the national road, and important offices servicing customers from the entire region are located nearby. This translates directly to the number of road incidents in a year. Based on the recorded data, ten collisions or accidents occurred at that crossroads in 2023, and as many as fifteen the following year. In relation to this, what is worrying is the calculated forecast, which assumes as many as fifteen incidents in the fourth quarter of 2026 alone. This is a fourfold increase compared to the average number of the incidents recorded per quarter.

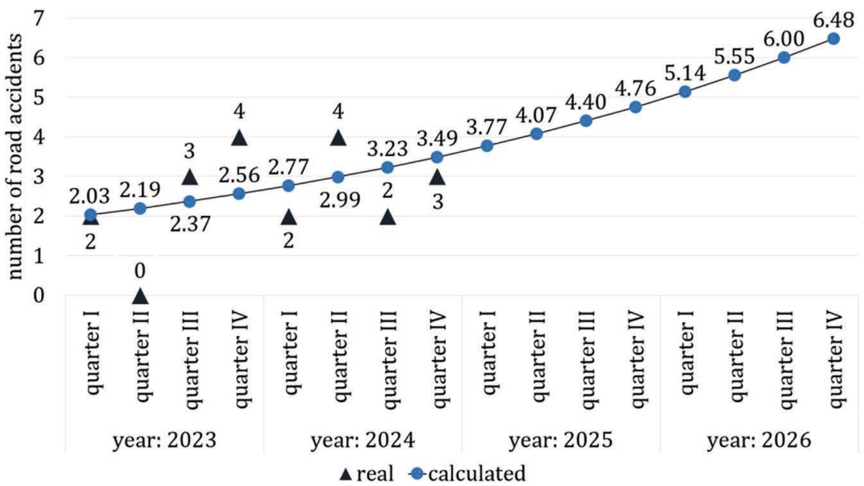
a)



b)



c)



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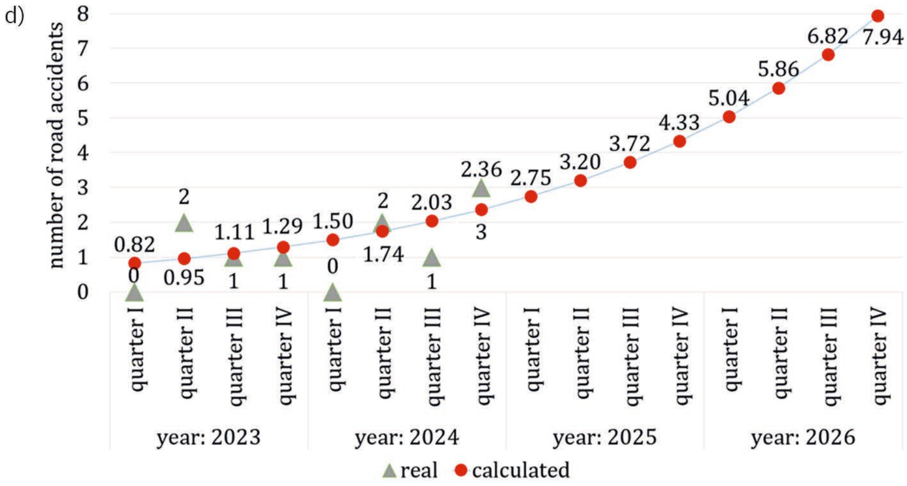

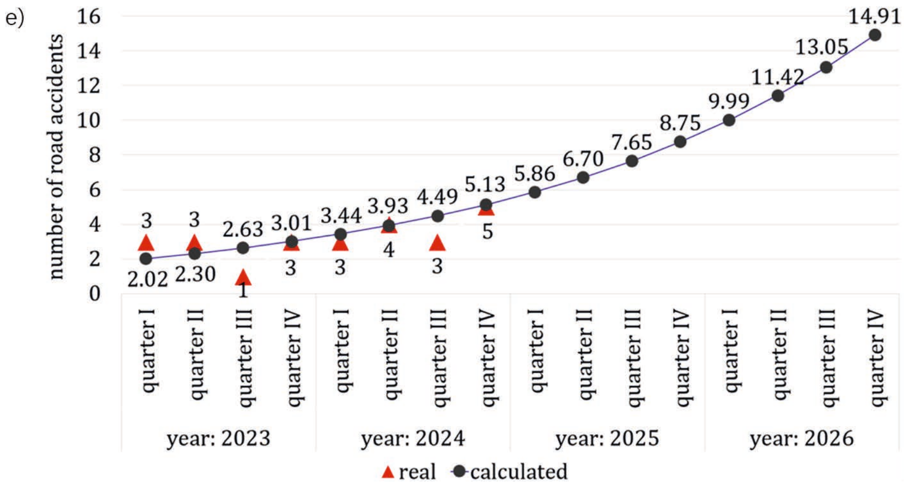

Fig. 17. The forecast number of road incidents, a) at the first crossroads, b) at the second crossroads, c) at the third crossroads, d) at the fourth crossroads, e) at the fifth crossroads (own elaboration)

Remedial action should be taken there in the near future to reduce the number of road incidents. However, due to the location and a small size of the crossroads, the number of those measures is limited. It is not possible to build a roundabout or install traffic lights at those locations. Those methods would improve safety the most. Therefore, other techniques must be used that will be just as effective as those mentioned previously. The use of relevant horizontal or vertical signs would be the simplest solution. Those signs would inform drivers about the potential hazard and increase their vigilance. A social education campaign should be run in parallel. Education and information campaigns should be targeted at both car drivers and pedestrians. Campaigns should raise the awareness of traffic rules and behaviour in difficult road conditions, such as those analysed in this article. A potentially viable solution worth considering could also be the introduction of a 40 km/h speed limit along the entire section of the main road. An alternative safety enhancement measure could involve the implementation of dedicated protective infrastructure designed to restrict vehicle parking in the immediate vicinity of the intersection. The installation of mechatronic systems to improve safety would be a worthwhile and interesting idea. Examples include interactive solar-powered signs with variable content or warning lights installed in the roadway that activate when cars are close to the crossroads.

When analysing Fig. 17b, it may be concluded that the number of accidents or collisions will decrease in the nearest future. The crossroads has been upgraded recently and devices improving visibility to drivers on the minor road installed. For example, a traffic mirror and horizontal signage advising of the need to give way were installed.

Using formula (9), the predicted accuracy of the method was determined as follows for each intersection:

Crossroads 1: $C = 0.19$

Crossroads 2: $C = 0.21$

Crossroads 3: $C = 0.21$

Crossroads 4: $C = 0.19$

Crossroads 5: $C = 0.17$

All C values calculated above are less than 0.35, so the forecast accuracy can be considered good.

6. Conclusion

Insufficient visibility at crossroads is one of the most serious hazards to road safety. It is obvious that this situation can lead to many road accidents and incidents, which are due to the impaired perception of other road users or to the incorrect assessment of the situation on the road. Every road user knows about the consequences of a wrong assessment of the situation on the road, but not all of them are aware of the high forces acting on cars during a collision even at low speeds and of the consequences of such a collision. Therefore, the aim of this article was to analyse the impact of the insufficient visibility of the situation on the road on hazards that arise when a vehicle drives across the crossroads.

A driver who cannot see oncoming traffic may take a decision to enter a crossroads without being aware of the impending hazard. A road incident then occurs, the consequences of which depend on many factors, including the speed of the cars. The situation is similar in the case of a driver moving along a priority road. He or she has limited visibility, too, and therefore has less time to react to the changing situation on the road. The above statements are confirmed by the results of the simulation in which a side car collision occurs.

Side collisions are among the most dangerous ones, as the consequences of the accident may include serious injuries due to high forces in operation and the lack of or inadequate protection in the case of such an impact. Under the conditions assumed in the simulation for the first and second scenarios, at a car driving speed of 50 km/h, the average value of the impact force was approximately 40 kN. It should be borne in mind that the accident coverage of the cars was insignificant in these scenarios. For the next two scenarios, at the same driving speed, the average impact force was already 102 kN, i.e. it was three times higher.

Hitting of a pedestrian may be another consequence of a collision or accident, also in the case of a side impact. Then the consequences become even more serious. The risk of such an event become higher as traffic density increases. As a result of the impact forces, cars can be pushed onto the foot pavement and contribute precisely to the hitting of pedestrians walking in accordance with traffic regulations.

In the simulation, no pedestrian was hit. It can be noted, however, that a car travelling at 50 km/h in accordance with traffic regulations changed its path during the collision so much that car deceleration to a halt took place as late as on the foot pavement.

Road users should be aware that the point of collision and the post-collision car movement are very short and there is often no time to react appropriately. The simulation showed that at a speed as low as 50 km/h one of the cars had a collision time of approximately 0.46 s, with a further reduction by 0.10 s at 60 km/h. The time until the cars came to a complete stop, however, varied between 1.5 and 2.5 s depending on the driving speed. Within such a time, it is difficult to react appropriately, particularly when it is not known which path the cars will take after the collision.

To summarise, it should be reiterated that insufficient visibility at crossroads leads to several dangerous situations, including drivers' delayed reactions, difficulties in assessing the situation on the road, an increased accident risk, and problems in interpreting the signals given by other road users. The simulation results and the reasoning behind them should therefore influence the imagination of road users, both pedestrians and drivers, so that they will pay special attention to how and where they leave their cars in order not to jeopardize their own safety and that of other road users.

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