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An analysis of collision avoidance manoeuvres in emergency traffic situations

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Summary

This paper provides an overview of the research into the driver behaviour in simulated near collision situations. The aim of such investigations is to determine various parameters characterising the driver performance, e.g. driver response time. The driver response time is a very important parameter used, for example, to analyse road accidents.

The results presented in this paper come from a study performed for two different emergency traffic situations using some predefined procedures (scenarios). The tests included situations in which a person driving a subject vehicle on a test track was to respond to obstacle mock - ups on a conflicting path (intrusion of a pedestrian from the left or from the right and intrusion of a vehicle from the right). The test data was used to determine the parameters describing the driver behaviour, i.e. the braking response time (braking manoeuvre), the steering response time (steering manoeuvre) and the intensity of the two manoeuvres.

This paper compares the values of the driver response time for two scenarios, each with two variants. The average values of the braking response time and the steering response time were determined on a closed track in relation to the Time-To-Collision (TTC) in the range 0,6÷3s, characterising a near collision situation.

Another parameter describing the driver behaviour discussed in this paper is the intensity of an avoidance manoeuvre. In the case of braking, the relative brake pedal displacement was analysed, while in the steering manoeuvre, the steering angle was taken into account. The average values of the braking displacement and the steering angle were presented in the function of the TTC. This paper looks at the relationship between the intensity of the driver response (braking, steering), the driver response time and the TTC.

Keywords: driver testing, driver performance, avoidance manoeuvre, response intensity

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1. Introduction

Road situations involving obstacles (other vehicles or pedestrians) on a conflicting path are not a new issue. However, they frequently lead to a serious or even fatal collision. The most hazardous situations include a sudden intrusion of a pedestrian entering a road from behind vehicles parked along the roadway or from a side street. Such situations pose a high collision risk because a driver generally has little time to respond, i.e. perform collision avoidance manoeuvres. In such cases, the consequences of a vehicle-pedestrian collision are generally very serious, especially for the pedestrian.

In an emergency situation, drivers may undertake various defence manoeuvres, the aim of which is to avoid an accident. They may choose to steer away or brake; they may also perform the two manoeuvres simultaneously yet with different intensity. As the behaviour of an average driver is known, it is possible to answer the question whether a driver responding to a certain emergency situation undertakes the right manoeuvres to avoid an accident or reduce its possible effects.

The moment at which a driver begins to perform accident avoidance activities is determined by their response time. 'Driver response time' is the time that passes from the moment a collision hazard, subjectively rated by the driver, occurs to the moment the driver initiates the collision avoidance manoeuvres (steering and/or braking).

Many manuals and guidebooks for forensic engineers provide one value of the response time determined for an average driver. Frequently, this value is not dependent on any parameter; sometimes the driver's gender or age is taken into consideration. However, the question arises whether drivers of the same age will react in the same way in different emergency situations [22, 42].

Although the driver response time determines the moment a collision avoidance manoeuvre is initiated by the driver, it does not determine its intensity. If the driver behaviour is to be characterised, it is important to know both the values of the driver 'response', which is analysed in this paper, and the value of the steering angle during the steering and deceleration by braking manoeuvres.

The results presented in this paper were used to analyse the driver behaviour not only on the basis of the driver response time in relation to the TTC but also the intensity of the steering and braking manoeuvres.

As shown by Stańczyk and Jurecki [31] in hazardous situations, drivers attempt to combine various avoidance manoeuvres. These, however, differ in intensity when performed by different drivers.

2. An overview of the methods of driver testing

Many investigations have been conducted to analyse the effects of the driver behaviour in strictly defined conditions and situations. As the driver behaviour on the road is dependent on a large number of factors, research projects cover a wide variety of topics. The major factors determining the driver behaviour include:

- driver physical fitness,
- driver mental fitness, e.g. level of fatigue,
- driving skills and experience,
- distractions, i.e. activities diverting a driver's attention from driving, e.g. talking on a mobile phone, talking to a passenger, looking at a roadside advertisement, etc.

Research concerning the driver behaviour can be conducted under laboratory conditions using specialist testing equipment and under field conditions in simulated road situations on a test track. The tests may involve determining the values of the response time for drivers with a different degree of physical fitness, drivers at different age groups (younger and older drivers), disabled drivers or drivers recovering from a disease or surgery.

Investigations may also aim at establishing the degree of disability or evaluating the rehabilitation progress after orthopaedic surgery, for instance, a total knee arthroplasty [32] a total hip arthroplasty [6, 31], partial or total limb immobilization [26], etc. on the basis of the driver response time. Other objectives include measuring the driver braking response time to check whether the former recommendations concerning the post-operation period after a total hip orthoplasty (THA) should last as long as six weeks [9]. Some studies on this subject required determining the values of a simple response. The braking response time was recorded using a special portable setup (RT2s) that assists driving evaluators in assessing driving safety. No real vehicle was employed in the tests.

The literature also reports on investigations carried out with a driving simulator to analyse how different diseases, e.g. Parkinson's disease, affect the physical and mental fitness of a driver [21]. A driving simulator is a device controlled by a microcomputer which can monitor two simultaneously performed tasks: steering (using a steering-wheel) and braking, which is achieved by pressing the accelerator and foot brake pedals. A driving simulator can also be employed to assess the effects of fatigue caused by long and monotonous driving [2]. Another factor analysed with a driving simulator is driver weariness; the study of fatigue conducted by Philip et al. [30] involved measuring the driver response time in a sleep laboratory and on an open French highway.

The driver behaviour can also be substantially affected by external factors such as road surface conditions, noise emitted by other vehicles or traffic density.

Investigations the aim of which is to establish the driver response to a simple stimulus (light or sound) seem easy to perform. They have, however, their limitations. Since they need to be conducted in conditions considerably different from those occurring during driving in a real vehicle, the experimental data cannot be extrapolated to on-road studies [26].

The most frequently analysed factors contributing to the driver behaviour include the driver's physical and mental fitness, the roadway environment, the weather conditions, the driver's age [19, 23], the driver's emotional condition, and impairment by alcohol, drugs, prescription medications and other substances with similar effect on the body [11, 27-28, 43]. The literature also looks at the effects of gender and self-assessment of skills [29]. Research on the subject shows that the driver behaviour, e.g. driver response time, and accordingly the decision making process [8], can be influenced by such activities as talking on a mobile phone (either a hands-free cellular device or a hand-held cell phone), listening to the radio, or talking to a passenger [1, 4].

As there is a multiplicity of factors contributing to the driver behaviour in various road situations, the investigations described in the specialist literature may focus on different test equipment and different methodologies.

The research methodology is largely dependent on the environment in which a test is conducted and on its aims. Investigations can be carried out in laboratory conditions using special equipment, e.g. to assess a driver's psychological performance on test tracks [7, 12, 36]. The research may involve determining the influence of the driving speed on the subsidiary auditory response time [39] or analysing the effect of the surroundings and the driving conditions on the performance of city bus drivers [40].

The behaviour of drivers in different emergency situations can be tested on a test track or in a simulator [24]. The investigations may involve determining driver responses to an obstacle on a conflicting path, for instance, a vehicle, a child's bicycle [20], a ball [5] or a cardboard box thrown into the road [10].

The studies performed by Jurecki and Stańczyk [14, 16] on a test track using a real vehicle were based on a simple scenario, in which a car mock- up entered a conflicting path from the right. Other near collision situations were simulated in a similar way. The first involved a car on a conflicting path from the right and an oncoming vehicle, which greatly limited the space available for the steering manoeuvre [36]. In another simulated situation, there was a pedestrian crossing the road from the right being on a conflicting path with a vehicle on the right lane [35]. The third situation considered was one in which a lorry entering a conflicting path from the right blocked both traffic lanes and it was impossible to avoid it [38].

3. Methodology of the tests on the track

The accident scenarios analysed in this paper were performed on a road circuit. A specially equipped subject vehicle was moving along a test track. The highest degree of surprise was achieved by hiding the obstacle mock- ups behind the curtains placed on each side of the test track. The simulated scenarios reflected roadway situations in which the visibility at an intersection was greatly limited (e.g. due to a high hedge, a row of trees, or high vehicles parked along the roadway).

The obstacles used in the tests were in the form of pedestrian and vehicle safety mock- ups made of polyurethane sponge covered with fabric to prevent damage to the subject vehicle. The mock- ups were constructed in such a way that they could withstand multiple impacts of the subject vehicle and, at the same time, ensure safety of the test participants. The driver behaviour was tested in two particular situations.

The objective of the study was to determine how different drivers responded in typical road situations. There were 30 participants aged 23-27 (with the average age being 24.62, standard deviations 0.95 years) [13,15]. The tests were conducted on a closed circuit using an Opel Astra II as the subject vehicle equipped with special apparatus to determine:

- the vehicle velocity and the longitudinal and lateral acceleration,
- the steering angle and speed,
- the displacement of the accelerator and brake pedals, etc.

The measurement system was connected with the mock-up release system. From the results it was possible to determine the driver response time according to the procedure presented in Fig. 1 as well as the brake pedal displacement and the steering angle [13].

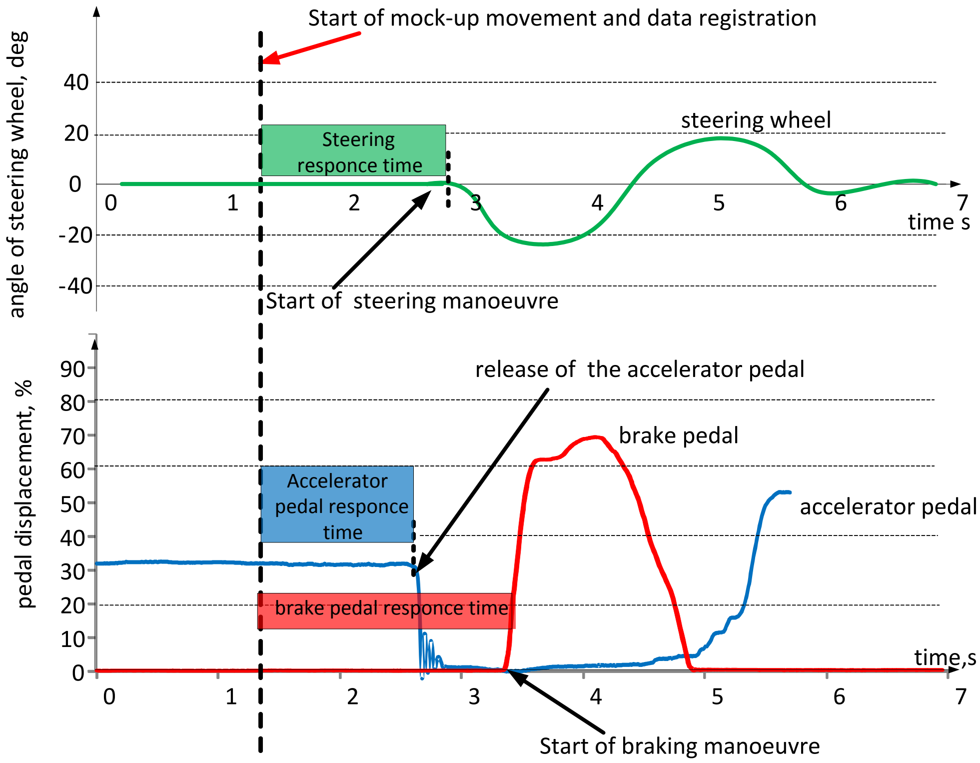


Fig. 1 Procedure to read the response time for the selected collision avoidance manoeuvres

One situation, called 'scenario 1', was conducted using a pedestrian mock- up entering a conflicting path in front of the subject vehicle either from the left (1L) or from the right (1R). Thus, two variants of the scenario were considered [15]. The diagrams of the road situations are presented in Fig. 2.

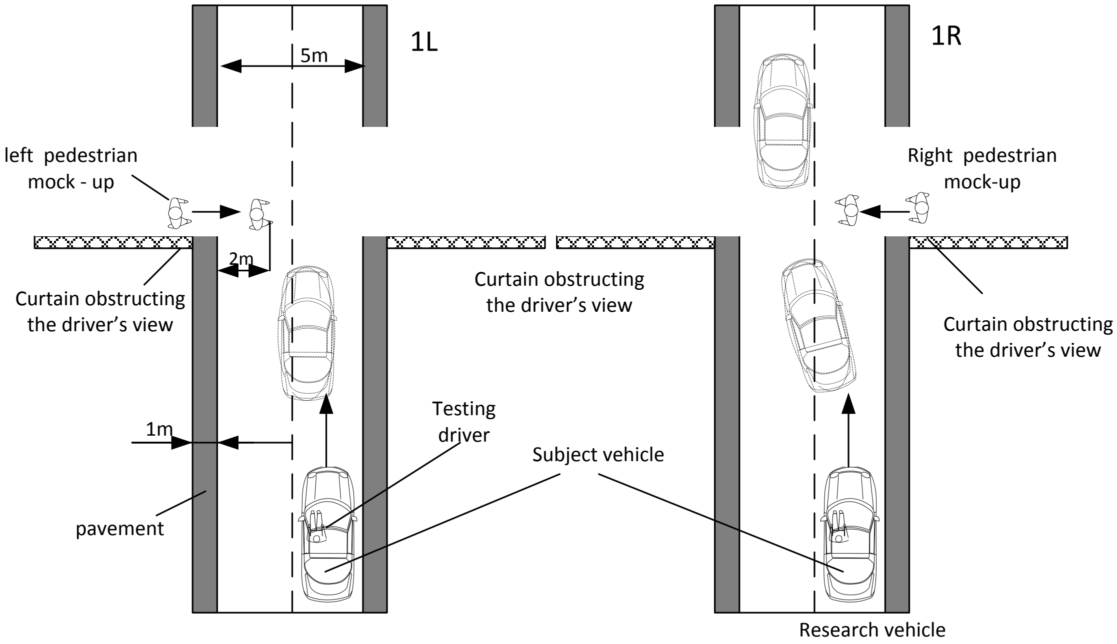


Fig. 2. Diagrams of the variants of scenario 1 with a pedestrian mock- up

The other scenario involved using a pedestrian mock - up as well as a vehicle mock- up [13]. The scenario illustrated in Fig. 2 was supplemented with a mock- up of a car intruding from the right. In scenario 2, there are also two variants of the simulated emergency situation. Variant 2L represents a situation when the vehicle mock- up enters from the right while the pedestrian mock- up enters from the left. Scenario 2R reflects a situation in which both mock-ups (the pedestrian and the vehicle) enter onto a conflicting path from the right. Details of the tests conducted according to this scenario were provided in [13, 17]. The diagrams of the two variants of scenario 2 are presented in Fig. 3.

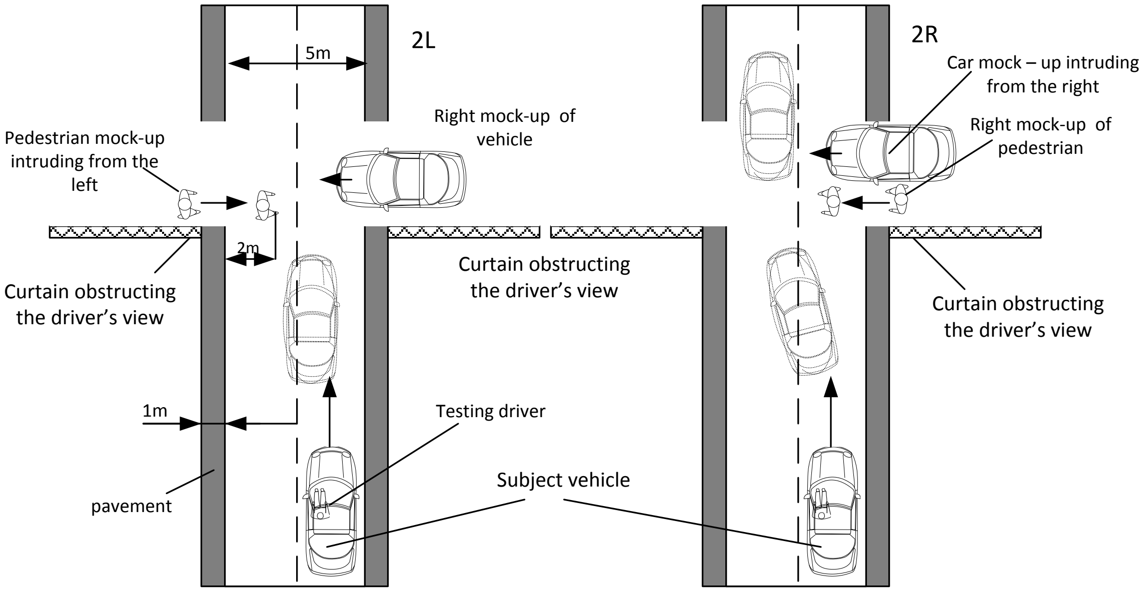


Fig. 3. Diagrams of the variants of scenario 2 with pedestrian and vehicle mock- ups

There were four variants of the situation. All the tests were conducted using the same method. The parameters in all the test runs were the same, as shown in Table 1 [13, 15].

Table 1. Parameters of the test runs in the analysed scenarios

TTC, s	**0.6**	**0.72**	**0.9**	**1.2**	**1.44**	**1.8**	**2.16**	**2.4**	**2.7**	**3.0**
Velocity of the subject vehicle, km/h	60	50	40	60	50	40	50	60	40	60
Distance from the obstacle, m	10	10	10	20	20	20	30	40	30	50

The test runs were randomly mixed to achieve maximum surprise of the drivers participating in the investigation. During the tests, i.e. passes in a subject vehicle, there was no recommendation on the method of response to a given emergency situation. In all the test runs, drivers made their own response choice decisions, which were based on their individual assessment of a situation (as well as skills and experience). The information that the drivers were provided with was very general: to avoid a collision with the mock- ups. There were no details on how to achieve it.

During the tests, drivers behaved differently. For instance, at long TTCs, some drivers avoided both obstacles without deceleration, while others decided to apply brakes as the only avoidance manoeuvre. Most drivers, however, combined the two manoeuvres, i.e. deceleration and steering away.

In this study, the parameter assumed to determine the degree of collision hazard was the time-to-collision (TTC). This parameter was used also in previous studies by the author. Jurecki and Stańczyk [15] explain in detail why this parameter should be selected to analyse the collision-imminent situations. The time-to-collision is a parameter characterising a collision-imminent situation which determines the distance of the subject vehicle from the obstacle in time. The time-to-collision is calculated as the ratio of the distance of the subject vehicle from the obstacle S to the vehicle velocity V the moment the emergency situation occurs – see the diagram in Fig. 4.

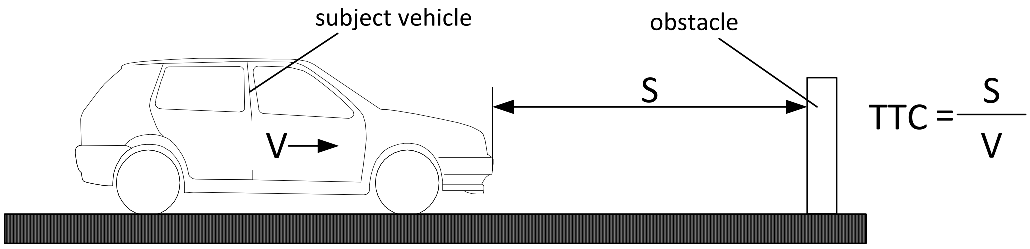


Fig. 4. TTC in an emergency situation

4. Results

4.1. Analysis of the driver response time

The driver responses to a simulated hazardous situation were different in the different test runs [18]. In his earlier works, the author discusses results obtained for the analysed scenarios focusing on the values of the driver response time and the frequency of the particular avoidance manoeuvres undertaken by the drivers. Figure 5 shows the average values of the braking response time (the braking manoeuvre).

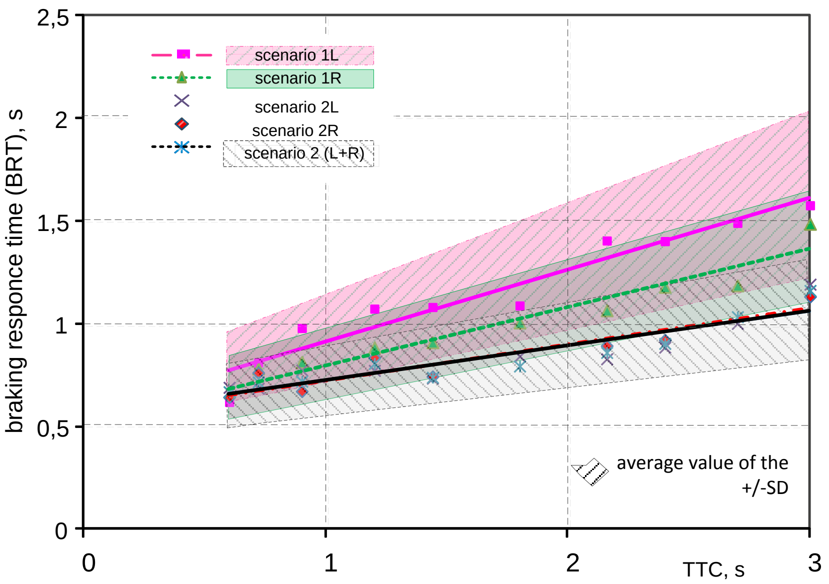


Fig. 5. Values of the braking response time (BRT)

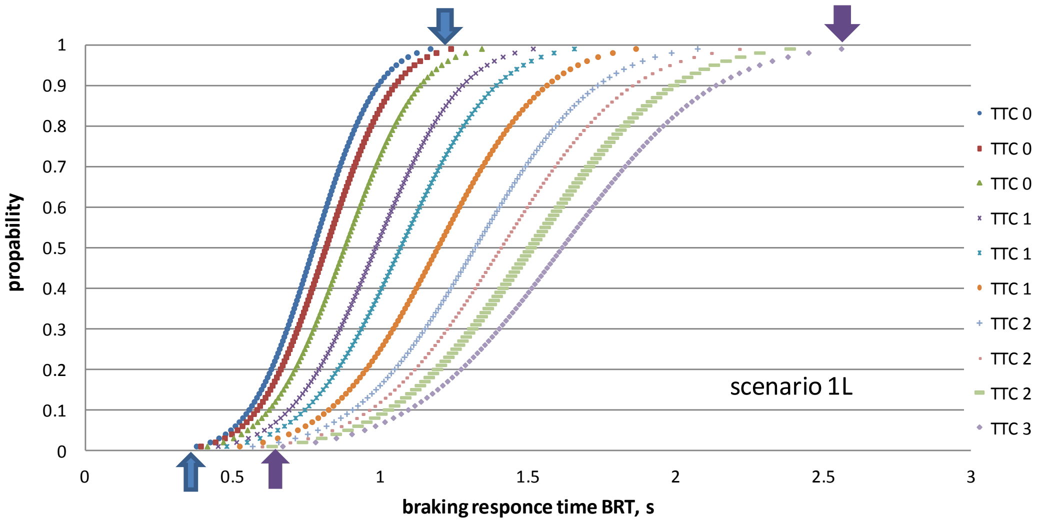
As shown by Jurecki et al. [13], the average values of the response time for both variants of scenario 2, i.e. 2L and 2R, can be considered equal. Figure 5 also illustrates the range of the driver response time determined for the average value of the +/- standard deviation for each analysed scenario.

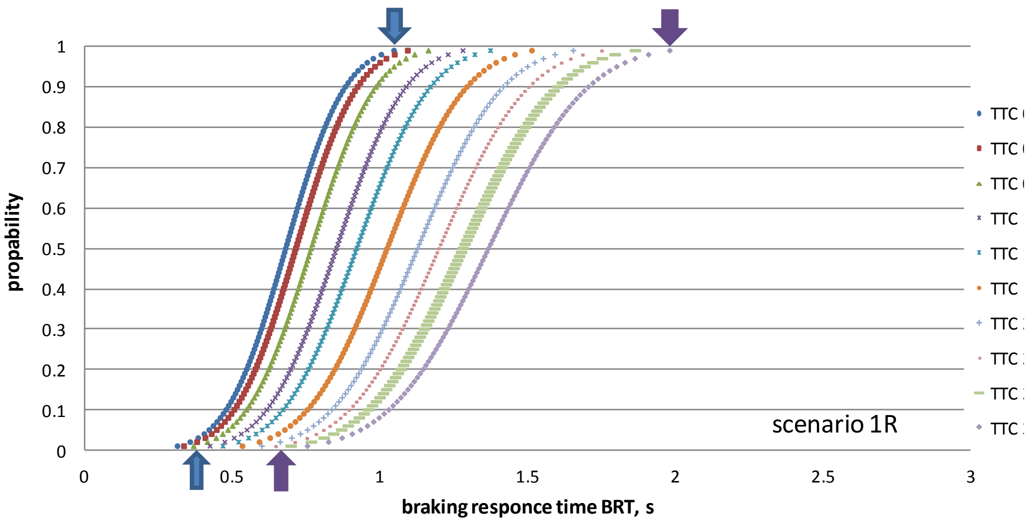
In the analysed scenarios, the values of the braking response time varied considerably. The differences in the average values of the braking response time between scenario 1 and scenario 2 reached even 0.6 s. It should be noted that the differences increased with the time-to-collision. For example, in a road crash reconstruction, it is necessary to assume a certain response time to be used in computer calculations. Such a large difference in the response time may have a significant influence on the final result. It is important to remember that in this time a vehicle moving with a velocity of 60 km/h covers a distance of about 10 m.

In the considered range of the time-to-collision, the values of the braking response time increase linearly with an increase in the time-to-collision. It is interesting to note that the greatest values of the braking response time were obtained for scenario 1L, in which the pedestrian intrusion was from the left. Shorter response times were reported in scenario 1R. However, the shortest response times were obtained for both versions of scenario 2, in which the collision-imminent situations were the most complex. We can thus propose a thesis that the degree of complexity of emergency situations can substantially affect the driver response times.

In Fig. 5, the average values are located along the regression line (as confirmed by the coefficients of the linear correlation in Table 2). However, there are considerable differences in the response time between the particular drivers, and these increase with higher TTCs.

Figure 6 shows the cumulative distribution functions for the driver response time BRT registered at different TTCs for all the analysed scenarios. From the distribution function it is clear that when the TTC is short, the values are generally more concentrated than those observed at longer TTCs. For TTC=0.6 s the response time ranges between 0.3 s and 1.0 s depending on the scenario. The largest scatter is observed for situations with long TTC; the response time may even range 0.7÷2.5 s.


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
propability
0
0.5
1
1.5
2
2.5
3
braking responce time BRT, s
scenario 1L
TTC 0
TTC 0
TTC 0
TTC 1
TTC 1
TTC 1
TTC 2
TTC 2
TTC 2
TTC 3


1
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1
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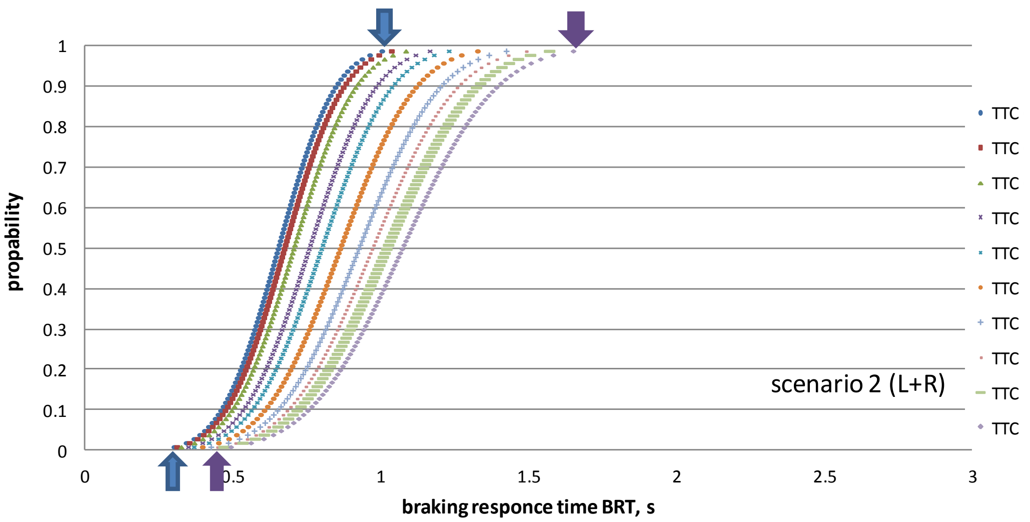
braking responce time BRT, s
scenario 1R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0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
propability
0
0.5
1
1.5
2
2.5
3
braking responce time BRT, s
scenario 2 (L+R)
TTC
TTC
TTC
TTC
TTC
TTC
TTC
TTC
TTC
TTC

Fig. 6 Cumulative distribution functions for the braking response time (BRT)

Figure 7 compares the average values of the steering response time (SRT), with steering as an obstacle avoidance manoeuvre, for the analysed scenarios. Additionally, the figure shows the range of the average values of the +/- standard deviation for each of the analysed scenarios.

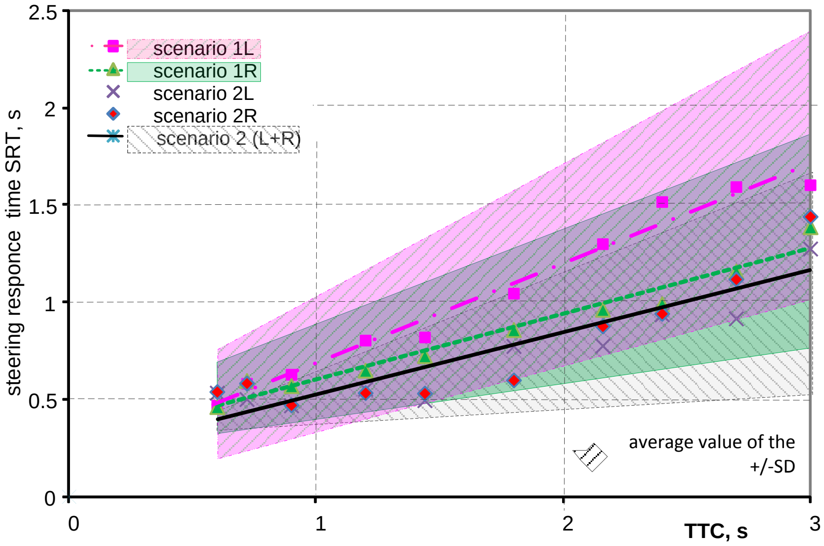


Fig. 7. Values of the steering response time (SRT)

The comparison of the braking response time with the steering response time shows that the relationships were qualitatively similar. For the analysed variants of the two scenarios, the differences between the extreme values of the steering response time were slightly greater than those determined for the braking response time. The steering response time was about 0.1 s higher for scenario 1R than for scenario 2. It is worth noting that the average braking response time is generally longer than the steering response time; this suggests that, on average, drivers make a decision to steer away before they make a decision to brake. During the tests, where TTCs were shorter, the differences between the response times were greater; they reached 0.2÷0.3s. For longer TTCs, e.g. TTC=3s, the values of the response time were similar; this indicates that the two accident avoidance manoeuvres were undertaken simultaneously.

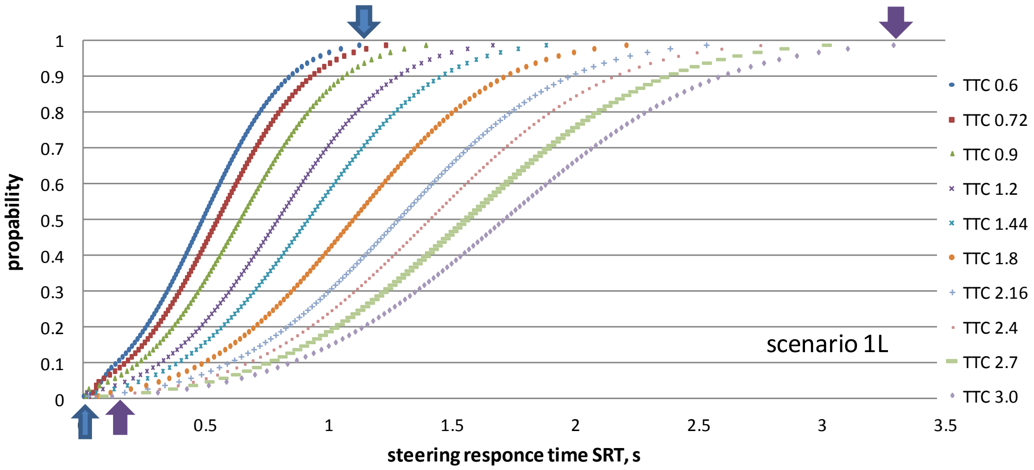
Figure 8 shows cumulative distribution functions for the steering response time registered at different TTCs for the analysed scenarios.

As can be seen, the differences between the responses during tests where TTCs were short are relatively small. The higher the value of the TTC, the wider the range of the response times registered for all the drivers tested.

The analysis of the test data reveals that the driver response time is not the only parameter able to characterise the driver responses. The value of the driver response time indicates the moment at which a particular response is initiated. It was thus vital to thoroughly analyse the curves plotted for the particular driver responses (braking and steering).

The braking responses were compared with the steering responses using the results from all the test runs. For this purpose, the curves of the relative brake pedal displacement and the curves of the steering angle were plotted in the function of time. The relative brake pedal displacement (in percentage) was calculated each time as the ratio of the actual brake pedal displacement to the maximum brake pedal displacement.

Examples of the relative brake pedal displacement curves for TTC=2.4 s are shown in Fig. 9. The plots represent the brake pedal displacements recorded for individual drivers, as indicated by different colours. The graphs provide information on both the driver response time and the response intensity.


propability
steering responce time SRT, s
scenario 1L
TTC 0.6
TTC 0.72
TTC 0.9
TTC 1.2
TTC 1.44
TTC 1.8
TTC 2.16
TTC 2.4
TTC 2.7
TTC 3.0
0
0.1
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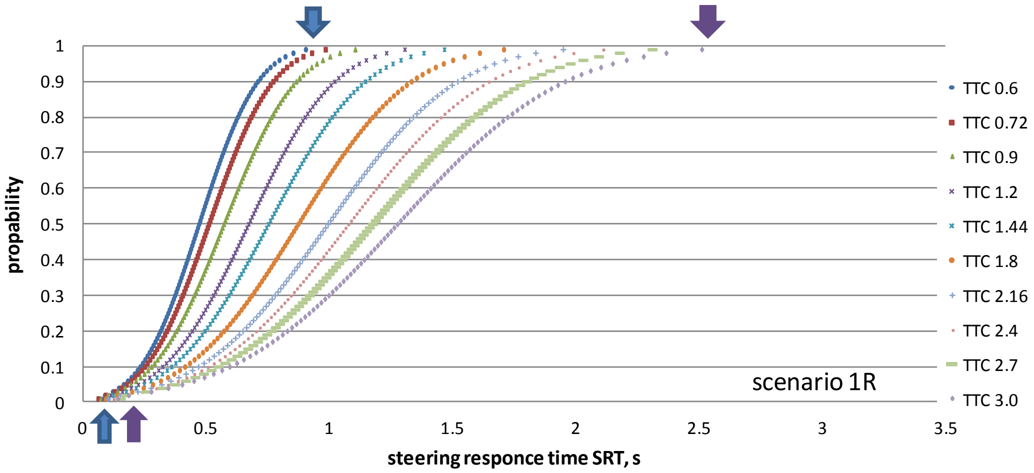
propability
steering responce time SRT, s
scenario 1R
TTC 0.6
TTC 0.72
TTC 0.9
TTC 1.2
TTC 1.44
TTC 1.8
TTC 2.16
TTC 2.4
TTC 2.7
TTC 3.0
0
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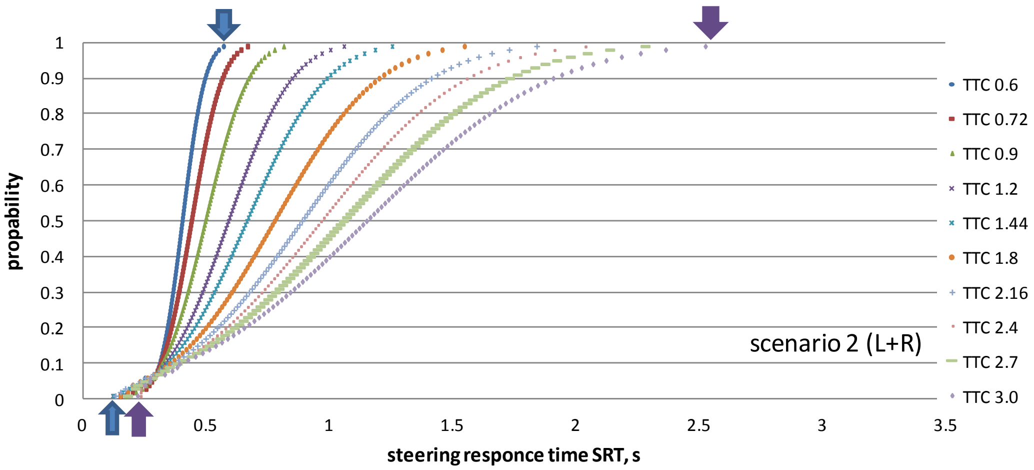
propability
steering responce time SRT, s
scenario 2 (L+R)
TTC 0.6
TTC 0.72
TTC 0.9
TTC 1.2
TTC 1.44
TTC 1.8
TTC 2.16
TTC 2.4
TTC 2.7
TTC 3.0
0
0.1
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0.4
0.5
0.6
0.7
0.8
0.9
1
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1
1.5
2
2.5
3
3.5

Fig. 8 Cumulative distribution functions for the steering response time (SRT)

From the curves of the relative brake pedal displacement shown in Fig. 9 it is clear that the response time is not the only parameter varying from one variant to another. As can be seen from the curves, the braking manoeuvre was performed in different ways. The drivers tested not only began the braking manoeuvre at different times but they also performed it differently. The maximum values of the relative brake pedal displacement were different and they ranged from 10 to 100%. As shown in Fig. 9, the lowest values of the displacement were obtained in scenario 1L. How can this be explained? The diagrams in Figures 1 and 2 obtained for the four scenario variants indicate that scenario 1L was the ‘easiest scenario’ for the drivers. In scenario 1L values of driver response time are longer. In this scenario, drivers decided to apply brakes less frequently, and if the braking manoeuvre was undertaken it was far ‘less intensive’.

Different drivers responded differently in scenario 2L. Since the space was considerably limited and insufficient to perform a left or right steering manoeuvre, the brake pedal displacement was the highest in this scenario variant. It should also be noted that in scenario 2L the braking responses were the most similar.

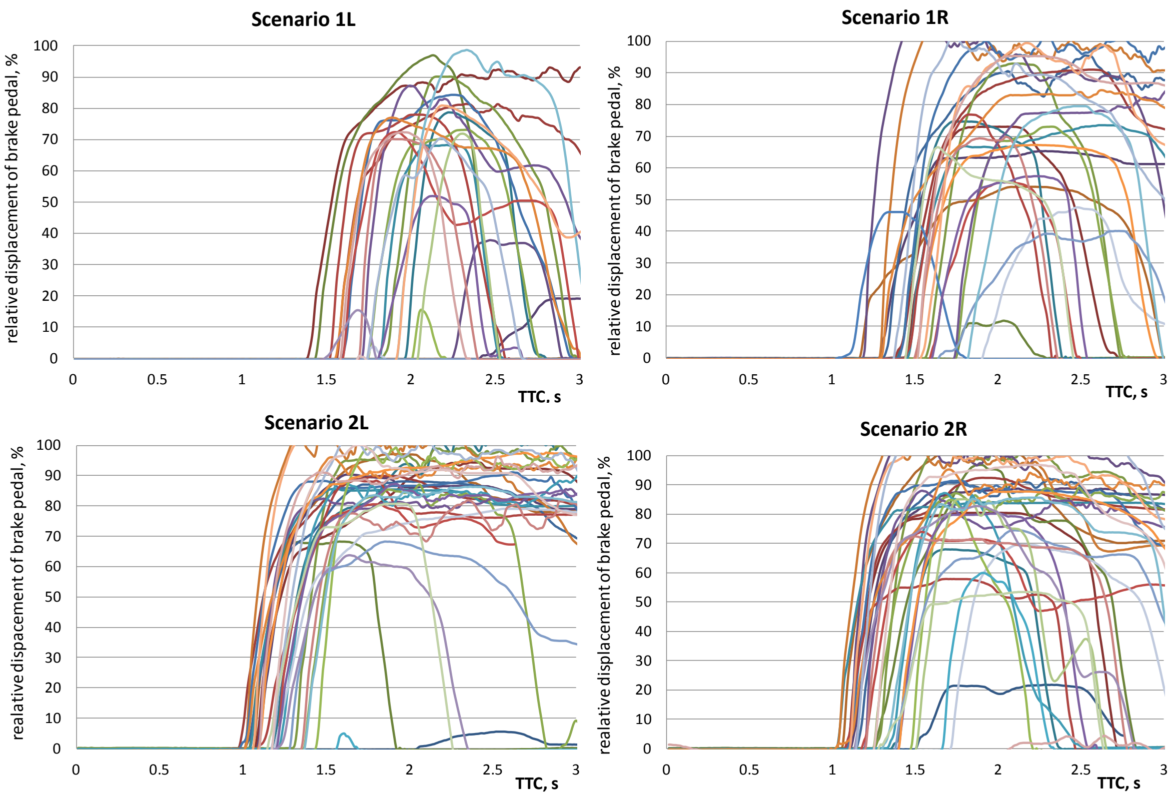

Fig. 9. Examples braking responses of different drivers in situations with TTC=2.4s

The values of the steering angle were analysed in a similar way. Examples of the steering angle curves obtained for TTC=2.4 s are shown in Fig. 10. Analysing the steering wheel angle curves, we can see that the intensity of the steering manoeuvre (defined as the maximum steering angle) is also dependent on the variant of the scenario. The lowest values of the steering angle (like in the case of the brake pedal displacement) were obtained in scenario 1L, in which drivers used the smallest steering angles to avoid a pedestrian mock-up. The maximum steering angles obtained in scenarios 2L and 2R were similar, even though there were some differences in the shape of the curves.

The relationships obtained in the test runs with other values of the time-to-collision were similar to those presented in Figs. 9 and 10.

A question can thus be asked: is it possible to generalise the intensity of avoidance manoeuvres (braking or steering) undertaken by drivers in the scenarios considered? The answer to this question can be found by determining the maximum responses for the braking manoeuvre (brake pedal displacement) and the steering manoeuvre (steering angle), for each of the 30 drivers used in each of the test runs conducted.

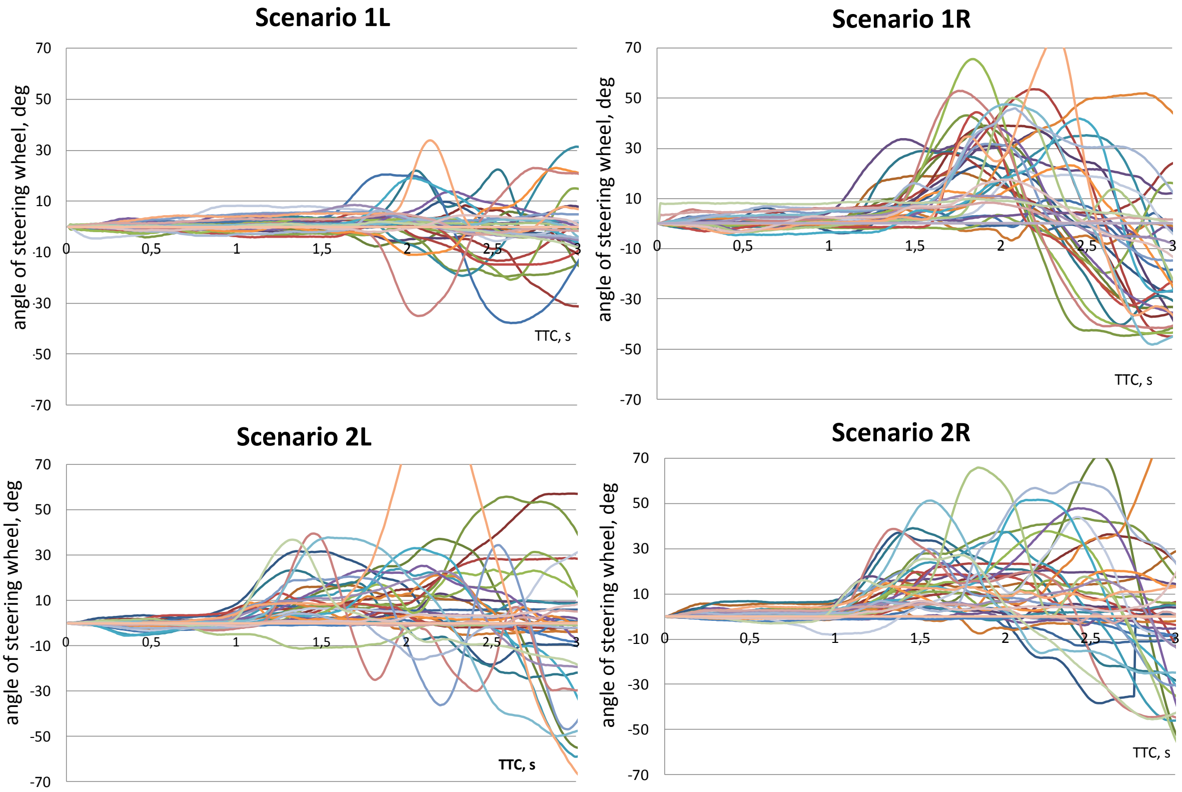

Fig. 10. Examples of steering responses of different drivers in situations with TTC=2.4 s

It was also possible to determine the relationships between the average maximum relative brake pedal displacement and the time-to-collision (see Fig. 11). As can be seen from the diagram in Fig. 11, the lowest values of the relative brake pedal displacement were reported at low values of the TTC. When the time-to-collision was short, it was simply too late for an intensive response. In many cases, drivers initiated emergency braking after they steered away to avoid a collision with an obstacle. In real conditions, however, this would result in a collision.

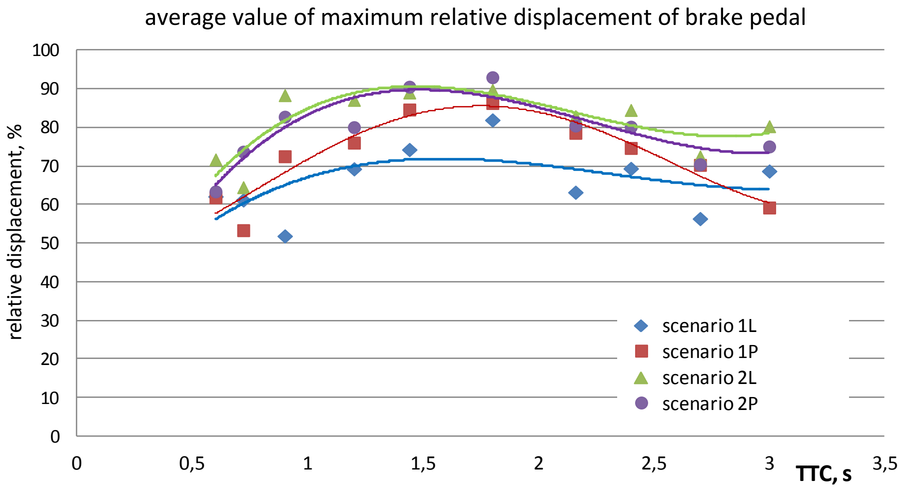

Fig. 11. Comparison of the average maximum brake pedal displacements for the different scenarios

When the time-to-collision ranged 1.2s÷1.8s, the average maximum brake pedal displacement for all the drivers was 80÷90%. At the highest values of the time-to-collision, the relative brake pedal displacement decreased slightly. It should be emphasised that in scenario 1L, the relative brake pedal displacement was the lowest almost through the whole range of the Time-To-Collision. The highest values of the relative brake pedal displacement were obtained in scenarios 2L and 2R. The values for the two variants were quite similar. The driver response times were also similar; they were shorter than in scenarios 1L and 1R. Additionally, the highest braking intensity was reported in scenarios 2L and 2R.

The average maximum steering angles determined for all the analysed scenarios are presented in Fig. 12. The lowest and significantly different values of the steering angle were obtained in scenario 1L. The obstacle avoidance manoeuvres in this scenario were the least intensive because drivers did not need to change lanes; they only had to correct the vehicle's path slightly.

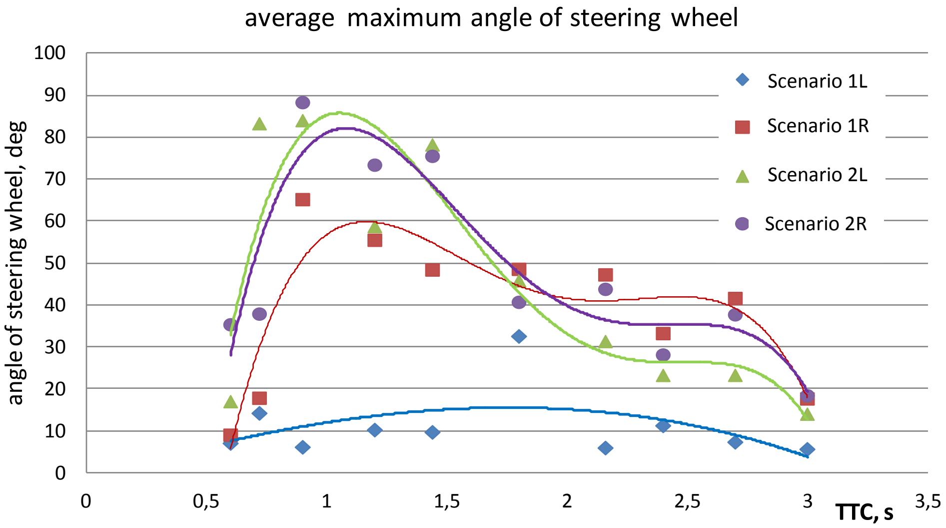

Fig. 12. Comparison of the average maximum steering angles for the different scenarios

In the more complex scenario 2 (variants 2L and 2R), which involved using both a pedestrian mock- up and a passenger car mock- up (entering from the right), the maximum values of the steering angle were similar; they were also the most intensive despite the fact that variants 2L and 2R of this scenario seem to differ considerably (the pedestrian mock- up crossing from the left or from the right). Since similar results were obtained for the average relative brake pedal displacement, it can be concluded that the response times were equal [13] and that the driver response intensity was similar. It can be assumed that the presence of a bigger and more demanding car mock- up affected the driver response to the pedestrian mock- up. Such a response is easy to explain because it is the car not the pedestrian that is subconsciously perceived as a 'more demanding' obstacle with which a collision would be more serious. Does this mean that a driver can underplay easier obstacles?

It seems that in the event of an inevitable collision with either of two different objects, e.g. a car or a lorry, drivers will choose to collide with an obstacle that gives them a certain, even illusory, chance to survive. Further research is required to confirm such behaviour with regard to two different obstacles. However, will the decision be the same if the collision is to be with a real human and not a mock- up?

The average values of the steering angle for the lowest values of the TTC (0.6÷0.72s) were small. After a time-to-collision of 0.9 s was achieved, there was a considerable increase in the values of the steering angle for all the scenarios apart from scenario 1L. The values of the steering angle were the highest when the time-to-collision ranged 1÷1.5s. After the time-to-collision exceeded 1.5 s, the average responses were less intensive. At TTC=3, they reached 15 degrees.

The analysis of the brake pedal displacement and steering angle curves showed that it was necessary to determine if the intensity of a driver response was affected by the time of its occurrence. The intensity of the braking and steering responses was evaluated with respect to two variables: the response time and the time-to-collision.

Figure 13 shows diagrams of the relative brake pedal displacement in the scenarios considered. The results were graphically represented in a 3D coordinate system, where the x-axis shows the values of the TTC for the particular test runs, the y-axis illustrates the braking response times of all the drivers used, and, finally, the z-axis indicates the values of the relative brake pedal displacement, which is a measure of the braking manoeuvre intensity.

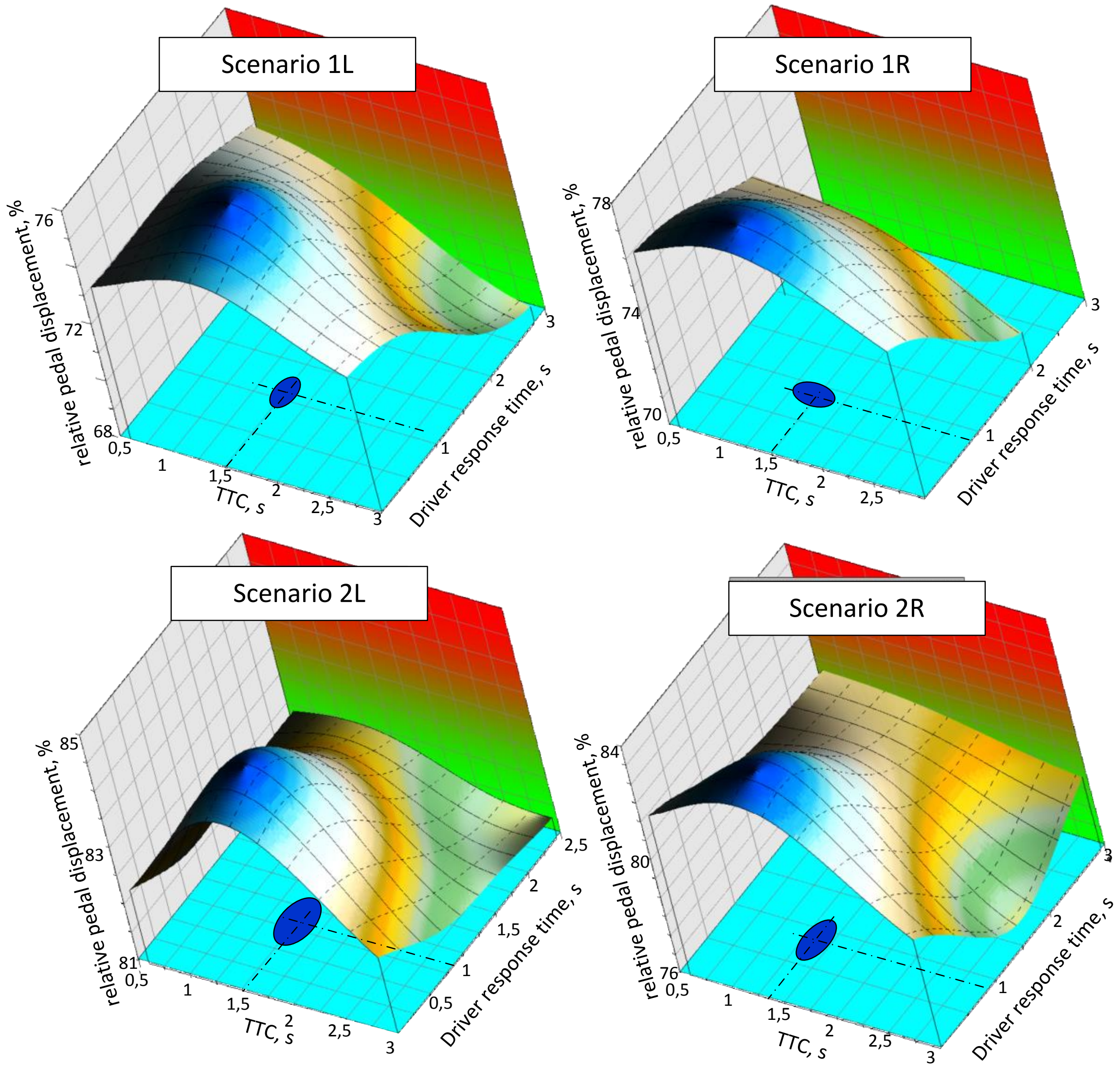

Fig. 13. Relative brake pedal displacement vs. TTC vs. driver brake response time (BRT)

From the diagrams it is clear that the maximum values of the brake pedal displacement were reported at similar values of the TTC and the response time for all the drivers in all the scenarios. In all the scenarios considered, the test runs during which the intensity of the braking manoeuvre was the highest were those with the time-to-collision ranging from 1.2 s to 2.0 s (like in Fig. 11 showing the average values). The highest values were recorded at a TTC of about 1.5 s.

As can be seen from the diagrams in Fig. 13, for each of the scenarios there exist a certain response time range and a certain time-to-collision range characterising a collision-imminent situation in which the braking intensity is the highest. The highest braking intensity was reported for response times ranging from 0.8 s to 1.2 s and for a time-to-collision ranging from 1.35 s to 1.5 s. For ranges smaller or greater than those presented, the responses were less intensive.

Figure 14 compares the maximum values of the steering angle in the steering manoeuvre.

The maximum values of the steering angle obtained in relation to the time-to-collision and the driver response time varied between different variants of the scenarios. As can be seen, the diagram for scenario 1L differs considerably from the others. In this scenario, the maximum values of the steering angle were reported at a TTC of about 1.7 s and a driver response time of about 1 s. In scenario 1R, the steering angle reached its maximum values at a TTC of about 1.2 s and a driver response time of approximately 0.5 s. For scenarios 2L and 2R the results were similar; the highest values of the steering angle were recorded in the test runs with a time to collision of approximately 0.7s and a driver response time of about 0.5 s.

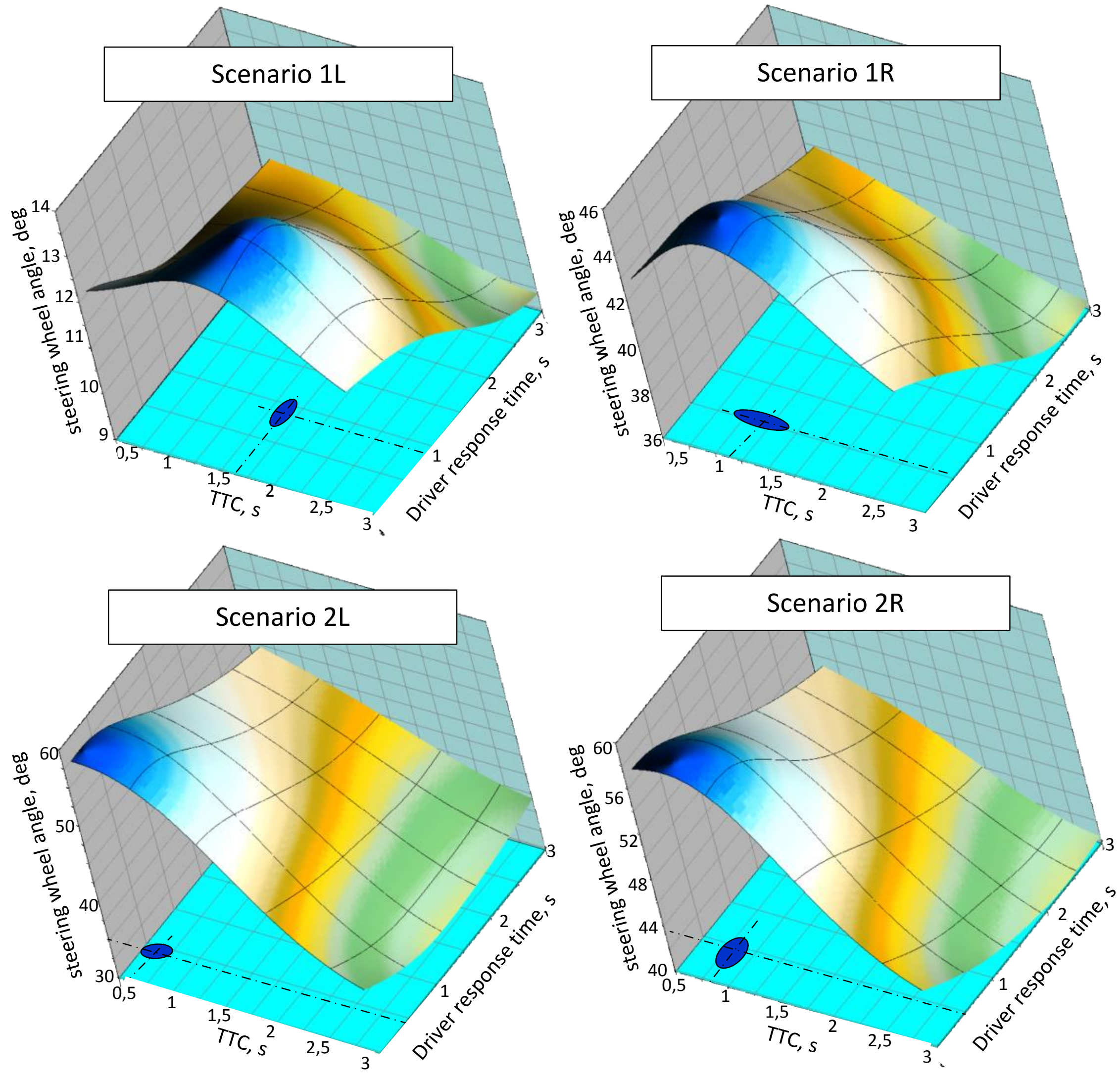

Fig. 14. Maximum steering wheel angle vs. TTC vs. driver steering response time (SRT)

From the diagrams in Figs. 13 and 14 it is evident that the steering responses were more intensive and more varied than the braking responses. It should also be noted that the steering responses were more dependent on the test scenario.

5. Conclusions

The analysis of the driver behaviour in two scenarios has shown that even a slight modification to a scenario (collision-imminent situation) may result in completely different driver responses. For example, a small change in the relatively simple scenario 1, i.e. a change in the direction of entry of a pedestrian mock- up onto a conflicting path – a pedestrian crossing from the left (scenario 1L) or from the right (scenario 1R) – had a considerable effect on the parameters characterising the driver behaviour.

The findings were used to draw an important conclusion on how a road accident reconstruction should be performed. In a road crash reconstruction it is important that the driver performance be represented correctly. This is achieved using parameters characterising the driver behaviour obtained from tests during which the situations simulated were similar to the real collision event. It is then possible to assume an appropriate driver response time and determine the intensity of the avoidance manoeuvres undertaken by a driver.

The results of this investigation corroborate the relationship between the driver response time and the time-to-collision – a parameter characterising a hazardous situation on a road. Results of the author's previous studies were used to show that in the analysed scenarios the response time increased linearly with the TTC.

The paper has assessed the intensity of collision avoidance manoeuvres (braking and steering away) undertaken by drivers in a collision-imminent situation. It was essential to establish what relationship exists between the moment the driver initiates a response (value of the response time) and the response intensity. The results concerning the braking and steering manoeuvres were represented in relation to the driver response time and the time-to-collision using 3D diagrams.

The study involved determining at what response time and time-to-collision (TTC) the highest values of the braking response and steering response occurred.

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