THE IMPACT OF THE SAFE FOLLOWING DISTANCE ONTO THE TRAFFIC SAFETY

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Resume

This paper provides an analysis of the values of safety distance between the two moving vehicles, based on the parameters of the behaviour of young drivers. The main objective of this research was to determine the driver's response time for braking manoeuvre (BRT) in car-following situations. The test results were used to verify certain recommendations for the vehicle driving parameters, the principles of driver's performance to increase road traffic safety, etc. The driver's response times, determined during the testing in the simulator, were used to assess the recommended values of the safe following distance under different road conditions and various ways of driver behaviour. In the paper, for different values of BRT a safety distance in emergency traffic situations was determined.

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1 Introduction

The behaviour of the driver's in different road situations is very varied because it can depend, on many factors. In the car-following situations, the drivers must correctly maintain an adequate distance between vehicles, to ensure safety in traffic. Different factors can determine the values of a driver's response time and the way of performance of the driver in various emergency situations. Researchers were, for many years, from many countries, trying to determine how various factors can affect the driver's behaviour in these situations. The driver's tests can be conducted under different conditions and road situations, i.e., on a test track, in a simulator, or using special test devices. Both healthy and sick, young or older drivers, with or without experience, can participate in the tests. Since the driver's behaviour may depend on many factors, so the variety of research in this area is understandable. Studies in the driving simulator are very popular in this field, although known are limited to use of this research method. In the simulators, the tests were performed a many tests e.g., to analyse the performance of the old drivers [1-2], drivers with various chronic diseases, e.g., Parkinson's or Alzheimer's disease [3], or other disabilities. A fairly large number of researchers were concerned with influence the complex orthopaedic surgeries that adversely affect driver's physical fitness [4-5] restrictions, which can be important during various road situations [6]. For example, in the work [7], the authors describe an attempt to evaluate the behaviour of drivers for 5 different variants related to the limitation of limb mobility. Many of the tests analysed the influence of other factors on driver's behaviour [8]. In tests of driver's behaviour, such factors can be analysed: tiredness [9], experience [10], age [11-13] stress [14], the influence of environmental factors [15-16] and others.

Drivers' behaviour is also influenced by factors such as alcohol [17], used medicine, or drugs [18]. In the currently manufactured vehicles, the driver can use many devices such as: multimedia stations, GPS navigation, and control systems of various systems that can distract drivers and negatively affect, among others, his reaction times. Hence, many studies analyse this aspect as well. Many drivers use mobile phones while driving, including hands - free sets. The way the use of such devices, perhaps negatively affects the behaviour of drivers. These tests are described in many publications [19-22]. Many numbers of papers described analyses,

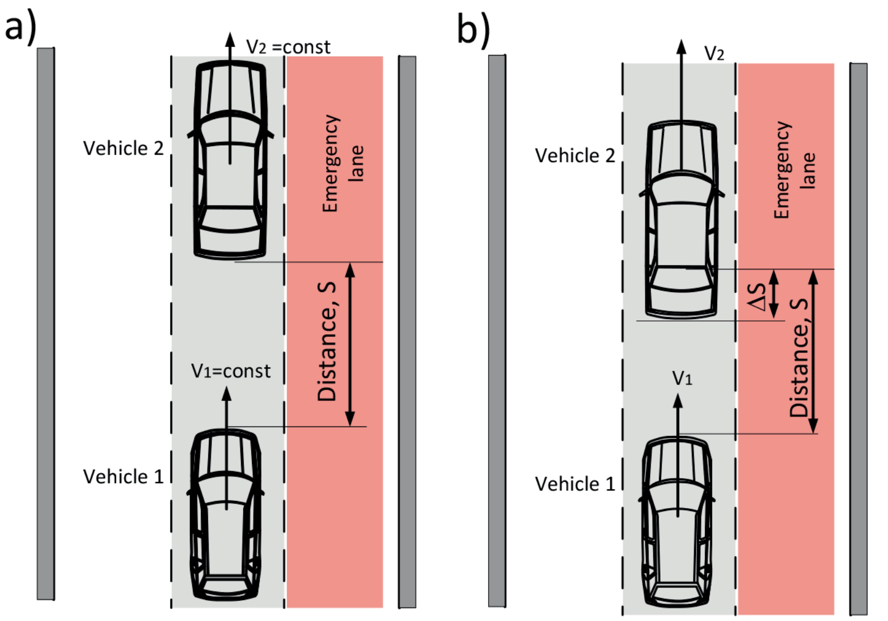

Figure 1 *Diagram of the road situation; a) in the initial phase, b) when vehicle 2 braking*

which determine the influence of various roadway factors on driver behaviour [23].

Now, because the vehicles are equipped with different systems supporting the driver, much research has been undertaken to determine the influence on the driver's behaviour [24- 26].

Some studies focus on the construction details of control systems [27], for example, analysed the influence of the type of keyboard interface (touch screen keyboard vs. numeric keypad) on driving performance and eyeball movements.

Test with the use of a mobile phone carried out on motorway driving in a car-following situation has been realised on younger and older drivers [28]. Muttard analysed the influence of chosen factors on the driver's behaviour, such as the driver's age, fatigue, dispersion of attention, road lighting level, and the free space around the car [29]. The investigations carried out in the simulator have some advantages and disadvantages. A main argument for conducting investigations in a virtual environment is to perform identical, pre-defined situations [30]. Many virtually created road situations can be impossible or dangerous to perform under real conditions. The road tests realised for these situations, may generate high risk to the participants and damage to the used measurement devices [31]. In a simulator is possible to check the driver's performance under specific psychophysical conditions such as great fatigue, driving after consumption of alcohol, medications, or drugs, etc. Driving simulators can be used to simulate the following various situations [32]. These road situations can be very dangerous since the motion of vehicles is realised at a high speed. For this reason, the implementation of research in the simulator does not cause hazardous situations in the traffic [33]. Issues related to the car following movement were analysed in publications [34-37]. Threat factors affecting the behaviour of drivers [38-39], and possible risks occurring during the traffic [40-42], the impact of road shaping [43] in this intersection [44-45], may cause drivers' response times to change [46-49]. The response time may change when one has to be activated with time pressure [50].

To simulate various dangerous road situations driving simulators can be often used. In most of them, the possibility of their reproduction in real conditions would be associated with great danger. Hence, the high popularity of using this way of testing, which, ensures repeatability and stability of measurement conditions. One of the quite dangerous situations is driving in a column. In this situation, vehicles move on the road at quite high speeds with various (sometimes small) distances between them. For all the moving vehicles, any movement stability disorder can cause dangerous consequences. Such disorders include, for example, rapid braking of a preceding vehicle or a sudden appearance of an obstacle. Many publications recommend ensuring a high level of safety, and in this car-following situation, appropriate distance should be maintained [51]. In the paper [52] Bradstone et al. described the studies, in which the distance between vehicles on motorways was determined by use of specially equipped vehicle. Problems related to different road situations, and the values of safety distance between them, have been discussed by numerous researchers [53].

The paper describes the safety distance on a motorway from the aspect of the behaviour of young drivers in an often encountered road situation. The values of the driver's response time for braking manoeuvre (BRT) to determine the safe distance were measured and analysed in the test. In this paper were analysed influences of chosen factors for calculating values of the safety distance.

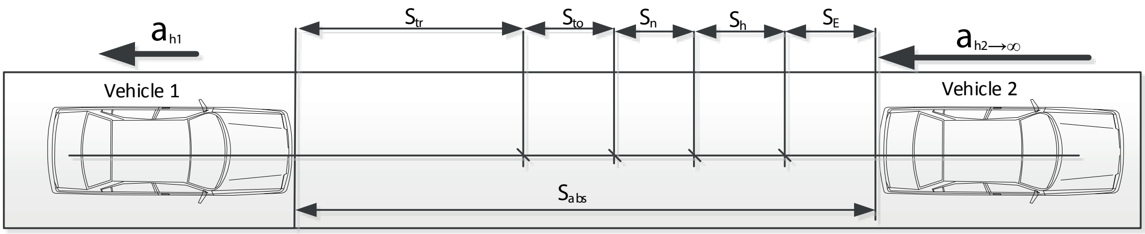

***Figure 2** Diagram for determining the absolutely safe distance*

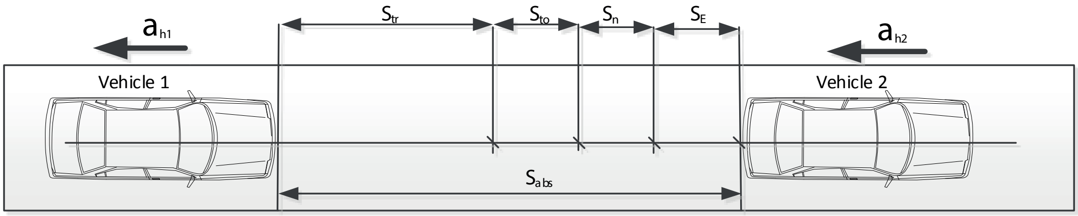

***Figure 3** Diagram for determining the relatively safe distance*

2 Definitions of the safe distance

The aim of the tests realised in the driving simulator was to determine the behaviour of young drivers in situations of sudden braking by the preceding vehicle. The test was realised on a straight section of the road on a motorway. The test road had two traffic lanes and an emergency lane. The road situation is shown in the diagram in Figure 1. Between these vehicles was a safety distance S.

In the literature on this subject [54-57] we come across different terms characterizing the safe following distance. Two terms are considered here: absolutely, and relatively safe distance.

The absolutely safe distance is defined as the gap between one vehicle and the next that enables the following vehicle to decelerate (a_{h1}) and avoid a collision with the preceding vehicle that suddenly stops ($a_{h2} \to \infty$). The situation may take place, for example, when the lead vehicle approaches the scene of a multi-vehicle collision, or there is a sudden intrusion of another vehicle or a wild animal into the roadway. The value of the safe distance can be determined from the following:

$$S_{abs} = S_E + Vp_1\left(t_r + t_o + \frac{t_n}{2}\right) + \frac{V_{p1}^2}{2a_{h1}} = S_E + Vp_1 T_R + \frac{V_{p1}^2}{2a_{h1}}, \quad (1)$$

where: S_{abs} - absolutely safe distance, S_E - minimum distance between the vehicles when stopped; we can assume e.g., S_E=*2 m*, V_{p1} - initial driving speed of the following vehicle (vehicle 1), a_{h1} - deceleration of vehicle 1, t_r - driver response time, t_o - brake system activation delay time (0.2 to 0.6 s), t_n - pressure build-up time (0.2 s), T_R - non-braking time.

The value of the time T_R is:

$$T_R = t_r + t_o + \frac{t_n}{2}, S.. \quad (2)$$

It is possible to determine the absolutely safe distance according to:

$$S_{abs} = S_E + S_{tr} + S_{to} + S_n + S_h, \quad (3)$$

where: S_{abs} - absolutely safe distance, S_E - minimum distance between the vehicles when stopped, S_{tr} - driver reaction distance, S_{to} - brake activation delay distance, S_n - pressure build-up distance, S_h - braking distance for value of a_{h1}.

The diagram for determining the absolutely safe distance is shown in Figure 2.

The relatively safe distance is defined as the gap between one vehicle and the next that enables the following vehicle to brake and avoid a collision when the preceding vehicle decelerates (a_{h2}) to stop:

$$S_{rel} = S_E + V_p\left(t_r + t_o + \frac{t_n}{2}\right) + \left(\frac{V_p^2}{2a_{h1}} - \frac{V_p^2}{2a_{h2}}\right), \quad (4)$$

where: V_p - initial driving speeds of vehicles 1 and 2, a_{h1} - deceleration of the following vehicle (vehicle 1), a_{h2} - deceleration of the preceding vehicle (vehicle 2).

If assumed that the both analysed vehicles can obtain identical deceleration during braking $(a_{h1} = a_{h2})$, one obtains:

$$S_{rel} = S_E + V_p\left(t_r + t_o + \frac{t_n}{2}\right) = S_E + V_p T_R. \quad (5)$$

The diagram for determining the relatively safe distance is shown in Figure 3.

Using the results of tests conducted earlier by the authors, for a similar road situation [8, 58], one can assume that the average value of braking response time determined for tested drivers is about 1.1 s. There was a large diversity of results of driver response time for braking, ranging from 0.74 to 1.99 s, depending on the driving behaviour.

As described in previous publications of the first author, the driver's response time used for the

Table 1 *Vehicle traffic parameters in subsequent phases*

Time of phase (Growing time) (s)	Vehicle 1 (subject vehicle)			Vehicle 2 (preceding vehicle)			Reduction in the distance between vehicles, ΔS (m)
	Description	Speed (km/h)	Distance (m)	Description	Speed (km/h)	Distance (m)	
0	Car-following situation Vehicle move at a constant speed	100	-50	Car-following situation Vehicle move at a constant speed, time brake lights	100	0	0
(+0.5) 0.5		100	-36.10	Brake system activation delay time 0.5 s and pressure build-up come on,	100	13.90	0
(+0.2) 0.7	Driver reaction time to brake lights 0.9 s	100	-30.55	Pressure build-up time brake lights come on, deceleration increases from 0 to a_{h2} = 9 m/s^2	96.8	19.40	0.05
(+0.2) 0.9		100	-25.00	Constant deceleration a_{h2} = 9 m/s^2	90.3	24.60	0.4
(+0.5) 1.4	Brake system activation delay time 0.5 s	100	-11.10		74.1	36.00	2.9
(+0.2) 1.6	Pressure build-up time 0.2 s for vehicle 1, deceleration increases from 0 to a_{h1} = 9 m/s^2	100	-5.60	Constant deceleration a_{h2} = 9 m/s^2	67.6	39.95	4.45
(+2.09) 3.69	Constant deceleration a_{h1} = 9 m/s^2	V_1 = 29	30.9	Constant deceleration to stop a_{h2} = 9 m/s^2	0	59.50	21.4
(+0.9) 4.59	Constant deceleration a_{h1} = 9 m/s^2 to the Vehicle stops	V_1 = 0	34.5	Vehicle stops			25

reconstruction of accidents should be assumed based on investigations conducted under very similar conditions [58-59].

The used value of the braking response time for a very "good driver" of 0.9 s may turn out to be either a little shorter or longer than that obtained on the test track [31].

Based on the many tests realised in both research environments by the Author, may say, that the values of the driver's response time for identical situations, determined during tests on the track and tests in the simulator, are different but correlated [59-60].

This paper analyses a hypothetical road situation, the diagram of which is presented in Figure 2. Vehicle 1 and Vehicle 2 at initial moment, move with constant speeds, e.g., 100 km/h at a certain distance from each other, e.g., 50 m.

This paper analyses a hypothetical road situation, the diagram of which is presented in Figure 2. Vehicle 1 and Vehicle 2 at initial moment, move with constant speeds, e.g., 100 km/h at a distance between them, e.g., 50 m.

At some point, suddenly, the driver of Vehicle 2 - begins to brake with deceleration a_{h2}. The driver of Vehicle 1, at the sight of the stop light, begins to react. From the moment when the brake lights come on in vehicle 2, to the moment when the braking by the driver of vehicle 1 is initiated with a predetermined deceleration, e.g., 9 m/s^2, a certain time passes (for this analysis it was assumed about 0.5 s). This time is a sum of the brake system activation delay time and the pressure build-up time. During this time, the driver of Vehicle 1 begins to respond after the driver response time, for instance, 0.9 s.

In the next step, after e.g., 0.5 s, vehicle 2 begins to brake with deceleration a_{h2}. During these manoeuvres, the distance between Vehicle 1 to Vehicle 2 is decreased

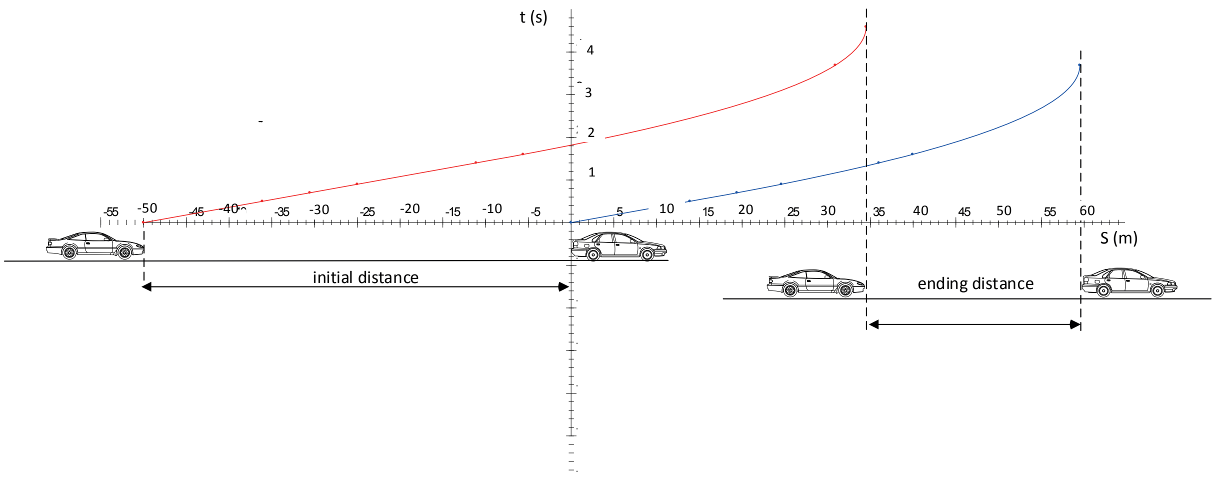

Figure 4 *Result of the time-space analysis for vehicles driving at an initial distance of 50 m*

and if an appropriate distance between vehicles is maintained, a collision does not occur.

In the analysed road situation, the distance between vehicles is equivalent to the relatively safe distance defined above. The driving parameters of both vehicles are shown in Table 1. The decrease in the distance between vehicles is significant, and it is 25 m. It should be noted that the safe distance between vehicles is still maintained. In this situation, the Vehicle 1 moving between the initial moment to the moment when the vehicle stops distance is about 84.5 m.

The Titan Cybid® software for the time-space analysis may show, that if the initial distance between vehicles is decreased, while the other simulation parameters are kept constant, a collision may occur - Figure 4. For situation presented in Table 1, the value of the minimum distance between the vehicles is about 25 m.

When the initial speed of the vehicles is increased to a value of, for example, 120 km/h (at the same value of the braking response time of 0.9 s), the minimum relatively safe distance should be longer. These values of the distance between vehicles can be considered sufficient, assuming that all the other parameters are constant.

If deceleration used by vehicle 1 (a_{h1}) is smaller than the deceleration reached by vehicle 2 (a_{h2}), then there is a dangerous decrease in the distance between them. This situation may occur when one of the vehicles (Vehicle 1) taking part in the event is not equipped with modern safety systems, e.g., the brake assist system (BAS). What would have happened if the driver response time had been different - shorter or longer - than the predetermined 0.9 s? The important question is: how does a change in the driver response time affect the minimum relatively safe distance between vehicles?

In some countries, there are certain recommendations for the distance between vehicles. They are the two-second distance (in time) or a 50 % distance (in space) calculated as half of the speed read from the speedometer. Can, however, these values be considered appropriate? Will the recommendations be sufficient in all the cases and, more importantly, for all drivers?

In this paper, the distance between vehicles is equivalent to the safe distance. The driver response time measured during the tests in the simulator, was one of the parameters used to determine the relatively safe following distance.

The simulation results were analysed to determine the distances at which it was possible to avoid a collision.

3 Tests in driving simulator

The testing of the driver was carried out at the Kielce University of Technology using a Oktal® dynamic driving simulator, shown in Figure 5. Its construction and main parameters were described in other papers by the authors [58]. The fragment fully equipped driver's cabin car the Hyundai Getz and three Full HD monitors, were placed on a 6 DOF mobile hybrid platform.

Identical to the real vehicle, the vibration of the steering wheel differs, depending on the surface type, and the driver feels resistance moments on the steering wheel. Additionally, 5.1 system speakers reproduce sounds related to cooperation of wheels with the road or behaviour of other participants of the traffic.

The system for visualizing the used road situation, while simultaneously controlling the platform motions, uses two computers with Scanner Studio® software. This software allows the modification of vehicle parameters based on the Callas® model of vehicle, the creation of a road profile, and the setting of the road environment for individual test scenarios on different types of roads. A user can create and modify a database that is easy to adjust to the needs of investigations.

It is also possible to develop a scenario through open sources (e.g., *Road XML*) by importing the 3D files with different roadway environments, comprising

Figure 5 *View of the Oktal® driving simulator*

Table 2 *Statistical parameters of the braking response time (BRT)*

Parameter of BRT	Values (s)
Mean values RT	1.16
SD	0.42
Median values	1.10
Quantile 0.10	0.74
Quantile 0.25	0.85
Quantile 0.75	1.41
Quantile 0.90	1.73
Quantile 0.99	1.99
Minimum value	0.5
Maximum value	2.7

buildings (e.g., 3DS, FLT, DAE, OBJ, DXF, OSG, and IVE formats).

Road type modification may involve changes in the pavement type, coefficient of grip, and road roughness. These parameters are very important for use by the model of vehicle dynamics in the software.

In the simulator, realised tests of 60 young drivers aged 22-23 drove on the right lane, as shown in Figure 6, with a speed of 100 km/h. In the tests a specified constant distance of 10 m to 50 m from the preceding vehicle was maintained. The research procedure has been described in the paper [58]. In the realised scenario, there were no other vehicles moving in around of the test vehicle. At a randomly selected moment, a vehicle moving in front of the research vehicle brakes with high deceleration 9 m/s^2.

Drivers of the tested vehicle were free to choose emergency manoeuvres: only braking, bypassing the braking vehicle, or both manoeuvres combined braking and steering. The tests involved registering the values of driver response time. The registered values of braking response time (BRT) in this test is the time, determined from the moment when the brake lights light up in the preceding vehicle, to the moment when the driver of the testing vehicle presses on the braking pedal.

4 Results

4.1 Driver response time for braking (BRT)

In the analysed scenario, there were no any limitations to the driver's behaviour. Authors analysed values of braking response time for all the tests for different distances between vehicles. To simplify, the further analysis in terms of safe spacing, the data collected in the study [58] were used and analysed as a single set. Statistical values, determined for them, are presented in Table 2. It can be seen, that the values of the mean and median braking response time are not equal, so it can be said that the distribution of the obtained values is asymmetrical. This is confirmed by the analysis of the normal distribution (Chi-Square test = 20.937, df = 4, p = 0.00042); a better fit applies to gamma distribution (Chi-Square test = 9.09, df = 4, p = 0.0588).

The values of the braking response time can significantly contribute to the driving safety in a road situation. A minimum safe distance between vehicles can be determined in two different ways: as a gap in space, when the distance is calculated as half of the speed expressed in km/h read from the vehicle

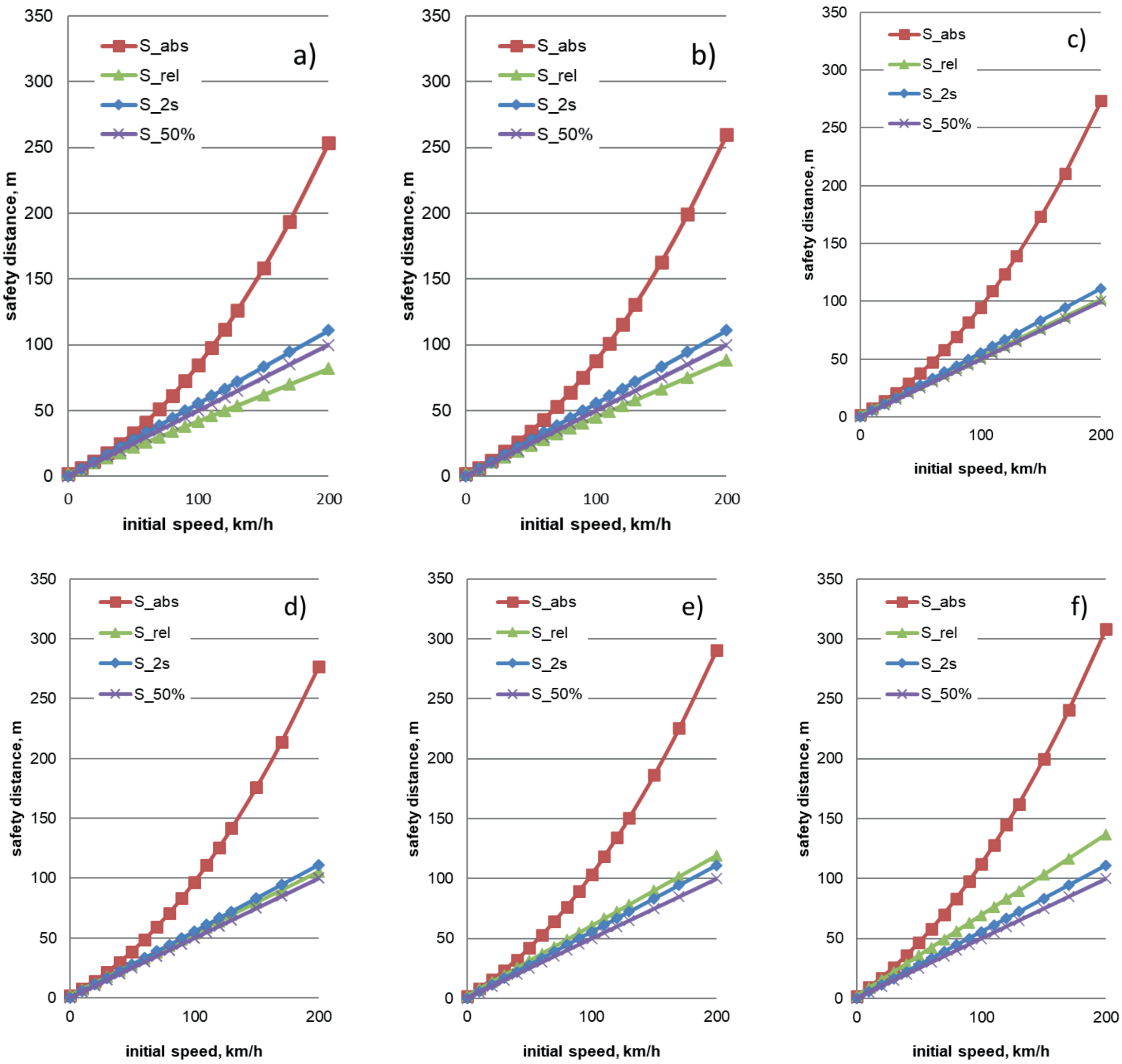

Figure 6 *Safety distance for various values of the BRT; a) the 0.1 Quantile, b) the 0.25 Quantile, c) median value; d); the 0.75 Quantile e) the 0.9 Quantile, f) the 0.99 Quantile*

speedometer (e.g., recommended in Germany or Poland) $S_{50\%}$, or as a gap in time, when the two-second rule is applied S_{2s} (e.g., in France).

When the two vehicles move one after another with identical speeds in the same direction, the distance between them is constant. In such a case, the required distance is equivalent to the relatively safe distance. Following the relevant recommendations, one can assume that the safe distance between vehicles moving, for example, with a speed of 100 km/h should be approximately 50-55 m. However, one can ask whether the large distance is not too large.

The driving safety in analysed situation is relatively high as long as the traffic flow is homogeneous. Some drivers, however, may want to decrease the distance between vehicles, which would result in a gradual decrease of the safety level. At smaller distances, a problem may occur in an emergency when the lead vehicle performs unexpected manoeuvres or just brakes suddenly. The driver in the vehicle behind starts to respond to the situation, most frequently to the brake lights coming on the preceding vehicle. Analysing the values of the braking response time in a car-following situation, one can notice a great diversity of results.

Comparing the response time for braking to that assumed in a hypothetical situation (see Table 1), one can question what distances ensuring safety are suitable for all drivers. What about people whose response time will, for some reason, be longer? Drivers with longer response times include not only people advanced in age, sick or physically disabled, but the young people as well who, for some reason, did not respond early enough.

The diagrams in Figure 6 show different values of distances between vehicles, based on the measured values of the BRT. The curves show the relatively safe distance S_{rel}, the absolutely safe distance S_{abs}, the two-second distance recommended for drivers in some countries, denoted as S_{2s}, and the 50% distance calculated as half of the speed read from the speedometer in km/h, denoted as $S_{50\%}$.

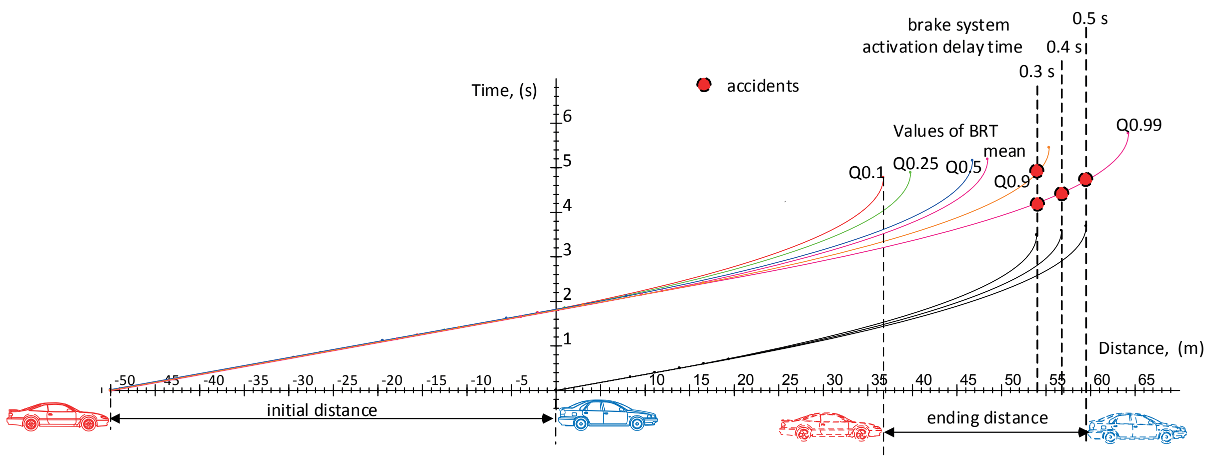

Figure 7 *Effect of changing the brake system pressure build-up time on the safe distance*

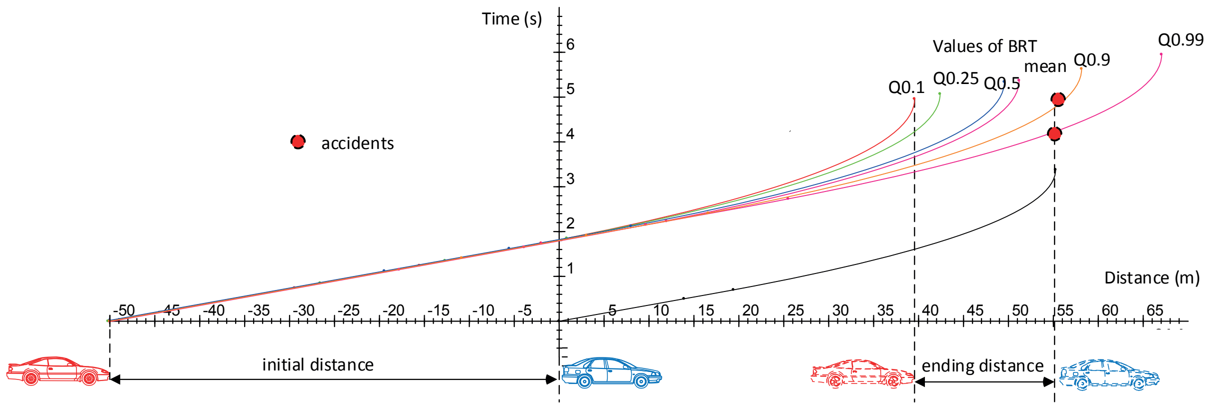

Figure 8 *Effect of changing the value of braking deceleration of vehicles on the safe distance*

Figure 6a shows the distance between vehicles for different driving speeds, assuming that the values of the BRT, recorded by the simulator, were at the level of the 0.1 Quantile. In this case, only 10 % of the tested drivers had shorter response times. This response time is determined for young, healthy, rested driver, with very good skill. From the analysis of the Figure 6a, one may notice, that the relatively safe following distance S_{rel} is smaller than the recommended S_{2s} and $S_{50\%}$ distances. The values of the S_{2s} and $S_{50\%}$ distances seem to be a certain trade-off between the absolutely safe distance S_{abs} and the relatively safe distance S_{rel}. The S_{2s} distance is slightly larger than the $S_{50\%}$ distance. At a driving speed of 120 km/h, the absolutely safe distance S_{abs} is nearly twice as long as the relatively safe distance S_{rel}. One can notice that above this value, the absolutely safe distance S_{abs} increases significantly.

Figure 6b presents a safety distance calculated for drivers, which have a response time of about 0.25 Quantiles. Interesting conclusions can be shown from the analysis of the distance between vehicles if one takes into account the average value of the *BRT* - see Figure 6c. The curve corresponding to the relatively safe distance S_{rel} shifts up and approaches the $S_{50\%}$ curve. It can thus be assumed that for drivers with an average braking response time, the relatively safe following distance S_{rel} is the same as the $S_{50\%}$ distance. This finding is particularly important because the $S_{50\%}$ distance is the easiest to calculate by the driver himself during driving. Figure 6c shows distances between vehicles assuming that the driver response time for vehicle 1 is equal to the median values. The distances were suitable for 50 % of the drivers tested. One can see that the S_{rel} distance is close to $S_{50\%}$ and slightly lower than S_{2s}.

However, if we look at Figure 6d, we can see that the distance S_{rel} should be slightly longer than $S_{50\%}$ and approaches S_{2s}. The curves in Figure 6e show the distances between vehicles for the braking response time of drivers equal to the 0.9 Quantile. The relatively safe distance S_{rel} is longer than the S_{2s} and $S_{50\%}$ distance. The relatively safe distance S_{rel} equivalent to the S_{2s} distance can be considered safe for 90 % of drivers. However, what about drivers whose response time is higher than the 0.9 Quantile? For them, the relatively safe distance, equivalent to the S_{2s} distance, may turn out to be insufficient. If the distances presented in Figure 6f were used in practice, they would ensure safe driving conditions in a car-following situation for 99 % of drivers. The relatively safe distance should be greater than the S_{2s} distance, and for 100 km/h speed is up to 140 m.

The analysed case concerns the case in which the main braking parameters of both cars are similar.

Interesting observations, regarding the safe distance can be made, when changing the assumed parameters of the braking process. An example of changes in the safe distance, in a situation when one of the vehicles (vehicle 2) will have a shorter brake pressure build-up time by 0.1 and 0.2 s, is shown in Figure 7. It may seem that such a small change cannot have a negative effect. However, it turns out that for the less capable drivers, whose BRT is equal to or greater than about 1.7 s (about 0.9 Quantile and above), combined with a very capable preceding vehicle, such a change makes it quite feasible for drivers to create an accident.

The next analysis was carried out for the situation where the driver from vehicle 1 is moving in a vehicle that is not fully operational and its braking deceleration is only 8 m/s^2, while the preceding vehicle brakes very effectively with a deceleration of about 10 m/s^2. The results of the spatial-temporal analysis in such a situation are shown in Figure 8. It can be seen, that even small changes in values of deceleration for analysed vehicles can cause an accident. Variations in deceleration can be caused by modern technology, as well as the technical condition of brakes, tyres, etc.

5 Conclusions

Drivers have a very large impact on the number of traffic accidents. Many factors are influenced by the behaviour of the driver's. To characterize the way the driver's behaviour a parameter that is often used, is the response time. The values of the BRT are of a great significance when emergency situations are analysed. Those are the values that can be used in simulation programs used to reconstruct a road accident.

From the analysis it is evident that the distances recommended in some countries, i.e., the distance equivalent to 50 % of the value read from the speedometer, $S_{50\%}$, and the two-second distance, S_{2s} ensure high safety for vehicles in the car-following mode, and therefore should be generally recommended. Unfortunately, for a certain group of drivers, whose braking response times are higher than the 0.9 Quantile, the recommended following distance may not provide full safety. The investigations conducted in a simulator confirm that for 10 % of drivers, the recommended value turned out to be insufficient. However, it should be remembered that this article analyzes the behaviour of young drivers, in the case of the elderly the response times are longer. For drivers with short response times, the recommended following distance seems too large. If, however, there is a risk of dynamic changes, e.g., due to fatigue, stress, disease or difficult driving conditions, it is not at all easy to assess whether the driver response time, corresponding to a safe following distance, is too short or too long.

In the analysed road scenario, the drivers were free to decide on the use of emergency manoeuvres [61]. Various studies show, that the safe distance is a relative value. It can change dynamically depending on circumstances on the road. The data is consistent with what drivers say, namely, that driving on a motorway is theoretically easier, but it does not mean that we should take less care.

The drivers perceive the safe following distance very subjectively, that may in practice lead to a dangerous traffic hazard. Using the results from various investigations, we can propose the following recommendations for the safe following distance. When the adjacent lane on motorway is clear and the vehicle is equipped with ABS and ESP systems, which suggests that, in an emergency, the manoeuvres of braking and steering away can be used, the minimum safety distance between the vehicles moving with a speed 100 km/h should be for the best drivers (level of the response time of drivers about 0.1 - 0.25 Quantiles) about 42 - 45 m. This value in smaller than the distance recommended in many countries, distance in time 2 s. In an identical situation, the minimum distance between the vehicles for the average driver (median or mean values of driver response time), amounts to 52 - 53 m. These values are slightly larger than the distance calculated for time equal 2 s. For drivers with a large driver response time about of 0.75 Quantiles, distance increases to about 60 m. These values for 0.9 Quantiles of BRT increases to 70 m. If we wanted the distance to be appropriate for 99 % of drivers in the analysed situation, the value could reach up to 77 m.

The article presents an analysis of situations in which the braking parameters of both cars are similar. Other variants were analysed, however, one still does not know, for example, how the safe following distance can be affected by the vehicle condition or the vehicle features (especially those related to the braking system), or what would happen if the brake system activation delay time and the pressure build-up time are much greater than those assumed in this study.

As such questions can be expanded, it is vital to continue the research on the subject, taking into account further factors.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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