Assessment of Drivers' Reaction Times. Tests on the Track and in the Driving Simulator

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This paper describes research studies analyzing the behaviour of drivers in the simulated accident risk situation. The study was conducted in two environments: on the Kielce Car Test Track and in the driving simulator autoPW of Warsaw University of Technology. The same 3 (different) situational scenarios of accidents were performed in both environments and the same group of 100 drivers was examined. Each of the examined persons performed the same set of tests, randomly ordered, carried out for various values of the time TTC (time to collision), received as combinations of the tested vehicle velocity and its distance from the roadblock. The vehicle speed was changed within the range from 36 up to 60 km/h, and the distance of the vehicle from the first roadblock from 5 up to 50 m. The paper presents exemplary results of the research studies.

1. PREFACE

One of the basic methods used by experts in the reconstruction of road accidents is different types of mathematical models of the human-vehicle-environment system. The correctness of expertise, performed from purely human perspective associated with pleading someone guilty and imposing respective punishment, is also of great economic importance that is related to compensations paid by the insurance companies.

Among the many factors affecting the accuracy and credibility of the analyses of accidents conducted with such methods, the most important include: the complexity of models – car motion model, model of human activities, crash model and others, here also the so-called "validation" of models, timeliness and accuracy of estimates of input data; expert skills and knowledge.

Among the input data, one of the key used in the computations that are carried out in the process of reconstructing the course of the accident is the "reaction time", i.e. the time that elapses from the moment of the risk occurrence until the driver starts reacting towards the vehicle control mechanisms. The research studies aim to develop and update a database of reaction times, but also the behaviours of drivers of road vehicles are the subject of this paper. The studies were carried out under the research project N509 016 31/1251. They were made by three teams: the Kielce University of Technology (the leader), Warsaw University of Technology, and Cracow University of Technology.

2. DETERMINATION OF THE DRIVER'S REACTION TIMES

The manuals and training materials for forensic experts and experts of automotive technology and traffic, and data on drivers' reaction times are some of the fundamental data provided in the publications and used to analyze the course of road accidents. Most often they are, however, the results of reaction tests for the so-called simple stimulus (a single audio or light signal) while a driver's way of reaction is also simplified – it is to influence one of the car controls (brake pedal, handbrake lever, steering wheel) [1, 2, 9, 14]. The results of such research are often published as a recommendation to the experts, e.g.: [1, 15].

In real driving situations (excluding driving e.g. in the column on the highway, wherever we respond to the "stop" light of the car preceding to ours), the driver reacts to more complex stimuli. However, it is difficult to find data in the literature references 10-15 years backwards on reaction times where both the stimulus and the driver's reaction are complex (as in real life situations of any accident). Being conscious of this, tests were made of reactions to complex stimuli, but they were often highly simplified situations. For example, in the already quoted papers [2, 9], stimulators lights stuck on the vehicle windscreen were applied in the studies on reactions to a complex stimulus.

In recent years, studies that are carried out on the roads or rail tracks increasingly rely on the implementation of certain selected, recognized as representative, assumed accident scenarios. Authors presented those types of tests in their previous papers ([3, 6, 10, 11]).

A summary of this brief literature review can be concluded that studies are essential where the reaction times are to be determined not towards a stimulus or a set of simple stimuli, but towards a certain simulated accident risk situation. The number of results available in literature for this type of testing is small and includes some selected specific cases.

3. CONCEPT OF THE RESEARCH CHARACTERISTICS

The basic assumption of the studies was that reaction times would be determined towards a complex situation, not a simple stimulus. A real accident risk situation will be simulated through realisation of the selected scenarios. Three representative situations were selected for the realisation: collision with a pedestrian, with a passenger car, and with a truck. No modes of action were imposed on drivers during the studies. Depending on the assessment of the situation, they decided about what defensive manoeuvre is to taken (exclusively braking, exclusively circumventing the roadblock, or both activities simultaneously) and about its "intensity". The assumption was made that a special attention would be paid to the group of the greatest risk – namely young drivers (aged up to 25 years). The population of such drivers was dominant in the studies. The research was conducted in two environments: on the car testing track (real car – a simulated risk situation) and in the driving simulator autoPW of Warsaw University of Technology. It was assumed that the same pre-accidental situation scenarios will be realised in both environments as well as the same group of drivers will be tested therein. An important element will be to assess the correlation of results obtained in the car-on-the-track conditions and in the driving simulator.

When formulating the research concept the risk time notion was used (in some western publications, the time is also referred to as TTC – time to collision). It was also defined in previous papers of the authors [3, 6, 7] as the time allowed to the driver from the moment of having noticed a roadblock to a possible collision with it, and it can be used by the driver to undertake the defensive actions. In their earlier research studies [3, 10, 11], the authors proved that reaction times obtained during both tests on the track and in the simulator depend very clearly on the risk times. This means that the driver when assessing the situation is guided separately neither by driving velocity nor a distance from the roadblock but is aware of the reaction time in which decisions are to be taken. When the driver realises that there is more time, then a decision-making process is longer and most certainly it takes longer for the driver to respond. It was also found in those studies that probability of a decision to be taken by the driver on the choice of a defensive manoeuvre (braking or circumvention) depends on the risk time.

Based on previous experiences [3, 10, 11], a range of the risk time was assumed in the presented research studies from 0.3s to 3.6s. No trials were made in tests on the driving track with the risk time lower than 0.5s for safety reasons. The assumed value of the risk time was obtained by the mutual combination of the value of velocity at which the tested vehicle was moving with and the distance from the roadblock at the time of having noticed it. Parameters of individual trials are presented in Table 1.

Pursuant to the summary provided in Table 1, 17 attempts were made on the track and 22 trials in the simulator. To avoid the routine effect and in order to introduce some element of surprise, the tests were mixed randomly, and additionally the so-called "empty runs" were added. The population of 100 drivers (men) was tested where young drivers (aged up to 25 years) were a dominant group.

The tests were carried out for three accident risk scenarios, taking place at the intersection of two double-lane, two-way roads with a limited visibility

Table 1. Realised initial values of risk time for individual trials while testing

Trial No. (s – trials in driving simulator only):	**1s**	**2s**	**3s**	**4s**	5	**6s**	7	8	9	10	11
Risk time, [s]	**0.3**	**0.35**	**0.4**	**0.45**	0.5	**0.554**	0.6	0.72	0.8	0.9	1.0
Velocity of tested vehicle V, [km/h]	60	51.4	45	40	36	65	60	50	45	40	36
Distance from roadblock at the moment of occurrence S, [m]	5	5	5	5	5	10	10	10	10	10	10
Trial 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
Velocity of tested vehicle V, [km/h]	60	50	40	60	36	50	60	40	50	60	50
Distance from roadblock at the moment of occurrence S, [m]	20	20	20	30	20	30	40	30	40	50	50

to the right and left. Closer description was given in section 5 of paper. 100 different drivers in 3 different scenarios were tested and more than 13 000 trials (driving runs) were made.

4. DRIVING SIMULATOR autoPW

The car driver simulator autoPW is situated in the Vehicle Traffic Simulation Research Lab at the Warsaw University of Technology Faculty of Transport [8, 16]. It is a laboratory station allowing for testing a driver staged vehicle traffic conditions, including in pre-accident traffic situations. The basic elements of the simulator are as follows:

- natural driver's cabin originating from a medium-class passenger car with a set of furnishing elements (Fig. 1), main and auxiliary (side) screens on which image is projected (via projectors) that is visible through the windscreen of the car (sight angle in horizontal plan is about 90°), a system of vehicle control elements position sensors (acceleration pedals, brake, clutch, gear shift lever, dashboard controls),
- computer system of the simulator and data acquisition system serving information flow between sensors and the computer system.

The simulator autoPW is the static simulator, the vehicle cabin remains motionless during the work of the simulator (the driver does not feel with their body any inertia stimuli). The mathematical model of the vehicle that is used in the simulator [8] describes the vehicle motion dynamics. It was positively experimentally verified for typical tests recommended by ISO. The construction details are available in reference sources [8, 16].

5. APPLIED TEST SCENARIOS

As mentioned before, 3 scenarios of accident risk situations were realised:

- Scenario I: a passenger car entering the

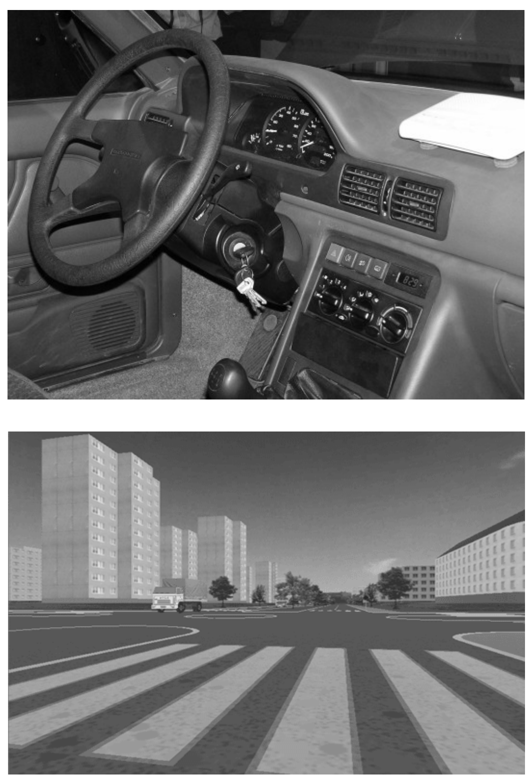

Fig. 1. Inside of the car cabin in the driving simulator and example of scenery mapping in the simulator

intersection perpendicularly from the right side, while another car moves on the left lane from the opposite direction towards the tested vehicle;

- Scenario II: a pedestrian, an adult perpendicularly enters the road (on the right traffic lane);
- Scenario III: a large truck passing perpendicularly through the intersection with 2-lane carriageway, so that both lanes are blocked.

Graphic capabilities of autoPW driving simulator [8], allow for graphical mapping of the actual road junction. The intersection of Kosiarzy and Piechoty Łanowej Streets, located in Warsaw, was selected for testing. The picture of the intersection and the way of its mapping in the simulator was illustrated in Fig. 2. Images of single-family houses in the simulator were built based on natural images. Also, the geometrical-spatial parameters (mutual distance, width of roadway, sidewalk, etc.) and colours were accurately reproduced.

In order to be able to compare later the results obtained on the track and in the simulator, the Polonez car (that was used in tests on the Kielce testing track) data was entered into the vehicle dynamic model in the simulator. While testing on the track, the car was equipped with appropriate measurement apparatus allowing to record car motion parameters and impact of the driver on the control mechanisms. The „safe" mock roadblocks that had been created especially for those tests had dimensions of actual roadblocks. A special system for their guiding and driving was designed.

In the already mentioned tests, and described in [3, 10, 11], a scenario was realised involving a sudden appearance of the roadblock in the form of a passenger car entering from the side (right side). Then a slightly different scenario was additionally tested in the simulator, which gave the drivers a choice, a possibility of making more defensive manoeuvres. Analysis and the choice among several options became a certain difficulty for the tested drivers. It turned out that the little difficulty caused, although a small increase but a clearly observable one in reaction times. A decision was made to verify the result, also in tests on the track. The first out of the currently realized scenarios is a more difficult variant of the basic scenario of the quoted tests. The difficulties introduced involved:

– the left traffic lane is occupied by the second roadblock – the car approaching from the opposite direction larger than the passenger car;
– the first roadblock „enters" into the traffic lane that is used by a moving tested vehicle at a distance of 2 m (0.5 meter deeper than in the previous tests);

Figures 3 and 4 illustrate sample images of the scenario I realisation in the simulator and on the track.

Fig. 2. Intersection of Kosiarzy and Piechoty Łanowej Streets in Warsaw (the actual image and mapping in the simulator)

Fig. 3. Realisation of scenario I in the simulator (selected images from one of the trials)

Fig. 4. Realisation of scenario I on the track (selected shots from one of the trials)

The rationale for the selection of scenario II were the already mentioned results of earlier tests in which differences of reaction times could be observed depending on the level of the scenario complexity. It was decided to examine whether there is a difference in time and how drivers react to a situation in which there is a risk of collision with a car and a human being. A major problem was matching of the human figure movement velocity, due to the assumption that the experiments conducted shall be characterized by a substantial degree of risk time. If we assume that the speed at which adult male moves walking normally, for example, is 1.5 m/s [15], then for trials of the shortest value of the risk time a dummy would still be on the sidewalk (which was 1m wide), so the driver could pass by, while at the longest times - the dummy would have already moved on the left lane

Fig. 5. Realisation of scenario II in the simulator (selected images from one of the trials)

Fig. 6.Realisation of scenario II on the track (selected shots from one of the trials)

of the carriageway, and therefore it would require only to slightly brake and continue driving one's own lane. It was adopted as a unifying principle for all the trials that whenever the car has reached the roadblock level, the pedestrian silhouette should be located near the centre of the right traffic lane. In this way, a common feature of all trials was the opportunity to choose only one out of three manoeuvres: braking, circumventing from the left hand side, or braking connected with circumvention from the left hand side. Location of the pedestrian made it impossible to bypass him or her from the right hand side, even in trials that were characterised by a long risk time. Figures 5 and 6 illustrate exemplary images of the scenario II realisation in the simulator and on the track.

The third testing scenario (Fig. 7, 8) differed from the previous ones not only by the kind of the roadblock. In contrast to the earlier scenarios, in this case the choice of a defensive manoeuvre was

Fig. 7. Realisation of scenario III in the simulator (selected images from one of the trials)

Fig. 8. Realisation of scenario III on the track (selected shots from one of the trials)

eliminated. Blocking of both traffic lanes enforced the only reaction – emergency braking. The scenario was introduced after consultations with experts. In their opinion, a situation in which emergency braking is the only reaction is a frequent case in analyses of the actual accidents. The effect of traffic lanes blocking is obtained by a passage of a roadblock through the intersection and exclusion of the left side of the road from traffic using the "construction works" sign.

6. EXEMPLARY RESULTS OF MEASUREMENTS

The accumulated large number of the measurements results allows for a broad analysis of the psychophysical properties of the drivers. Fundamental analyses may involve such properties as the driver's reaction time, effectiveness of defensive actions taken, nature of those actions and so on. Here are sample results achieved. This is a list of drivers' reaction times on the brake pedal (for the whole population of examined drivers) as a function of risk time obtained for the testing scenario I – Fig. 9 and Fig. 10.

Out of the most relevant comments on the results presented, the attention should be paid to the dependence of the driver's reaction time on the risk time. For longer times at risk, both the average value and the standard deviation of the reaction time on the brake pedal keep growing. The

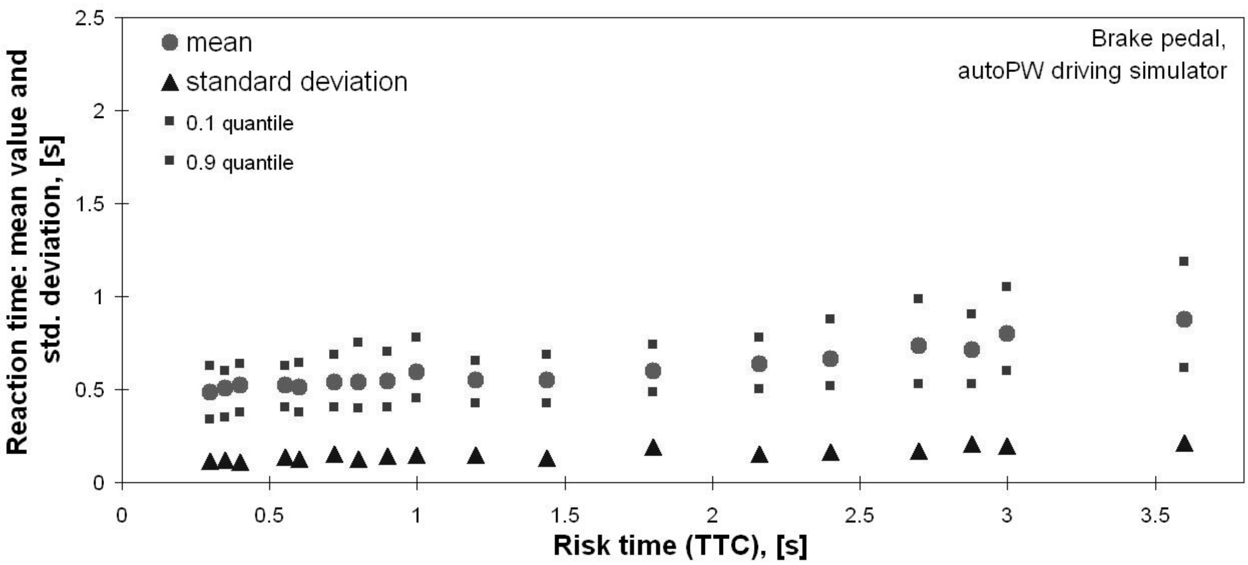

Fig. 9. Reaction time on the brake pedal for scenario I, in driving simulator

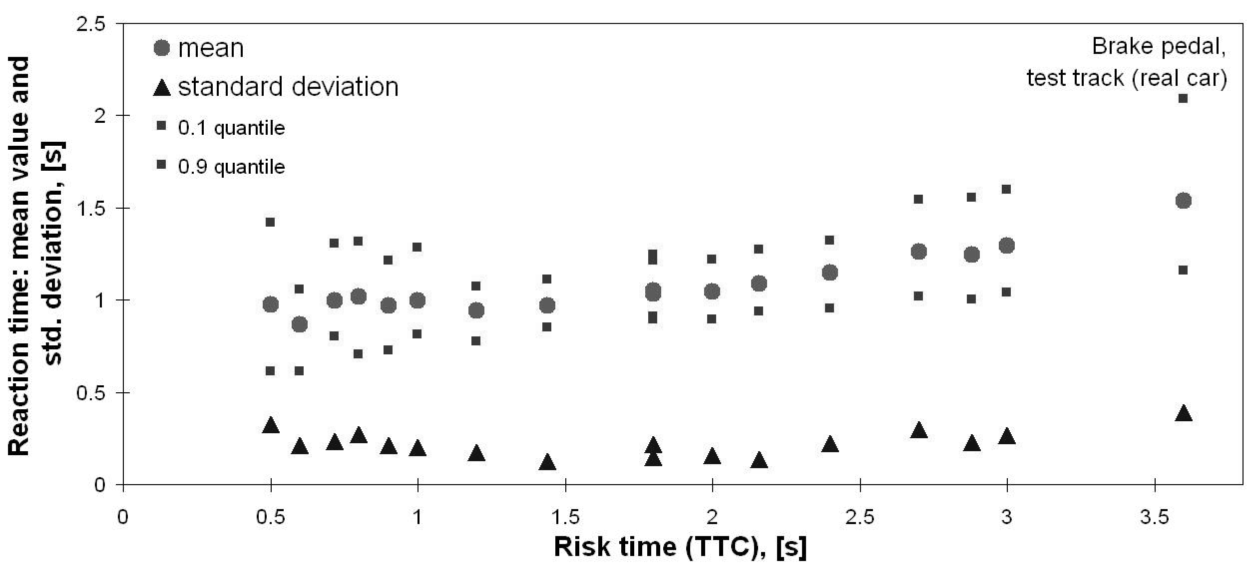

Fig. 10. Reaction time on the brake pedal for scenario I, tests on the track

qualitative similarity of the above dependence for tests in the simulator and on the track is visible. Quantitatively, the reaction times in the simulator are slightly shorter. Those are observations that confirm the conclusions of the previous papers written by the authors [3, 10, 11] where they pointed out to the strong correlation of research results in both testing environments.

More detailed and more extensive analyses of the testing results are the subject of ongoing works, and some are already available e.g. in [4, 5, 12, 13].

7. CONCLUSION

The research studies described above and conducted under the project N509 016 31/1251 were implemented for 3 scenarios of the accident situation in two testing environments: the Kielce Car Test Track and the driving simulator autoPW. 100 different drivers in 3 different scenarios were tested and more than 13 000 trials were carried out. The scope of research studies, conducted by the authors, can be considered as very extensive. This related to a need of synchronising many organisational activities. Particularly troublesome were tests performed on the track, because many times the weather was not sufficient to conduct individual tests, but there were also some cases where the whole series of trials had to be cancelled. The authors used many new solutions such as the way of pedestrian traffic animation in the simulator testing. The specially constructed safe mock roadblocks along with their guiding and driving systems were used in testing on the track. An extensive research material was gathered, which shall be analyzed successively. The results obtained will enable the development and update the database on both reaction times and shall determine the way how drivers react in accident risk situations.

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