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## DRIVER'S REACTION TIME UNDER EMERGENCY BRAKING A CAR – RESEARCH IN A DRIVING SIMULATOR

### CZAS REAKCJI KIEROWCY W WARUNKACH AWARYJNEGO HAMOWANIA SAMOCHODU – BADANIA W SYMULATORZE JAZDY SAMOCHODEM\*

*Extract. The paper presents results of research on the reaction time of drivers of motor vehicles in case of accident risk. These studies have been conducted in an autoPW driving simulator - research project N509 016 31/1251. During a simulated pre-accident situation, a test driver, as he was trying to avoid a collision with an obstacle, has been forced to perform a braking manoeuvre. 107 people of different age and driving experience have been studied. Various scenarios describing risk situations (the speed of a car driven by a tested driver, the distance between the vehicles at the initial moment) have been considered. Reaction times were determined at the controls of the vehicle and they have been presented in a time to collision function. The presented results provide important information on the analysed subject (for instance reaction time dependence on risk time). They have also confirmed the usefulness of this type of simulation studies in connection with the possibility of fairly accurate reproduction of the environment appearance and an event scenario in relation to possible real situations.*

**Key words:** tests of drivers, drivers' reaction time, risk time, car driving simulators.

*W publikacji przedstawiono wyniki badań dotyczące czasu reakcji kierowców pojazdów samochodowych w sytuacjach zagrożenia wypadkowego. Badania te zostały wykonane w symulatorze jazdy samochodem autoPW w ramach projektu badawczego N509 016 31/1251. W zainscenizowanej sytuacji przedwypadkowej, badany kierowca próbując uniknąć zderzenia z przeszkodą, zmuszony był do wykonania manewru hamowania. Przebadano 107 osób różniących się wiekiem i doświadczeniem w prowadzeniu samochodu. Rozważono różne scenariusze opisujące sytuacje zagrożenia (prędkość samochodu, którym kierował badany, odległość pomiędzy pojazdami w chwili początkowej). Wyznaczono czasy reakcji na elementach sterowania pojazdem i przedstawiono je w funkcji czasu ryzyka (ang. time to collision). Zaprezentowane wyniki dostarczyły istotnych informacji na analizowany temat (np. zależność czasu reakcji od czasu ryzyka). Potwierdziły też przydatność prowadzenia tego rodzaju badań w symulatorach w związku z możliwością dosyć wiernego odwzorowania wyglądu otoczenia i scenariusza zdarzeń w stosunku do możliwych rzeczywistych sytuacji.*

*Słowa kluczowe:* badania kierowców, czas reakcji kierowców, czas ryzyka, symulatory jazdy samochodem.

#### 1. Introduction

According to statistical data, for instance [16, 19, 20], the most common cause of road accidents are persons driving the vehicles. It has been estimated that approximately 70% of accidents in Poland is a result of incorrect operation of a driver. Reaction time has been among the many features that characterize its function in the event of accident risk on a road. In short, it can be defined as the period from the time a threat appears to the moment a driver takes certain actions on vehicle controls to avoid an accident.

This parameter has a direct impact on the course of an accident situation, and road safety at the same time. On the other hand, it is one of the basic data adopted in the calculations carried out by experts from automotive and traffic engineering (and court experts) in the process of reconstructing accidents. The results of this analysis depend on values adopted in these calculations, which in turn, influence court's decisions concerning guilt of participants of the event or its absence. From both points of view, research on reaction time are thus fully justified.

The paper presents selected results of extensive research, conducted throughout 2007-2010, whose primary purpose was to gather particular reaction times. These studies have been conducted by three teams: the Kielce University of Technology (leader), the Technical University of Warsaw and Cracow University of Technology, under project no. N509 016 31/1251 "Development and update of the reaction times database of vehicle drivers."

#### 2. Justification of the need to test reaction time

Data on drivers' reaction times are crucial in the manuals and training materials for court experts and automobile engineering and traffic experts. Values presented in many publications differ significantly. However, as mentioned earlier, values adopted in the analysis by a court expert may strongly influence final decisions on drivers's fault.

(\*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie [www.ein.org.pl](http://www.ein.org.pl)

These differences often result from a variety of research methodologies (tool - test environment, test methodology, the multiplicity and "composition" of a focus group, the way of presenting results). From the perspective of usefulness for the accident reconstruction, it should be noted that no method developed so far could clearly be regarded as the best.

Generally, there are three methods (research environment) used for this type of research:

- stands for qualifying tests of drivers (used in the laboratories of transport psychology),
- experiments on roads or research/test tracks,
- research in driving simulators.

Evaluating reaction time in psycho-technical research is one of the sets of tests performed in the laboratories of psychology which are aimed at assessing general capacity of a tested driver within the scope of driving a car. These studies are characterized by a number of years of worked-out methodology and methods of assessing their results, for instance [22]. Reflection meters are used in the case of reaction time. Reaction time is estimated as the period from the onset of the light or sound stimulus to the moment of pressing a button on the desktop.

In the case of data from experiments on road or test tracks, these are often the results of reaction to so-called simple stimulus (a single tone or light), but the way drivers reacted is also simplified - it has to work on one of the vehicle controls (pedal brake, hand brake lever or steering wheel), [2, 5, 21, 31, 32]. The results of such research are often published as a recommendations to the experts, for instance [2, 33].

In real road situations (for instance, driving off in the column on a motorway, where the reaction takes place to the light "stop" before the car), a driver reacts to a complex stimulus. However, in the literature prior to 10-15 years, it is difficult to find data concerning reaction times, in which both the stimulus and the reaction of a driver are complex (as in real life accident situations). So far, studies carried out complex reactions to stimuli, but they were often highly simplified situations. For instance, in [5, 21], in studies of the reaction to a complex stimulus stimulator's lights stuck on the windscreen were used. In recent years, studies on the roads or tracks rely more often on the implementation of specified accident scenarios that were considered representative. The authors in previous papers [6, 13, 25, 26] presented this type of testing.

At this point the "observation" study in real traffic should also been mentioned. These studies often rely on analysis of records of a camera (for instance, monitoring) placed on the roads [23]. Results of evaluation (reaction time) here, however, strongly depend on observer's arbitrary assumptions as to the time of the initial emergency situation, and therefore the stimulus.

Development of simulation techniques, increase of computer and systems productivity to generate images allowed to use virtual research environment for testing drivers - driving simulators. Their use increases the independence of weather conditions, promotes the growth of reproducibility of results and test conditions [6, 17, 22]. It also allows for implementation of virtually any scenario without jeopardizing safety. Moreover, the experience of the authors indicate a strong correlation of research results in a simulator and a real car on a test track [6, 13].

To conclude this brief review of the literature, it can be stated that there is a need for research in which the reaction times will be determined not to a stimulus or the system of simple stimuli, but to a certain simulated risk accident situation. The number of available results in the literature for this type of testing is low and comprise a selection of special cases.

### 3. Tests characteristics

The project carried out research for three selected scenarios for risk accident situations. They have been conducted both on Kielce Track, as well as in an autoPW driving simulator. A common feature of the scenarios was the obstacle appearing suddenly and with further reduced visibility. The scenarios differed in the type of an obstacle (car, pedestrian, a set of tractor-trailer), the nature of traffic obstacles and other elements on the road, which influenced the complexity of the situation. Over 100 people have been tested in each scenario. As already mentioned, both track and simulator tests have been performed on tested drivers. Moreover, in both research environments, tests were made for different values of initial risk time conditions (ratio of the distance from the obstacle to the speed of a car being driven by test driver).

This paper presents the results for the third scenario, which was performed in an autoPW driving simulator. Test sample has been shown in Figure 1.

In an attempt mapped a situation in which a truck (a set of tractor-trailer) passed perpendicularly through the crossroads of two-lane carriageway in such a way that both lanes were blocked. The view of a transverse road has been severely limited. The road barriers were set on the left lane with typical markings for road works. The task of drivers during the research was an attempt to avoid a collision with an obstacle, but the way to do it has not been imposed on them. The method of arranging the situation in practice, eliminated the option of choosing another defensive manoeuvre than the emergency braking (so-called emergency brake). Such an accident situation scenario was introduced as a result of the analysis of previous work by the authors [6, 7, 25, 26] and consultations with experts in the field of traffic accident reconstruction. The experts and court experts stressed the need to conduct studies in which the only reaction is hard braking, because regardless of the nature of the accident situation, it is definitely the most common defensive manoeuvre used by drivers.

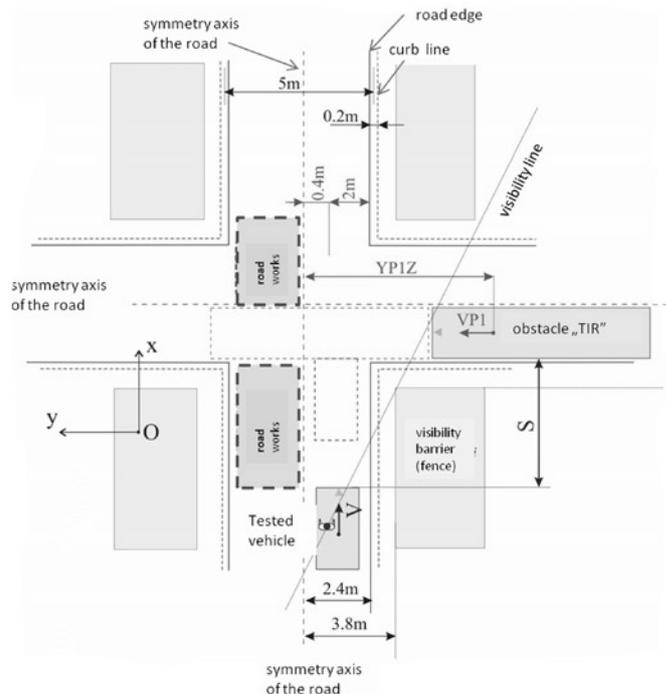


Fig. 1. Sample scheme for simulator tests (for scenario III)

For comparison, in the other scenarios that have been considered, the overall concept of the situation was similar – an obstacle which suddenly appears from the right side (car and pedestrian) at

the crossroads. The avoidance manoeuvre was possible in the above-mentioned situations.

The study was carried out in an autoPW driving simulator, built and operated at the Department of Transport, Warsaw University of Technology [3, 17, 30]. It is the laboratory stand which allows the testing of drivers in staged traffic conditions, even in pre-accident traffic situations [3, 8, 9, 17, 30].

Basic elements of the simulator:

- natural drivers's cab coming from a middle class car with a set of equipment, the main screen and a secondary (side) on which is displayed (using a projector) an image seen through the windscreen (the viewing angle in the horizontal plane is over 90 degrees), the arrangement of position sensors of the vehicle controls (accelerator, brake, clutch, gear lever, switches, dashboard),
- computer chip simulator and data acquisition system for the exchange of information between the sensors and the computer system.

Vehicle motion is simulated in a computer system based on data from the sensors (which measure the values that characterise drivers), and data describing the vehicle and road conditions. The image seen by the driver is generated according to his actions and planned surrounding scenery, sound effects and state of the dashboard indicators. The activities of the tested driver are monitored and recorded. The autoPW simulator is a static type and the cab of the vehicle remains still during simulator operation (the driver does not feel body inertial stimuli). The mathematical model of the vehicle used in the simulator [17, 18] describes the dynamics of a vehicle. It has been positively verified experimentally for typical tests recommended by ISO [10]. Details of its construction can be found in sources [3, 17, 30].

Graphic capabilities of an auto PW driving simulator enable accurate graphical model a real crossroads. The crossroads of two streets in Warsaw has been selected for the above-mentioned studies. Images in the simulator were built based on photographic documentation of a crossroads and its surroundings. The geometric-spatial parameters and objects' colours have been reproduced in an exact way.

Studies have been conducted for the data corresponding to a FSO Polonez vehicle. Importantly, the simulator cab came from this car. The possibility of subsequent comparison of results obtained in the simulator for the study on Kielce Track where the same car was used, has also been of importance.

Tests have been conducted on 107 drivers:

- drivers under the age of 25 years - 76 people in a sample;
- drivers between the ages of 26 to 35 years - 11 people in a sample;
- drivers aged 36 to 45 years - 10 people in a sample;
- drivers aged over 46 years - 10 people in a sample.

J Risk time has been taken as the basic parameter characterizing the test. This parameter is described in earlier publications by the authors, for instance [6, 7, 13, 14, 25]. In some English-language publications can be found under the name of TTC (Time To Collision). The

Table 1 Realised risk time values for each sample during the test

Sample no.:	1s	2s	3s	4s	5	6s	7	8	9	10	11
Risk time, [s]	0,3	0,35	0,4	0,45	0,5	0,55	0,6	0,72	0,8	0,9	1,0
Speed of a tested vehicle V, [km/h]	60	51,4	45	40	36	65	60	50	45	40	36
Distance from an obstacle in the time of its appearance S, [m]	5	5	5	5	5	10	10	10	10	10	10
Sample no.:	12	13	14	15	16	17	18	19	20	21	22
Risk time, [s]	1,2	1,44	1,8	1,8	2,0	2,16	2,4	2,7	2,88	3,0	3,6
Speed of a tested vehicle V, [km/h]	60	50	40	60	36	50	60	40	50	60	50
Distance from an obstacle in the time of its appearance S, [m]	20	20	20	30	20	30	40	30	40	50	50

tests were conducted for 22 risk time values from  $0.3 \div 3.6$  obtained as combinations of vehicle speed and distance from the obstacle, that is:

- speed of the tested vehicle: 36, 40, 45, 50, 51.4, 60 and 65 km / h,
- distance from the vehicle when the driver noticed the obstacle: 5, 10, 20, 30, 40 and 50m.

Summary of test parameters has been shown in Table 1.

Figure 2 shows the example of research in the simulator (view "from above"). The sequence shown in these four images (frames) illustrating the course of a sample.

Tests for individual risk times (TTC times) have been randomly (from the standpoint of the test) mixed, while maintaining the same order for each driver. In this way (including the so-called "empty-pass") approximately 2500 tests have been conducted.

The values characterising the tested vehicle, obstacles and values describing drivers's actions on car controls have been recorded. Fig. 3 shows a record of selected parameters for the sample shown in fig. 2 (an interesting aspect was pulsating action of the driver on the brake pedal seen in fig. 3d). These recordings were the basis for the analysis of driver behaviour. This study has been limited to the size of main evaluated value - reaction time.



Fig. 2. Case study sample, risk of 1.8 s duration, vehicle speed 60 km/h, distance from an obstacle 30 m, the attempt ended without collision

#### 4. The analysis of drivers' reaction times

Relationships characterized by reaction times were determined for the entire population of tested drivers. As described earlier, the specifics of the road situation in practice dictated one kind of behaviour: reducing traffic speed without the possibility of bypassing the obstacle. Therefore the following reaction times were determined:

- reaction time on the accelerator, understood as the time from the onset of the obstacle to the beginning of the leg off the ac-

- accelerator pedal, in short: "acceleration" reaction time or mental reaction time ("trg" in Figure 4);
- psychomotor reaction time during braking, as the time from the emergence of obstacles to the onset of force on the brake pedal, in short: "brake" reaction time ("trh" in Figure 4);
- motor reaction time during braking, determined as the time from the start of removing the foot from the accelerator pedal to the onset of force on the brake pedal, in short: motor reaction time ("trm" in Figure 4).

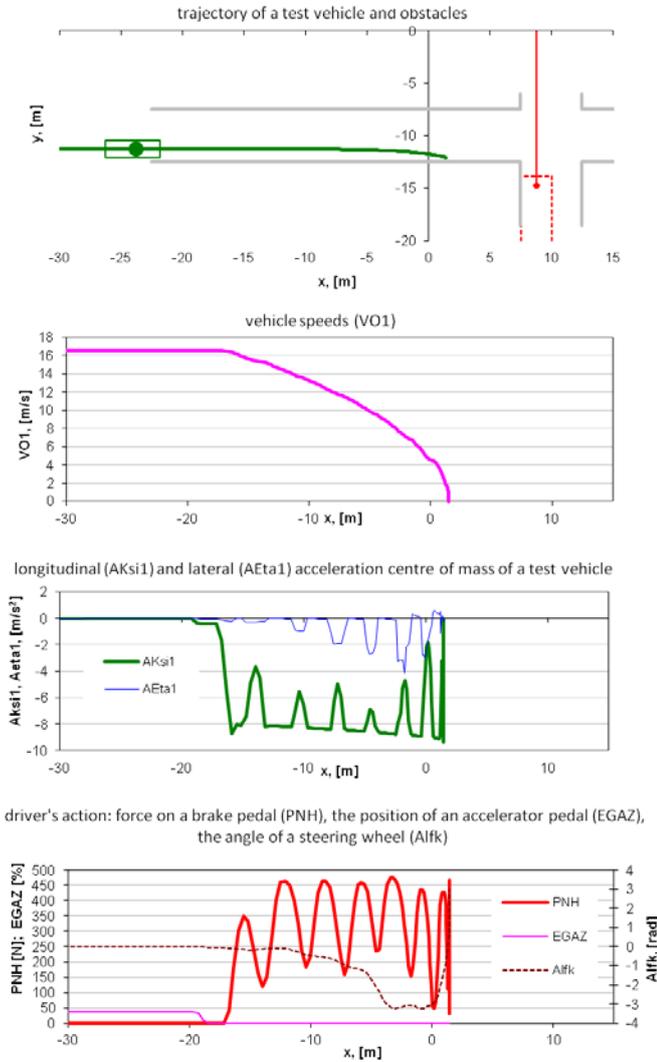


Fig. 3. Selected physical quantities recorded in a sample shown in fig. 2 (risk time 1.8 s), vehicle speed 60 km/h, distance from an obstacle 30 m vehicle speed 60 km/h.

Table 2. Order of tests' realisation

Sample no. according to order of realisation:	1	2	3	4	5	6	7	8	9	10	11
(sample no. according to risk time – tab. 1):	(14)	(13)	(12)	(11)	(10)	(9)	(21)	(22)	(20)	(18)	(15)
Risk time [s]	1,8	1,44	1,2	1,0	0,9	0,8	3,0	3,6	2,88	2,4	1,8
Sample no. according to order of realisation:	12	13	14	15	16	17	18	19	20	21	22
(sample no. according to risk time – tab. 1):	(4)	(2)	(1)	(3)	(16)	(17)	(19)	(5)	(6)	(7)	(8)
Risk time [s]	0,45	0,35	0,3	0,4	2,0	2,16	2,7	0,5	0,55	0,6	0,72

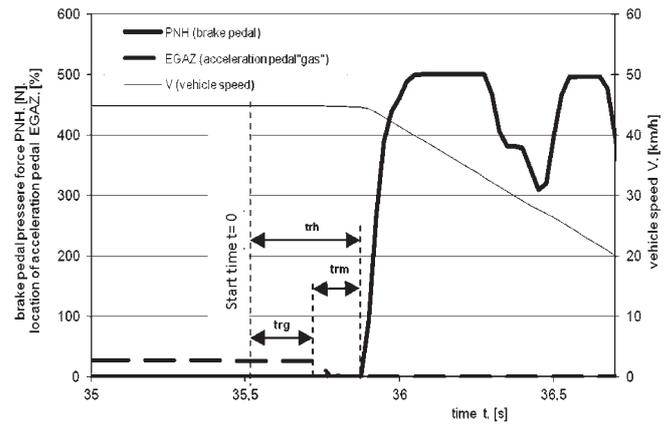


Fig. 4. Excerpts of selected waveforms recorded during a test - illustration of reaction times: trg – accelerator pedal reaction time "gas", trh – "brake" pedal reaction time, trm - motor reaction time

Figure 5 shows the "acceleration" pedal reaction times. The average values of this reaction time varied in the studied range of risk time from approximately 0.25 ÷ 0.6 s

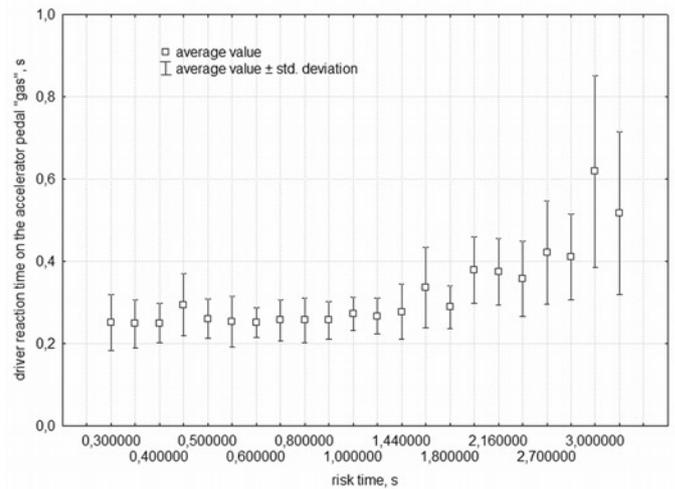


Fig. 5. Acceleration pedal reaction time "gas" in a risk time function

In terms of the risk time value of 0.3 ÷ 1.2 s it can be considered that they have taken approximately constant level of approximately 0.25 s. In terms of risk time over 1.2 s, average reaction time values increased approximately linearly in a risk time function. Similar qualitative conclusions were formulated in relation to standard deviation. For risk time smaller than 1.2 s, the standard deviation was at an approximately constant level, amounting to 0.045 ÷ 0.06 s, and then

began to rise to approximately 0.2 s, for the biggest analysed risk time of 3.6 s.

Deviations from described regularities occurred for risk times: 3.0 s 0.45s. For these tests the average and standard deviation values have taken a noticeably greater values than would appear from the trends described. Explanations of this phenomenon can be sought in the order of test implementation. As mentioned earlier, tests for subsequent risk time values have been mixed, but the same order for each of their drivers has been retained.

Schedule for each test are shown in table 2. This table identifies four specific tests, of whose distinctive feature was a big change of parameters compared to the previous test (mainly risk time).

The test of 3.0 s risk time was an attempt no. 7 and was performed after a few tests of increasingly less risk time value at the level of 1.0 to 0.8 sec. This could result in an additional surprise effect of a tested driver, as shown in the chart. A similar situation (large changes in the parameters of the sample) was at the test of 0.45 s risk time. This test was performed as no. 12 immediately after a series of tests with large values of the risk time: from 3.6 to 1.8 s

This time, the rapid changes in risk time also appeared with tests 2.0 s risk times (performed after several tests at risk times of 0.3-0.4 s) and 0.5 s (immediately after the tests of 2.7 s risk time). Interestingly, in these cases there were no visible changes of average values and standard deviations of reaction time.

Interesting was also the observation of phenomena tentatively named by the authors' "first attempt to effect". Previously conducted studies at initial drive time values, which differed significantly from the described trend (were larger) [10, 11]. Here, this effect has not been observed. The reason for that could be that the participants already had previous experience with this type of testing. We could observe a factor associated with the "adaptation" to the simulator and the arrangement of the accident situation. Another factor that has been considered was a relative simplification of this scenario in relation to the scenarios I and II. In practice, the only option of a driver was a violent braking reaction.

Mental reaction time values were at a similar level to that achieved in previous scenarios (for instance [10, 11]), where the driver can also bypass the obstacle.

Figure 6 shows the average values and standard deviations of psycho-motor reaction time (reaction time on the brake pedal) in a risk time function. Qualitatively, dependences shown in this figure were similar to those shown in fig. 5, however, the values obtained were higher. Average values of psycho-motor reaction time varied in the range of  $0.42 \div 0.92$  s. Standard deviation values ranged from approximately 0.05 to 0.29 s. In this case the tendency to "stabilize" at a constant level of average values and standard deviations for the range of small risk time values was less evident. There was a large variation of concentration of reaction time distribution values around the average value. The measure of this concentration were the standard deviation. Its greatest value was almost 6-fold greater than the smallest value.

The described earlier deviation from the general trend also observed for the test of 3.0 s risk time and to a lesser extent also for .45 s test. Regarding the results of this study to the results obtained in other scenarios [10, 11] very similar waveforms were also found. In the case of scenarios I and III ranges changes the reaction time have almost overlapped.

Motor reaction time values have been shown in figure 7. Average values of this reaction varied, for the investigated time range of risk time, from  $0.20 \div 0.34$  s, while standard deviations ranged around  $0.04 \div 0.15$  s. For risk time greater than 1.0 s was observed a clear upward trend for both the average values, as well as for standard deviations. For smaller risk time values, both average values and standard deviations of the motor reaction time were approximately constant (average of around 0.2 s; deviation of  $0.04 \div 0.06$  s). An interesting fact was

that in case of motor reaction, there was the lack of deviations from the general trend for the risk 3.0 times and 0.45 s.

Comparing the results for Scenario III with the effects of previous tests (scenarios I and II) waveforms were very similar both qualitatively and quantitatively [10, 11].

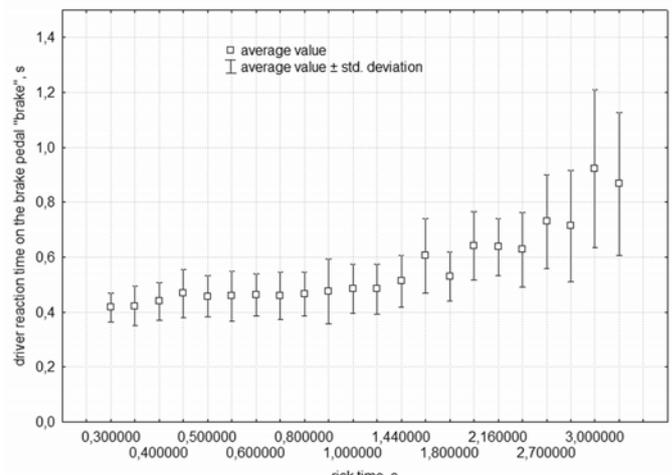


Fig. 6. Psychomotor reaction time (reaction time "brake") in a risk time function

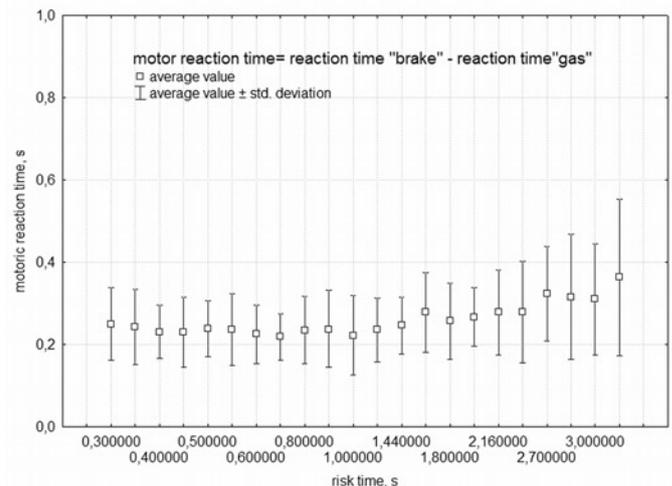


Fig. 7. The reaction times of drivers' motor reaction in risk time function

## 5. Summary

The presented results of drivers' tests for a particular scenario of an accident situation, support the view that the accident situation can be characterized by a risk time parameter. Similarly, as in previously conducted studies [6, 7, 8, 25] on smaller population of tested drivers and the research carried out for accident situations (the so called I and II scenarios [10, 11, 28]) the higher the risk time, the higher not only presented average reaction times but also the standard deviations that is their diversity increases - the dispersion of times distribution.

Another important observation is the quantitative similarity of the results obtained in the study of emergency braking to the results obtained in the scenarios (I and II). Average values of reaction times on the accelerator, the brake pedal and the motor reaction are at a similar level for particular risk times in all scenarios.

The last remark concerns the applied research tool - a driving simulator. The experience gained in the course of this study suggest that it might be a good tool to assess the behaviour of drivers in dan-

gerous traffic situations [4]. Despite the many flaws (animated image, lack of inertial stimuli in an autoPW static simulator, "the artificiality" of the situation), the results obtained with its help provide important information about the behaviour of drivers in such situations. In this simulator you can perform tests that in the real world are not feasible or dangerous [1, 29]. On the other hand, the use of the simulator will be fully justified after checking whether there is a correlation between the results obtained on this unit and performed tests on a test track. Its presence has been demonstrated previously for the average reaction time [6, 13]. Analysis should be conducted to verify whether a correlation exists also for a number of tests carried out with one driver in both environments.

This paper concentrates on the drivers's reaction time associated with the implementation of the process of emergency braking. The amount of gathered data during the investigation allows a much wider analysis of driver behaviour. Such works have been in progress. They concern the variation of time on different parts of the vehicle controls (pedals: accelerator, clutch, steering wheel). The analysis also concern the way of reaction, its "intensity" and the efficiency for the parameters characterizing the event (scenario, risk time, speed, distance from an obstacle, etc.). Intra-individual characteristics of respondents - age, professional qualifications, experience in driving, etc. have also been taken into account. The partial results of these studies were published in [9, 10, 11, 15, 26, 27, 28].

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