DRIVER'S REACTION TIME IN A COMPLEX ROAD SITUATION (BRAKING WITH DRIVING AROUND AN OBSTACLE)

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Summary

The way how vehicle drivers react to the road situations where the manoeuvres of braking and driving around an obstacle can be simultaneously carried out has been analysed. Three scenarios of simulated accident situations have been shown for which experiments were carried out on a motor vehicle testing track. Two scenarios were each played out with 100 drivers taking part in the tests and 30 drivers were subjected to tests according to the third scenario. For each of the scenarios, the drivers performed many tests characterized by different time-to-collision (TTC) values. The percentage distribution of specific drivers' decisions about choosing a defensive manoeuvre (one or more) has been shown. For the action that was taken most often, where both the defensive manoeuvres, i.e. braking and driving around, were combined, the sequence of steps most frequently followed to avoid a collision has been presented. The driver's reaction time values measured at braking and turning (to drive around an obstacle) have been given for the road situations under consideration. Both the average values obtained from the experiments and the quantiles shown in the graphs depend on the type of road situation and on the degree of risk, a measure of which is the TTC value.

Keywords: road accidents, drivers' behaviour, driver's reaction time

1. Introduction

Almost all the data about driver's reaction time that are available from the literature concern the situations where exclusively the braking manoeuvre was carried out. This is because of the methods adopted at the research works reported, e.g. the concept of tests with participation of two motor vehicles, proposed by H. Burg [1] and repeated afterwards by many researchers. The experiments were so arranged that only the possibility of braking was planned or, even if the test driver moved the steering wheel in any way, such movements were not recorded. Sensors were only installed on the brake pedal (and sometimes, additionally, on the accelerator pedal), which made it possible to record exclusively the reactions related to braking. At the time when research works in this field were initiated (most of them were done in 1980s), such an approach was absolutely

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reasonable. An overwhelming majority of motor vehicles were not provided then with ABS; therefore, the drivers were taught that in a critical situation, when the brake pedal is hit with maximum force for an accident to be avoided, no steering wheel movements should be made because this might cause the vehicle stability to be lost. The driver's reaction time values thus determined were quoted in handbooks and used at accident reconstruction for many years (basically, until today).

At present, this situation has radically changed. The vast majority of the motor vehicles that participate in road traffic have ABS. Only very few oldest vehicle models have remained that do not have such a system and they are now definitely disappearing. Most drivers already know that when driving a vehicle provided with ABS, they may try to avoid a collision with an obstacle by driving around it in spite of applying the service brake very hard at the same time. This means that these two manoeuvres may be performed simultaneously without a significant risk of loss of vehicle stability control. Obviously, this is very beneficial from the point of view of chances of avoiding a collision. However, the driver is facing the necessity of making a decision whether he/she should perform both of these defensive manoeuvres simultaneously. If the answer is yes, what should be done first and how intensively should it be done?

The research on drivers' behaviour in critical situations is expected to answer the question what decisions are made by the drivers in such circumstances and how this affects the values of driver's reaction time. Hence, the tests must be so arranged that both of these defensive manoeuvres should be possible and that all the actions taken by the drivers participating in the tests should be recorded.

2. Description of the experiments

The experiments were carried out on a motor vehicle testing track (real vehicle and simulated situation of a collision hazard). The research concept was formulated with using a notion termed TTC ("time-to-collision"), which is defined as the time that elapses between noticing and possible hitting an obstacle and that is available to the driver for the carrying out of defensive actions. In earlier publications by the same authors [2, 3, 4], this time was referred to as "risk time". At the works described there, it was shown that the driver's reaction time values, whether obtained from track tests or tests carried out on a simulator, very clearly depend on the TTC. This means that the driver, when assessing the situation, is not guided separately by the drive speed or the distance to the obstacle but he/she is aware of the time available for making a decision and reacting to the hazard.

Neither the TTC nor any equivalent idea occurs in the Polish literature dealing with accident analysis. Conversely, it has been quite frequently appearing in Western publications in the recent years, but it can be chiefly found in publications concerning the development of collision avoidance systems, e.g. [5, 6, 7] rather than in publications related to accident reconstruction. To elucidate this idea and to substantiate the TTC variability range adopted at the research works, the vehicle stopping time t_z (see equation (1)) as a function of the TTC has been presented in Fig. 1.

$$t_z = t_r + t_o + \frac{1}{2}t_n + t_h \qquad (1)$$

where:

t_z – vehicle stopping time;

t_r – driver's psychomotor reaction time;

t_o – brake system response time;

t_n – braking deceleration rise time;

t_h – braking time.

The estimation of driver's reaction time t_r was based on results of authors' experiments for two simulated accident situations played out in a precisely defined way (these situations are hereinafter referred to as "scenarios"), for which the highest and the lowest average values of time t_r were obtained [8, 9, 10]. The highest average values of the reaction time were obtained for "scenario 1", where the drivers came across 2 obstacles; they may be represented by the following equation [11]:

$$t_r = 0{,}197 \cdot \mathrm{TTC} + 0{,}713, \qquad (2)$$

The lowest average values of the reaction time were obtained for "scenario 3", where one obstacle in the form of a motor truck was encountered; these values may be defined as follows:

$$t_r = 0.157 \times \mathrm{TTC} + 0.181 \qquad (3)$$

For the time $t_o + \frac{1}{2}t_n$ taken together, a value of 0.3 s was adopted. In publication [12], the total value of this time is specified as 0.2–0.4 s. The braking time value t_h was estimated in accordance with equation (4):

$$t_h = \frac{v_p}{a_h} \qquad (4)$$

In the calculation example presented, the vehicle braking deceleration was assumed as a_h = 8.5 m/s^2 and two initial vehicle velocity values were adopted, i.e. v_p = 50 km/h and v_p = 100 km/h. For such input data, the braking time value th worked out at 1.63 s and 3.26 s, respectively.

The graphs in Fig. 1 show the vehicle stopping time for the lowest values of driver's reaction time (scenario 3, Fig. 1a) and for the highest values of this time (scenario 1, Fig. 1b). In each of the graphs, a line has been additionally plotted to represent graphically equation (5):

$$t_z = TTC \qquad (5)$$

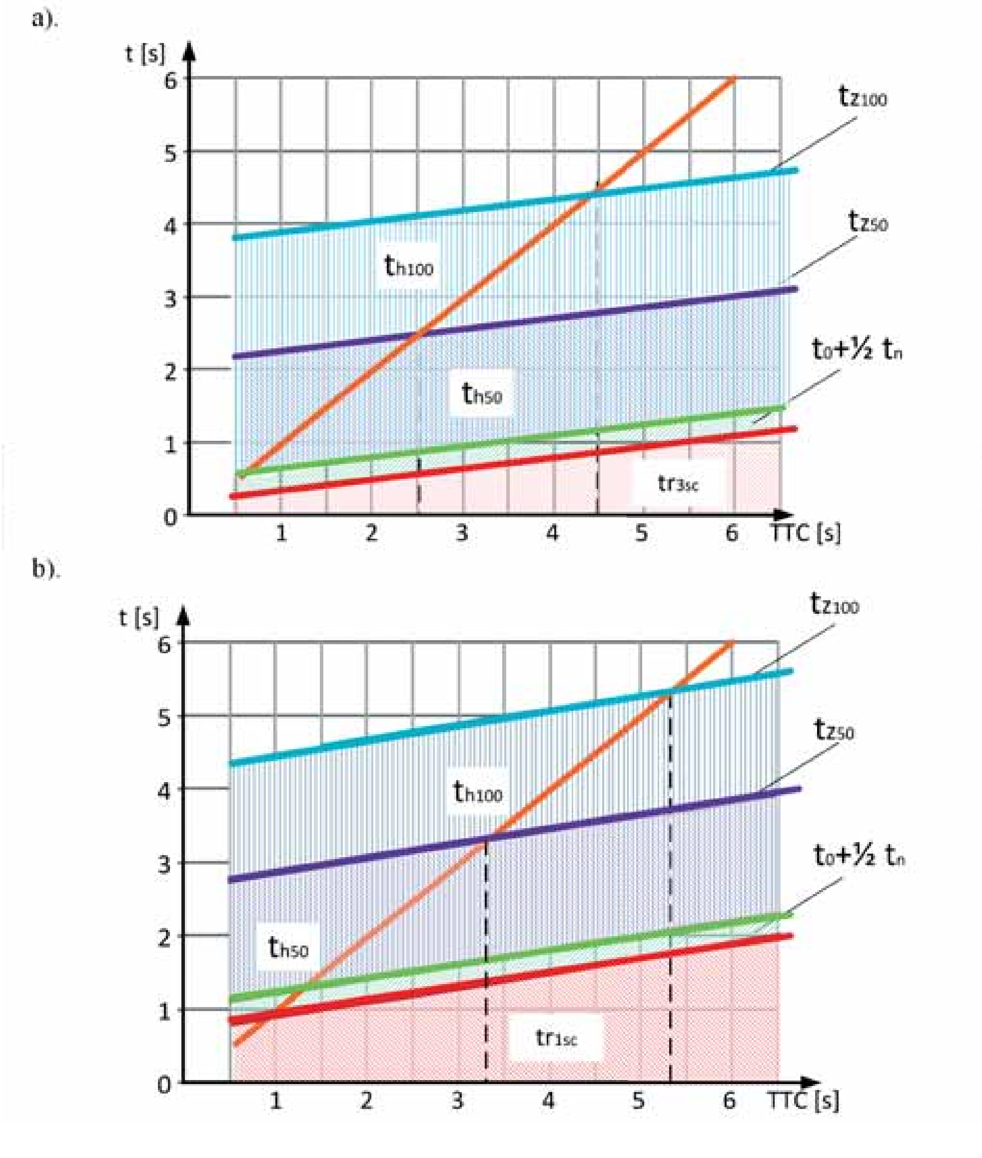

Fig. 1. Comparison of the vehicle stopping time and the TTC: t_{r3sc} – reaction time at scenario 3, t_{r1sc} – reaction time at scenario 1, t_{h50} – time of vehicle braking from a velocity of 50 km/h, t_{h100} – time of vehicle braking from a velocity of 100 km/h, t_{z50} – time of vehicle stopping from a velocity of 50 km/h, t_{z100} – time of vehicle stopping from a velocity of 100 km/h

There are two possible cases of termination of a sudden hazardous road situation for different values of the vehicle stopping time t_z. The case that $t_z \leq$TTC means that the collision has been avoided and if $t_z >$TTC then the road event has ended in a collision. The TTC limits below which a collision is unavoidable, read out from the graphs in Fig. 1, have been brought together in Table 1.

Table 1. TTC limits below which a collision is unavoidable

	Braking from an initial velocity of:	
	50 km/h	**100 km/h**
Scenario 1 (more complex)	3.29 s	5.32 s
Scenario 3 (simpler)	2.50 s	4.44 s

In the cases presented, the collision would be unavoidable if the driver exclusively braked with maintaining the straight-ahead direction of vehicle motion (e.g. if driving around the obstacle were impossible due to insufficient space). In very numerous cases, the driver does not have to reduce vehicle velocity to zero before an obstacle to avoid a collision; instead, he/she should reduce the velocity to a level at which the manoeuvre of driving around the obstacle could be safely carried out. If the vehicle is provided with ABS, the manoeuvres of braking and driving around an obstacle may be performed simultaneously. When driving a vehicle without ABS, more experienced drivers can reduce vehicle velocity by braking to such a value that they are then capable of trying, in the final phase of the manoeuvre, to drive around the obstacle (with giving up braking). So, if the possibility of carrying out both defensive manoeuvres is taken into account, the TTC limit below which a collision becomes unavoidable can be lowered by about 1 s (this means braking to a velocity of about 30 km/h instead of zero).

The values thus estimated provided a basis for adopting the maximum TTC values at the experiments. Finally, the tests were carried out for situations characterized by 17 different TTC values from the range of 0.5–3.6 s.

The problem of braking with driving around an obstacle will be analysed here with taking as an example the results of experiments carried out in accordance with three scenarios of pre-accident situations. At scenario 1 (mentioned previously), a passenger car entered the street intersection in front of the vehicle under test from the right side in the perpendicular direction while another vehicle was moving towards the vehicle under test from the opposite direction. At the next scenario under analysis (referred to as "scenario 2"), an adult pedestrian entered perpendicularly the right lane of the carriageway. One hundred drivers were subjected to tests with each of these two scenarios. The scenarios and the method of carrying out the tests have been described in more detail in publications [10] and [13].

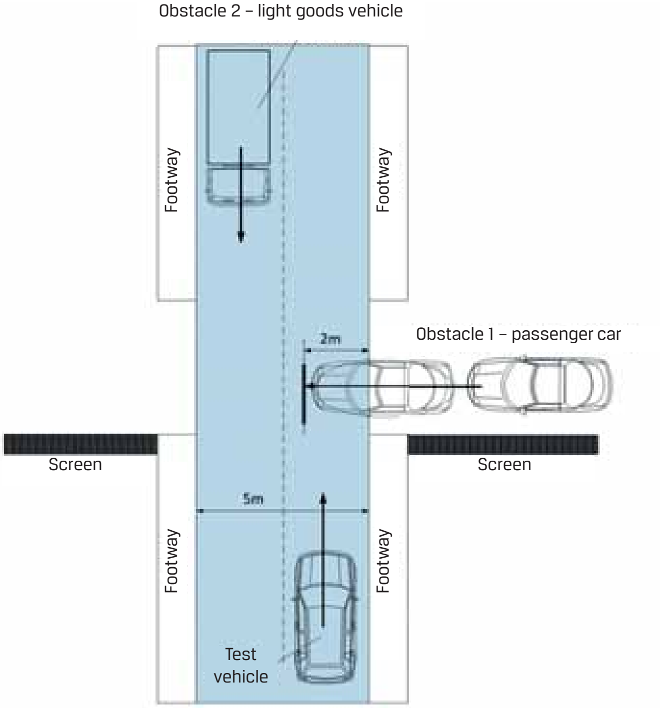

Fig. 2. Schematic diagram of scenario 1 of the tests

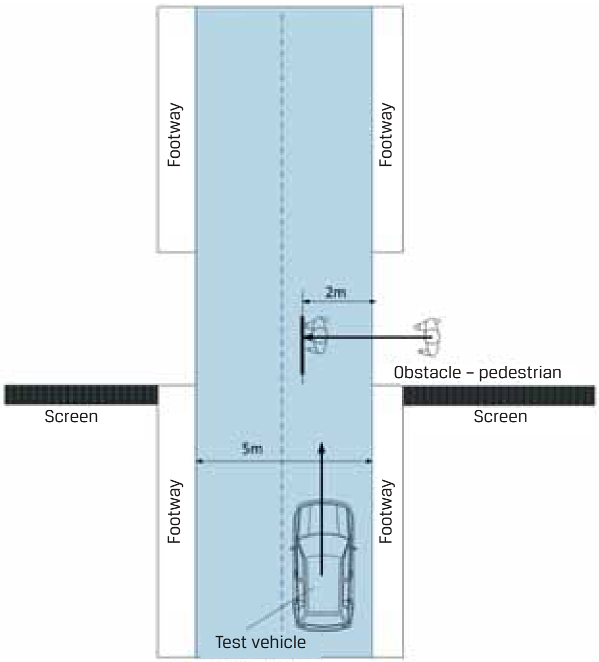

Fig. 3. Schematic diagram of scenario 2 of the tests

The last scenario that was analysed within this work was "scenario 5", which was also the one played out at the latest group of tests. At this scenario, as it was at scenario 1, two obstacles appeared, but now the obstacles were a passenger car entering the street intersection from the right side and a pedestrian entering the carriageway from the left side. In this case, the tests were carried out with 30 drivers who performed 10 trial drives each, with the TTC values ranging from 0.6 s to 3.0 s. A schematic diagram of this scenario has been shown in Fig. 4. The tests carried out to this scenario have been described in more detail in publication [14].

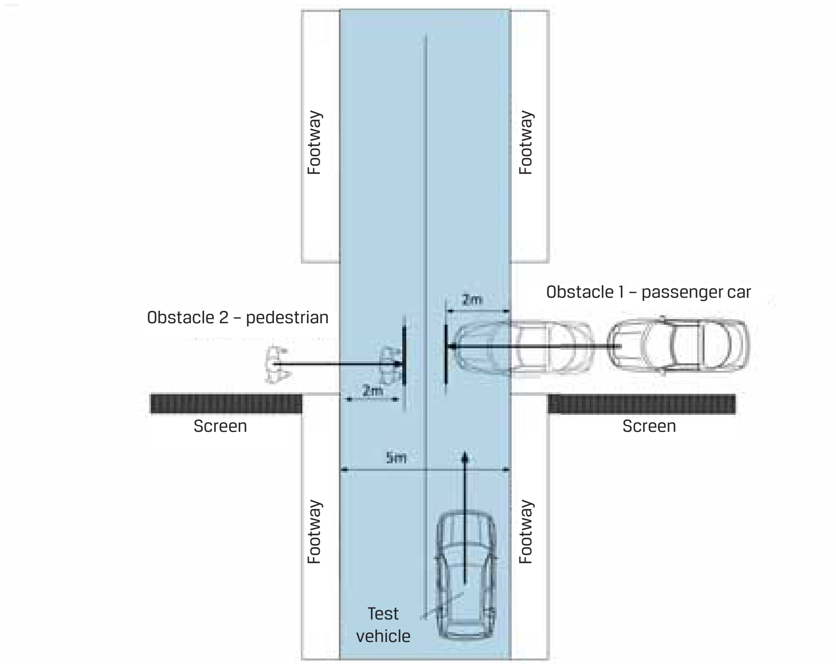

Fig. 4. Schematic diagram of scenario 5 of the tests

3. Analysis of drivers' behaviour in critical situations

A common feature of the tests described here is the fact that the drivers were not forced to react in any specific way to the accident hazard situation encountered. At each of the test scenarios and at each trial drive, the drivers decided by themselves how they wanted to react, depending on their own assessment of the situation and their individual experience. Their task was formulated in a general way: they were to avoid a collision with any of the obstacles. It turned out that in most cases, they combined the manoeuvres of reducing vehicle velocity and driving around the obstacles, although it happened, e.g. at high TTC values, that they tried to drive around the obstacles without braking. On the other hand, some cases also occurred that the drivers exclusively chose braking as the defensive manoeuvre. The percentage distribution of individual decision types depending on the TTC at the scenarios under consideration has been presented in Figs. 5, 6, and 7.

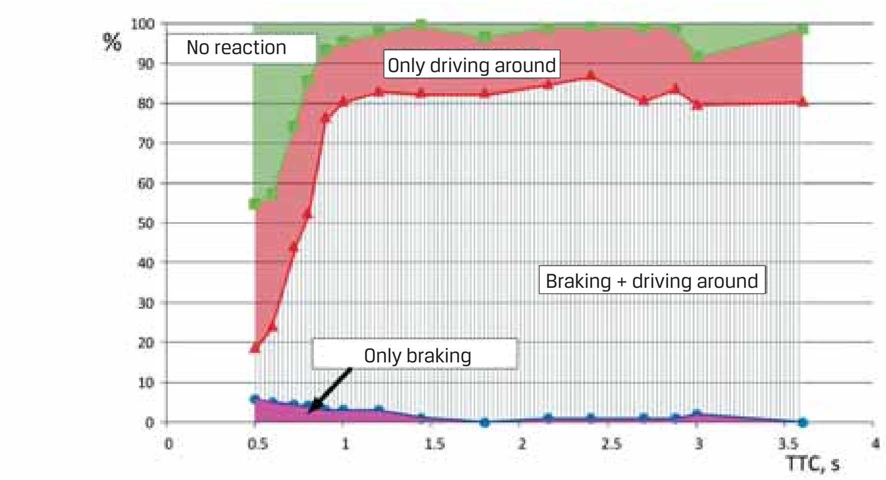

Fig. 5. Percentage distribution of drivers' decisions at scenario 1 of the tests

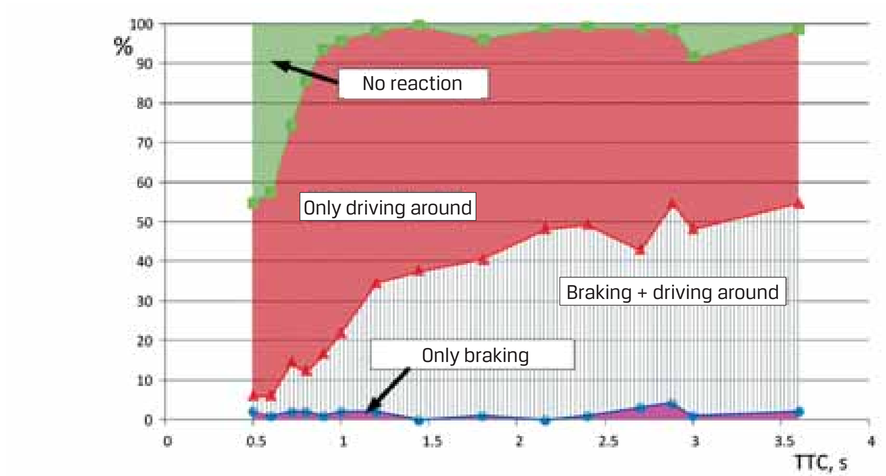

Fig. 6. Percentage distribution of drivers' decisions at scenario 2 of the tests

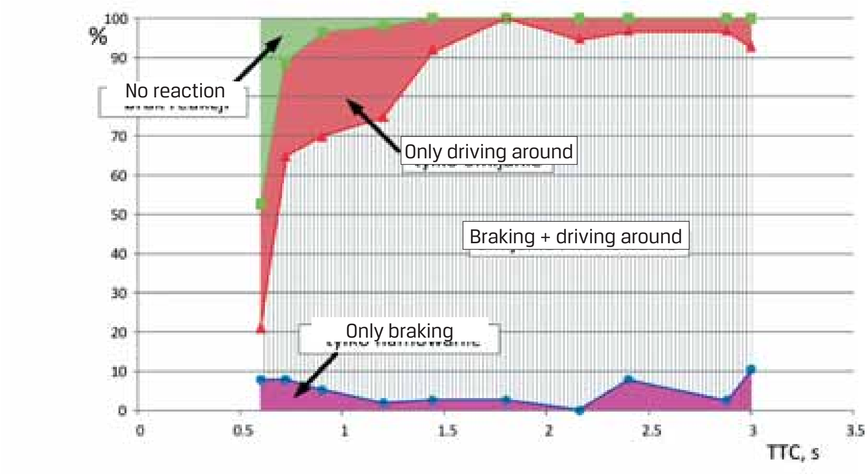

Fig. 7. Percentage distribution of drivers' decisions at scenario 5 of the tests

In most publications dealing with the reconstruction of road accidents, chiefly the values of driver's reaction time at braking are given. Similarly, exclusively the braking is taken into account as a defensive manoeuvre at accident analyses. However, the percentage distribution of drivers' decisions as shown in Figs. 5, 6, and 7 indicates that, contrary to popular opinions, the option with braking alone was chosen by very few drivers.

The manoeuvre of driving around the obstacle (either combined with braking or performed as the only defensive measure) was chosen in much more cases. It is symptomatic that at the tests to scenarios 1 and 5, where two obstacles were encountered, the overwhelming majority of drivers under test decided to combine the braking with the driving around the obstacles; for TTC > 1 s (1.4 s), the percentage of such drivers even exceeded 80%. At scenario 2, which was the easiest one among those presented, the driving around the obstacle without braking was chosen in more cases as against such a manoeuvre combined with braking, apart from the cases with the highest TTC values.

Noteworthy are also the test drives with the lowest TTC values. For such tests, the "no reaction" areas in the graphs are relatively wide. For TTC of about 0.5 s and 0.6 s, the percentage of the drivers who did not manage to react came close to 50%.

In consideration of this significant proportion of cases where the braking was combined with the driving around the obstacle, a closer look should be taken at the question how these manoeuvres were performed. Did the driver first apply the vehicle brakes with keeping the vehicle moving without changing the direction of motion (i.e. without turning the steering wheel) and begin to drive around the obstacle only when the vehicle velocity was reduced to a certain level? Alternatively, did he/she first react with gently turning the steering wheel and, only when the vehicle trajectory was modified, start braking? The proportion of drivers who chose the former option (at individual test scenarios), i.e. who applied brakes before starting the manoeuvre o driving around the obstacle, has been presented in Fig. 8.

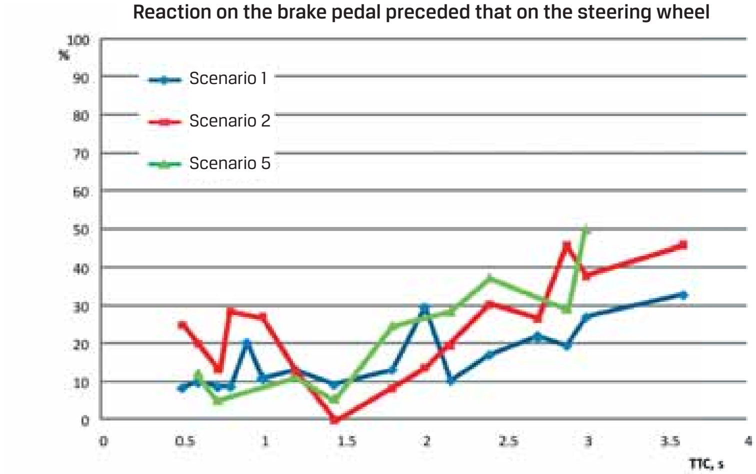

Fig. 8. Percentage of the drivers who applied brakes before starting the manoeuvre of driving around the obstacle, at the three test scenarios under consideration

It can be seen that at all the three scenarios under consideration, the percentages of the drivers whose reaction was as described above were close to each other; moreover, these percentages were definitely lower than those of the drivers who decided to react in reverse order. In the whole range of the TTC values adopted at the experiments, these percentages varied within limits from 0% to about 50%, with ranging from 0% to about 30% for the TTC of up to 2 s, while a rising trend became clearly visible for TTC values exceeding 2 s. For the highest TTC values, these percentages varied from about 20% to 50%. Noteworthy is the fact that in no case (at no scenario and at no TTC value) these percentages exceeded 50%.

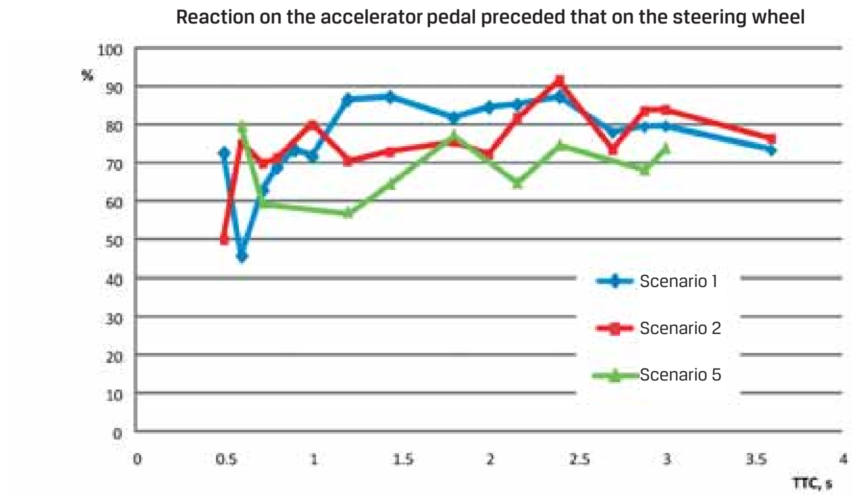

Fig. 9. Percentage of the drivers for whom a reaction on the accelerator pedal (the release of this pedal) was recorded to precede any reaction on the steering wheel

The behaviour of most drivers may be very well illustrated by the information provided in Fig. 9, where the percentage of the drivers has been shown for whom a reaction on the accelerator pedal (the release of this pedal) was recorded to precede any reaction on the steering wheel.

It can be seen in the previous graph (Fig. 8) that for most drivers under test, a reaction on the steering wheel was recorded to precede any reaction on the brake pedal. On the other hand, Fig. 9 shows that the reaction of most drivers on the accelerator pedal was recorded to take place even before their reaction on the steering wheel. At the tests where the TTC exceeded 1.5 s, about 60% to 90% of the drivers took their actions in such an order.

When the information shown in Figs. 8 and 9 is put together, a statement may be made that most of the drivers took their defensive actions in the following order in the whole range of the TTC values: releasing the accelerator pedal, afterwards a reaction on the steering wheel (changing the vehicle trajectory), and only then starting the braking manoeuvre.

Fewer drivers performed these manoeuvres in another order or they chose an option with only one defensive manoeuvre (except for very high percentage of the manoeuvre with driving around the obstacle at tests to scenario 2).

4. The values of driver's reaction time in a complex road situation

The term "complex road situation", wherever used in this paper, has the meaning that the driver under test has several options of the defensive manoeuvre to choose. It is his/her subjective decision whether only to brake, to drive around the obstacle, or to perform both of these defensive manoeuvres. This is an important distinctive feature of the research work presented here because in most experiments aimed at determining the values of driver's reaction time, the tests were so arranged that braking was the only possible (or the only recorded) driver's reaction. An experiment of this kind was also carried out by the authors of this paper. When the driver did not have to assess the specific situation and to choose the method of counteracting the hazard encountered, the measured values of his/her reaction time were considerably lower than those determined at the experiments where the necessity to choose the actions to be undertaken was taken into account (see e.g. the experiment results reported in publication [11]).

When the driver must choose a method of counteracting an imminent collision, not only his/her reaction time is longer but also the average values of this time vary depending on the complexity of the specific situation. The complexity of the situation has also an impact on the scatter of the values obtained. Figs. 10 and 11 show the average values of driver's reaction time at braking and turning (driving around the obstacle) as well as the quantiles being a measure of the scatter of results. The quantiles 0.1 and 0.9, which delimit the area covering 80% of the results obtained, have also been plotted in the graphs.

Time of the "braking" reaction at 3 scenarios: comparison of average values and quantiles 0.1 and 0.9

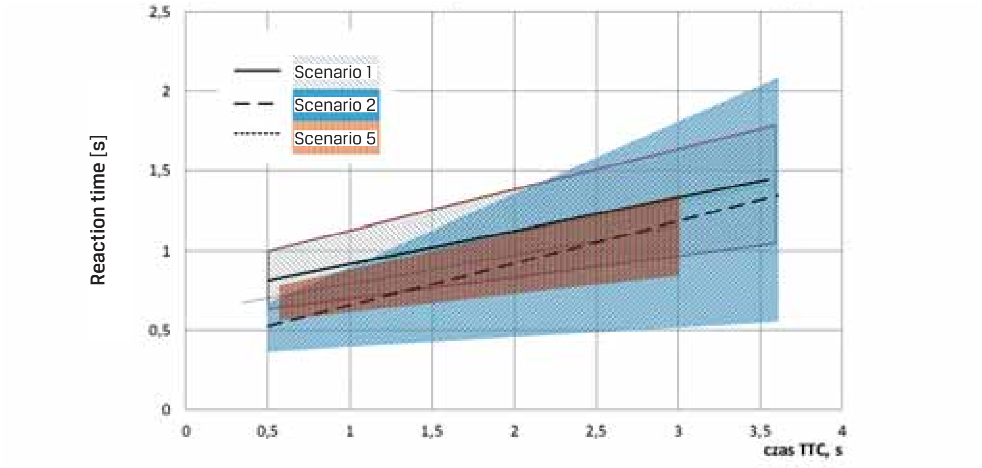

Fig. 10. Driver's reaction time values at the "braking" manoeuvre (with applying the service brake) at scenarios 1, 2, and 5 (average values and quantiles 0.10 and 0.90)

Time of the "turning" reaction at 3 scenarios: comparison of average values and quantiles 0.1 and 0.9

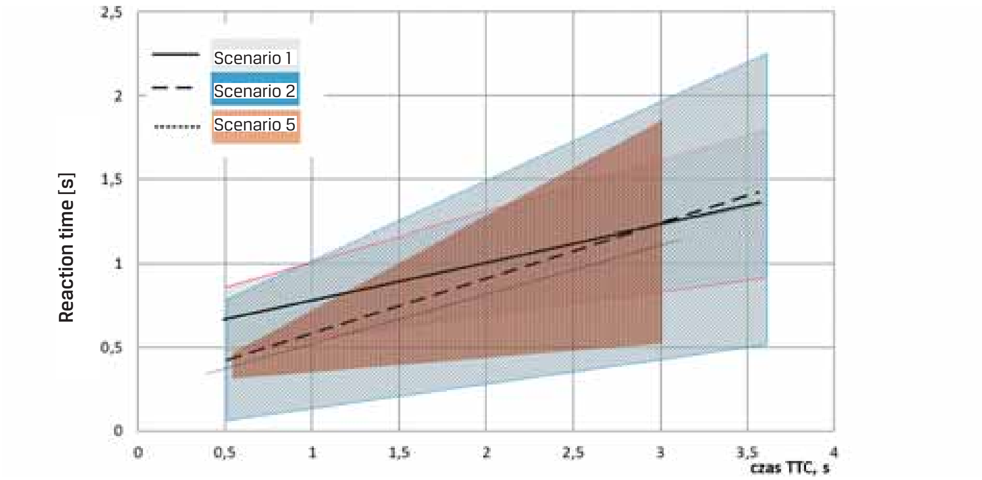

Fig. 11. Driver's reaction time values at the "turning" manoeuvre (driving around the obstacle) at scenarios 1, 2, and 5 (average values and quantiles 0.10 and 0.90)

The dependences of average values and quantiles on the TTC have been approximated in the graphs by linear functions. For the research results presented here to be usable for accident analysis purposes, the equations of the lines plotted in Figs. 10 and 11 have been given in Tables 2 and 3.

Table 2. Equations of the average value and quantile lines plotted in the graphs of driver's reaction time at the "braking" manoeuvre (with applying the service brake)

	Scenario 1	Scenario 2	Scenario 5
Average value	y = 0.197x + 0.713	y = 0.261x + 0.374	y = 0.165x + 0.563
Quantile 0.10	y = 0.138x + 0.556	y = 0.066x + 0.317	y = 0.120x + 0.469
Quantile 0.90	y = 0.256x + 0.869	y = 0.455x + 0.434	y = 0.236 + 0.637

Table 3. Equations of the average value and quantile lines plotted in the graphs of driver's reaction time at the "turning" manoeuvre

	Scenario 1	Scenario 2	Scenario 5
Average value	y = 0.222x + 0.556	y = 0.321x + 0.258	y = 0.285x + 0.239
Quantile 0.10	y = 0.141x + 0.406	y = 0.153x - 0.036	y = 0.087x + 0.273
Quantile 0.90	y = 0.303x + 0.705	y = 0.489x + 0.552	y = 0.591x + 0.122

5. Recapitulation

The analysis of vehicle drivers' reaction to the road situations where braking and/or driving around an obstacle can be undertaken to avoid a collision with the obstacle, as presented herein, makes it possible to formulate a few interesting conclusions.

The conclusion that should be considered most important is the finding that the drivers very seldom chose braking as the only defensive manoeuvre in the situations of this kind, while such an approach of the drivers is predominantly assumed at accident analyses.

In the great majority of cases, the driver's reaction was a combination of both the defensive manoeuvres, i.e. braking and driving around the obstacle, and the drivers who behaved like this, especially at the scenarios where two obstacles were encountered and the TTC (time-to-collision) was longer than 1 s (1.4 s), made even more than 80 % of the total.

A more detailed analysis of the method of combining the two defensive manoeuvres has shown that the most popular sequence of actions taken to avoid a collision was as specified below: releasing of the accelerator pedal, followed by a reaction on the steering wheel (to change the vehicle trajectory), and only then starting of the braking manoeuvre. Fewer drivers performed these manoeuvres in another order or they chose an option with only one defensive manoeuvre. The values of driver's reaction time at braking and at turning (driving around the obstacle), determined from the experiments carried out for the situations where any or both of these defensive manoeuvres could be undertaken, have been specified in this paper. Both the average values and the quantiles shown in the graphs depend on the type (complexity) of a specific road situation and on the degree of hazard, a good measure of which is the time that is to elapse until the moment of a possible collision, i.e. the "time-to-collision" (TTC).

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