RESEARCH ON BEHAVIOUR OF DRIVERS IN ACCIDENT SITUATION CONDUCTED IN DRIVING SIMULATOR

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Abstract

Following any type of statistics, the human being (a driver) is the weakest element of the man - vehicle – environment system. The paper discusses research on drivers' behaviours in pre-accident situations, conducted in driving simulator autoPW under the research project MNiSzW N509 016 31/1251. Tests have been performed in a staged situation of danger involving unexpected emergence of an roadblock - passenger car into the road area, with a simultaneous limitation of space for making a passing-by manoeuvre on the opposite traffic lane, which was caused by the fact that a delivery vehicle was approaching on the lane. The work presents issues that are related to the preparation of research scenario by realising vehicle traffic in the way assuring the probability of individual tests. Basic features of the autoPW car driver simulator have been characterised. The modifications, introduced in the simulator for purposes of the research, have been discussed. Selected research results – the probability diagrams of occurrence of a specific type of collision, depending on the so-called risk time (potential time that a driver has to avoid the collision), have been presented. The diagrams indicate a clear boundary beyond which avoidance of the collision becomes practically impossible. The results obtained have been compared to results of research being similar in their character, conducted in another research centre.

Keywords: *driving simulator, pre-accident situations, driver behaviour, driver reaction times*

1. Introduction

Accident statistics that are published annually by the Chief Police Station (KGP) indicate that vehicle drivers are the main causes of accidents on our roads. Therefore, traffic safety improvement should be related to change in drivers' behaviour (inter alia in a higher feeling of responsibility for your own behaviour and decisions that you make).

While in the area of accidents reconstruction, experts assume (based on both post-accident evidence as well as testimonies of witnesses, and also own knowledge and experience and literature) a defined way of behaviour of the driver in a given accident situation that is analysed. They also assume for reconstruction purposes, certain values of parameters that characterise that behaviour (e.g.: the way of reaction, reaction time, „intensiveness" of the reaction, etc.) [10, 11, 16, 18].

Recognition of the way of drivers react in accident situations is therefore demanded, however, this type of research is conductible in various ways. Tests in natural traffic conditions seem to be the best ones. However, it is dangerous and costly. Research studies on a test track, without involvement of traffic, are another way. Such form of tests is applied by many scientific institutions and research departments of vehicle manufacturers. An inconvenience that is linked to this type of research studies is dependence on whether conditions, season of the year, and difficulties in access to the track. A need of mapping a given accident situation is linked to high costs.

Development of simulation techniques, increase in computer capacity and image generating systems have allowed for building a virtual environment of driver research studies – car driver simulators. Application of such tool increases independence from weather conditions, and facilitates higher repeatability of results [3, 7, 12, 17]. However, such method is not is not free of disadvantages, e.g.: simplifications of the simulator compared to reality. If, however, there is a correlation of results that are obtained in the simulator with results of road tests (and such has been confirmed by the authors in their research studies, described in [3, 4, 8, 9, 12]), then such a method may be treated as supplementation of the road tests, and as a better research method in some especially dangerous situations.

The main goal of the hereto referred to research study is an update of a data base related both to reaction times of various drivers, for different pre-accident situations [14, 15], type of defence manoeuvres that they make, and their "intensiveness", etc.

The paper presents research on behaviours of drivers in the car driver simulator *autoPW*, conducted jointly by teams from the Warsaw University of Technology and Kielce University of Technology. The research involved an assessment of both the response time and the way of drivers' behaviour. Analogical research studies for the same scenario have been conducted while making tests on the Kielce Test Track.

2. Driving simulator *autoPW*

The driving simulator *autoPW* is situated in the Vehicle Motion and Dynamics Simulation Research Lab at the Warsaw University of Technology, Faculty of Transport [1, 7, 12]. It is a laboratory station allowing for testing a driver in 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 front windscreen of the car (sight angle in horizontal plane 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.

Fig. 1. Inside of the car cabin in the simulator

The computer system of the simulator consists of two PC computers. Vehicle motion is simulated in the main computer on the basis of data being fed from the sensors (measuring the quantities that characterise actions performed by a driver) and other data describing the vehicle and road conditions. Moreover, the computer generates image that is visible by the driver, respectively to their actions and planned background scenery (Fig. 2). The standard OpenGL („open graphic library") is applied herein. The auxiliary computer serves generating sound effects, monitoring of driver's actions, and entering indications of control lamps readings on the vehicle dashboard by the instructor supervising the tests. 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 [11, 12] describes the vehicle motion dynamics. It was positively experimentally verified for typical tests recommended by ISO [6]. The construction details are available in reference sources [1, 7, 12].

Fig. 2. Examples of scenery mapping in the simulator

3. Research Characteristics

The research tests have been made for a group of 100 drivers out of whom 70 aged up to 25 years, 10 at the age between 26-35, 10 aged 36-45, and 10 more than 46 years old.
The vehicle parameters, entered into the simulator, corresponded to the middle-class passenger car that was used in identical tests on the Kielce test track.

A pre-accident situation, involving an unexpected emergence of the roadblock in a form of a passenger car driving in from the side, was selected to conduct the tests. The vehicle was suddenly emerging from the perpendicular street from the right side. Such situations happen relatively often in single-family house settlements that are highly fenced or hedged, or at other crossroads at which a row of trees growing on the street sides or a parking high vehicle strongly limit visibility. In order to bring conditions of the experiment in the possibly closest extent to the reality, a decision was made to map the real crossroads in the simulator, corresponding to the situation described above. The picture of the selected crossroads has been illustrated on Fig. 3, and its mapping in the simulator – on Fig. 4.

Scenery of the crossroads was mapped in the simulator. The images of single-family houses have been made on the basis of natural pictures. Also, the geometrical–spatial parameters (mutual distances, width street pavement, sidewalk, etc.) and colours have been exactly mapped.

Fig. 3. The selected crossroads, located in Warsaw at Kosiarzy - Piechoty Łanowej Street

Fig. 4. View of the crossroads mapped in the simulator (sight angles on Fig. 3 and 4 are different)

The course of a single test was as follows: the driver had a task to drive the „tested vehicle" following a determined motion trajectory on the right side of the street at a specific velocity (Fig. 5). In a determined distance from the crossroads, the laterally moving vehicle make of Opel Zafira, marked as „roadblock 1", was emerging on the crossroads from the right side and then stopped, having "penetrated" 2m deep into the traffic lane area. In order to assure identical test conditions for many tests (with varying distances from the roadblock S and thus effecting „visibility line" of the driver in the tested car), the velocity of „roadblock P1" varied.

The drivers' task was to attempt avoiding a crash with the roadblock penetrating the traffic lane area; however, no way of responding to the occurring danger was imposed on the drivers. Depending on their individual, subjective assessment of a given situation, a driver was only able to brake, exclusively make the passing-by manoeuvre, or react in a complex way, using both types of actions with free „intensiveness." The passing-by manoeuvre was somewhat difficult due to the „roadblock P2" approaching from the opposite direction and thus limiting the space available for making the manoeuvre. Delivery vehicle Ford Transit was the roadblock P2. The task of the drivers was trying to avoid a collision both with roadblock P1, and P2.

Each driver performed 22 tests. The ***risk time*** was assumed as the basic parameter, characterising the test. This is the time that the driver has since the moment of having noticed the roadblock until a possible collision with it [8, 9]. The scope of change in this parameter was assumed from 0.3 s. to 3.6 s. Individual values of risk times were obtained as a combination of the vehicle velocity and a distance from the roadblock:

- driving velocity of the tested vehicle: 36, 40, 45, 50, 51.4, 60 and 65 km/h,
- distances from the vehicle at which the driver was noticing the roadblock: 5, 10; 20; 30; 40 and 50m.

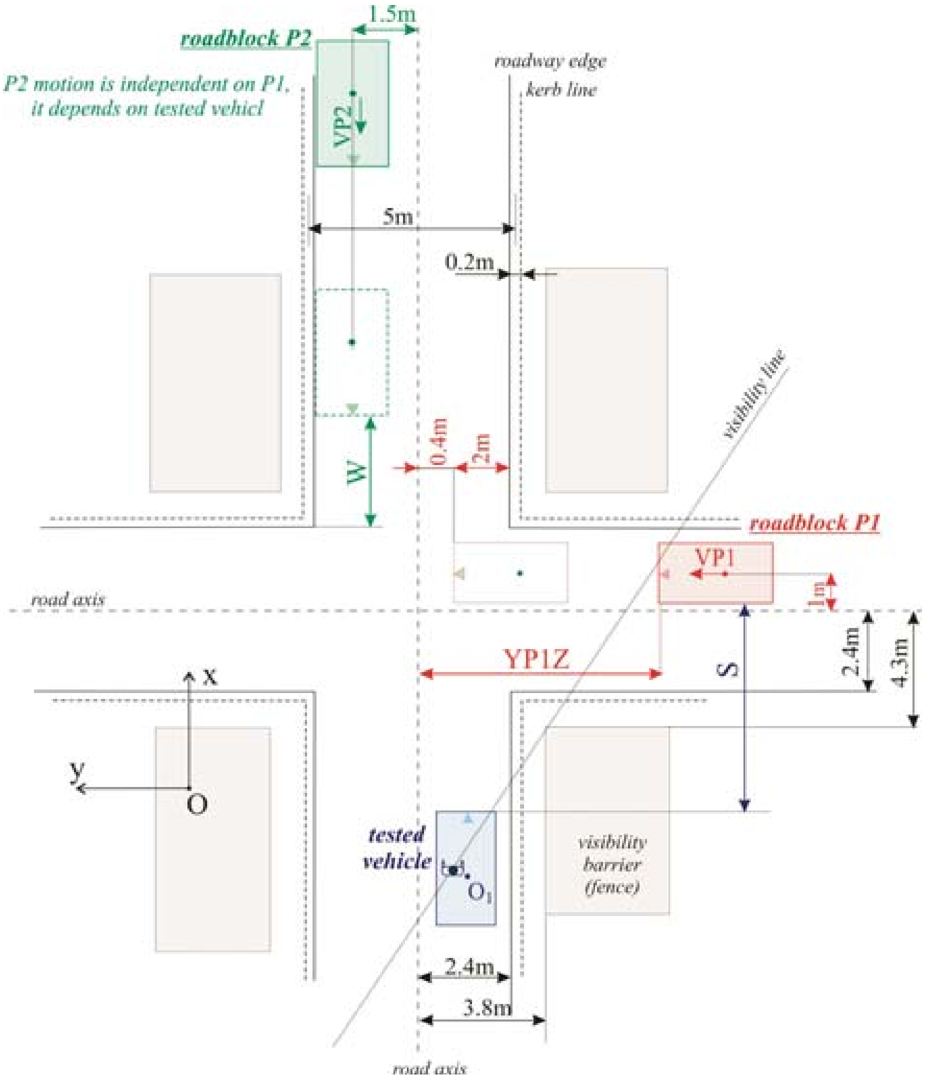

Fig. 5. Diagram of test for a scenario of research studies in the simulator

Parameters of tests that were conducted are presented in Table 1. In order to avoid routine actions performed by drivers during their subsequent attempts, their sequence was being changed in unordered way and unknown to the drivers, and moreover there were so-called „empty runs" that is, the ones whenever no roadblock occurred. Those attempts, which in identical tests on the track were not realised due to a danger posed on the persons being tested, were marked in bold. When preparing the research program, the authors were aware of the fact that it was almost impossible for the lowest risk time values to avoid collision. However, those attempts were introduced on purpose to examine whether in such situations the way of drivers' reactions is analogical to the situations where there is a chance of avoiding the collision, or may be it is different?

Almost 2500 attempts were conducted (along with the „empty runs") for the assumptions formulated above. Two examples of post-frame visualisation of the recorded drives are presented on Fig. 6 and Fig. 7.

Tab. 1. Values of risk times for tests considered in the simulator

Risk time, [s]	Vehicle velocity, [km/h]	Distance from roadblock, [m]
0.3	**50**	**5**
0.35	**51.4**	**5**
0.4	**45**	**5**
0.45	**40**	**5**
0.5	36	5
0.554	**65**	**10**
0.6	60	10
0.72	50	10
0.8	45	10
0.9	40	10
1.0	36	10
1.2	60	20
1.44	50	20
1.8	40	20
1.8	60	30
2.0	36	20
2.16	50	30
2.4	60	40
2.7	40	30
2.88	50	40
3.0	60	50
3.6	50	50

Fig. 6. Subsequent driving phases of the tested vehicle in accident situation in which the driver has failed to avoid the crash (Driver 089, V=60km/h, S=10m, risk time 0.6s)

Fig. 7. Subsequent driving phases of the tested vehicle in accident situation in which the driver has avoided the accident (Driver 096, V=50km/h, S=20m, risk time 1.44s)

5. Analysis of drivers' behaviour in arranged pre-accident situation

Quantities that characterise each ride (motion parameters of the tested vehicle and the roadblock, quantities describing the driver's behaviour) were recorded every time. The following parameters were recorded:

t [s] - current time,
x_{O1} [m] - position of the centre of the vehicle's mass in the configuration related to the road Oxy (see Fig. 5),
y_{O1} [m] - position of the centre of the vehicle's mass in the configuration related to the road (see Fig. 5),
ψ_1 [rad] - vehicle yaw angle,
V_{O1} [m/s] - vehicle velocity (specifically – the resultant velocity of the vehicle's centre of mass),
$\dot{x}_{O1}$ [m/s] - component on the "x" axis of the centre of mass velocity in the configuration related to the road Oxy,
$\dot{y}_{O1}$ [m/s] - component on the "y" axis of the centre of mass velocity in the configuration related to the road Oxy,
a_ξ [m/s^2] - longitudinal acceleration of the centre of mass in the configuration of $O_1\xi_1\eta_1$ related to the vehicle,
a_η [m/s^2] - lateral acceleration of the centre of mass in the configuration of $O_1\xi_1\eta_1$ related to the vehicle,
α_k [rad] - the steering wheel angle,
P_N [N] - the brake pedal force,
E_{PN} [%] - the variable describing a position of the brake pedal (0-100%),
E_{GAZ} [%] - the variable describing a position of acceleration pedal (0-100%),
E_{SP} [%] - the variable describing a position of the clutch pedal (0-100%),

x_{P1} [m] - coordinate x of geometrical centre of the roadblock P1,
y_{P1} [m] - coordinate y of geometrical centre of the roadblock P1,
x_{P2} [m] - coordinate x of geometrical centre of the roadblock P2,
y_{P2} [m] - coordinate y of geometrical centre of the roadblock P2,
KolizjaP1 - indicator of collision with roadblock P1 (0/1),
KolizjaP2 - indicator of collision with roadblock P2 (0/1).

A very large number of gathered measurement results will be analysed in detail in the course of further works. This work shall present dependence of the probability of occurrence of individual cases of collisions on the risk time values.

Fig. 8 illustrates (in the risk time function) the number of drivers who failed to avoid the collision with the vehicle moving from the right side of the crossroads – the roadblock P1. It is clearly visible that at risk times not exceeding 0.6 s, practically in 100% of cases the collision occurred. For the risk times ranging from 0.6 s to about 1.5 s, the number of recorded collisions declines in linear approximation. For risk times above 1.5 s, the collisions occurred in single cases only (from 0 up to 4).

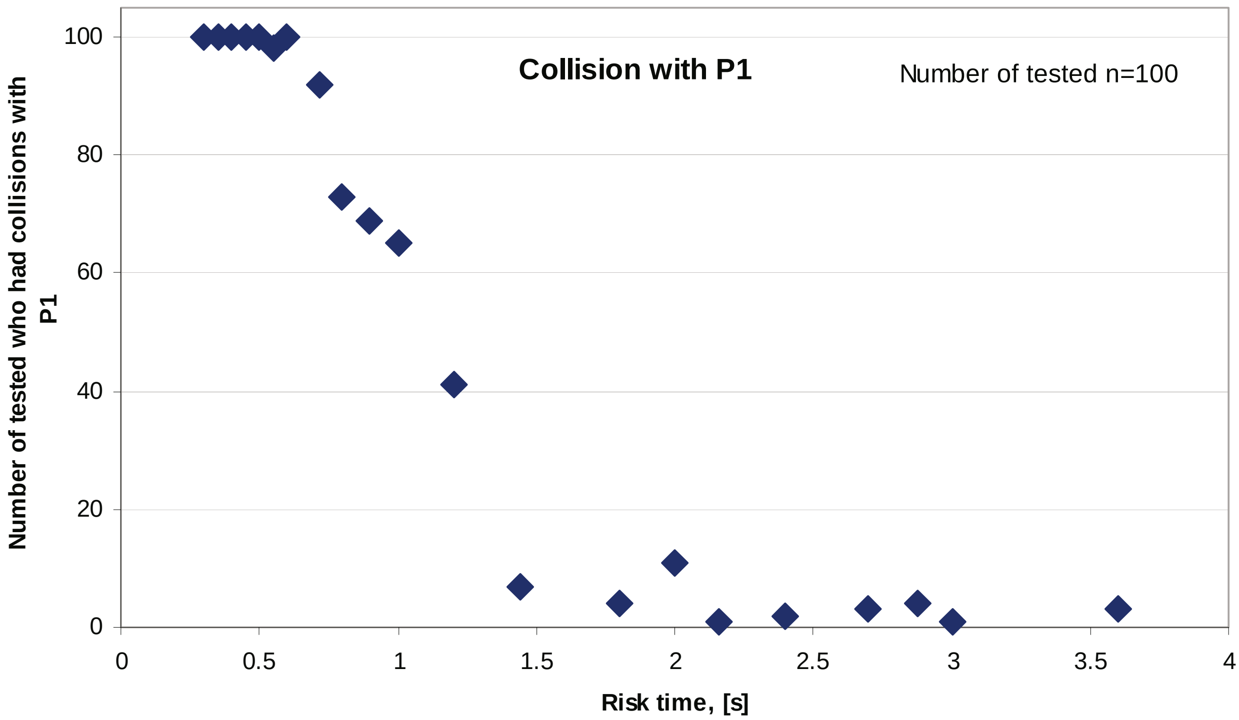

Fig. 8. Number of drivers who had a collision with roadblock P1 (driving in perpendicularly on the crossroads)

The interesting point is the risk time of 2s for which a considerably higher number of collisions was reported – 11, compared to the reaming attempts time response range above 1.5s. The authors link that to research performance procedure. This attempt was made as the first one. Therefore, that slightly higher value of the collisions number in that point can be explained by a bit higher surprise of the drivers than in the other attempts.

Similar research on possibilities of avoiding a collision have recently occurred as a result of works over development of accidents prevention systems, referred to as the PreSafe or PreCrash systems in specialised literature. As research studies on two subsequent pre-accident scenarios are envisaged under the research project implementation, and moreover, the research on each of those scenarios are to be realised both on the test track and in the simulator, the authors do not want prior to completion of the entire research cycle to carry our a thorough comparative analysis with other published research results. However, even now an example of a difference in results can be provided.

An assessment of possibilities to avoid a collision with a pedestrian has been presented in the interesting doctoral thesis [2]. The assessment was made also using distance in time (referred therein as TTC – time to collision). The presented assessment was as follows:

- $0 < TTC \leq 0.3$ s – avoidance of the collision is impossible;
- $0.3 < TTC \leq 0.5$ s – avoidance of the collision is possible by simultaneous braking and passing by;
- $0.5 < TTC \leq 0.7$ s – avoidance of the collision is possible only through passing by;
- $0.7 < TTC \leq 2.0$ s – avoidance of the collision is possible by braking only.

The results, presented on Fig. 8, move significantly upwards the time limit at which it is possible to avoid the collision, compared the ones quoted above. Although the results quoted above were obtained through tests on the test track, but the tests were conducted using the stimulator. The applied stimulator was in a form of flashing light (one or two) placed before the steering wheel on the dashboard. In the authors' opinion, the research results in the driver simulator where the assumed pre-accident situation was mapped in a quite realistic way should be considered as more reliable than tests with the stimulator, being a type of simple stimulus, nevertheless the latter ones are also of cognitive value.

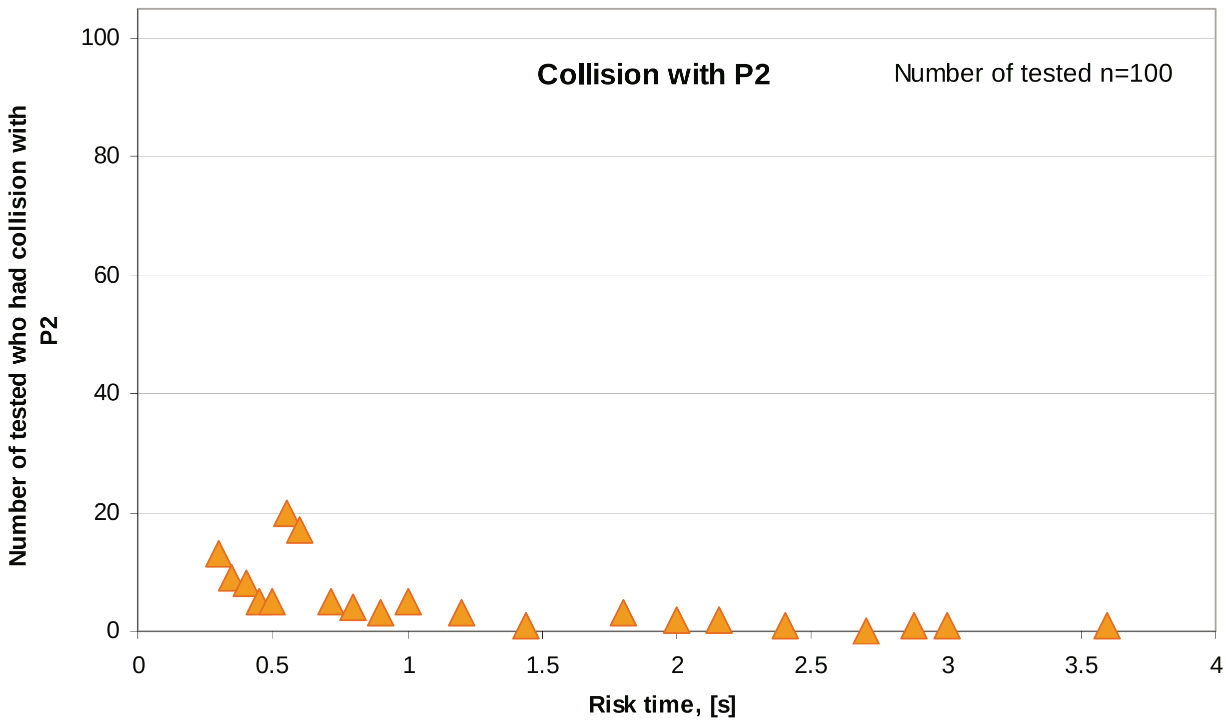

Fig. 9. Number of drivers who had a collision with roadblock P2 (approaching from the opposite direction)

Fig. 9 illustrates (in risk time function) cases of collisions with roadblock P2 – the vehicle approaching from the opposite direction, but Fig. 10 presents the number of cases in which the collision has occurred with both roadblocks (P1 and P2). The number of collisions with the second roadblock seems to be definitely lower. The maximum number of such collisions reached about 20%, however most of such situations were reported with respect to risk times not exceeding 0.6s (similarly to the case of collision with roadblock P1). For higher risk times, collisions with P2 occurred sporadically.

The results for attempts with their risk time of 0.554s and 0.6s are an interesting case. There is „unnatural" rise in a number of collisions with P2. In opinion of the authors, the situation was causes inter alia by specific risk time range. A driver was already noticing a possibility to avoid the collision and was making a risky attempt of passing by the roadblock P1. The risk time was however small enough that the sudden manoeuvre was ending unsuccessfully in a form of collision both with roadblock P1 and P2. In the first case (0.554s), also the velocity of the tested vehicle reaching 65 km/h was not insignificant. In those conditions, frequent occurrence of the lost motion stability could have been observed.

The runs on Fig. 9 and Fig. 10 practically overlap. This means that besides a few cases, the collision with roadblock P2 was occurring following a prior collision with roadblock P1.

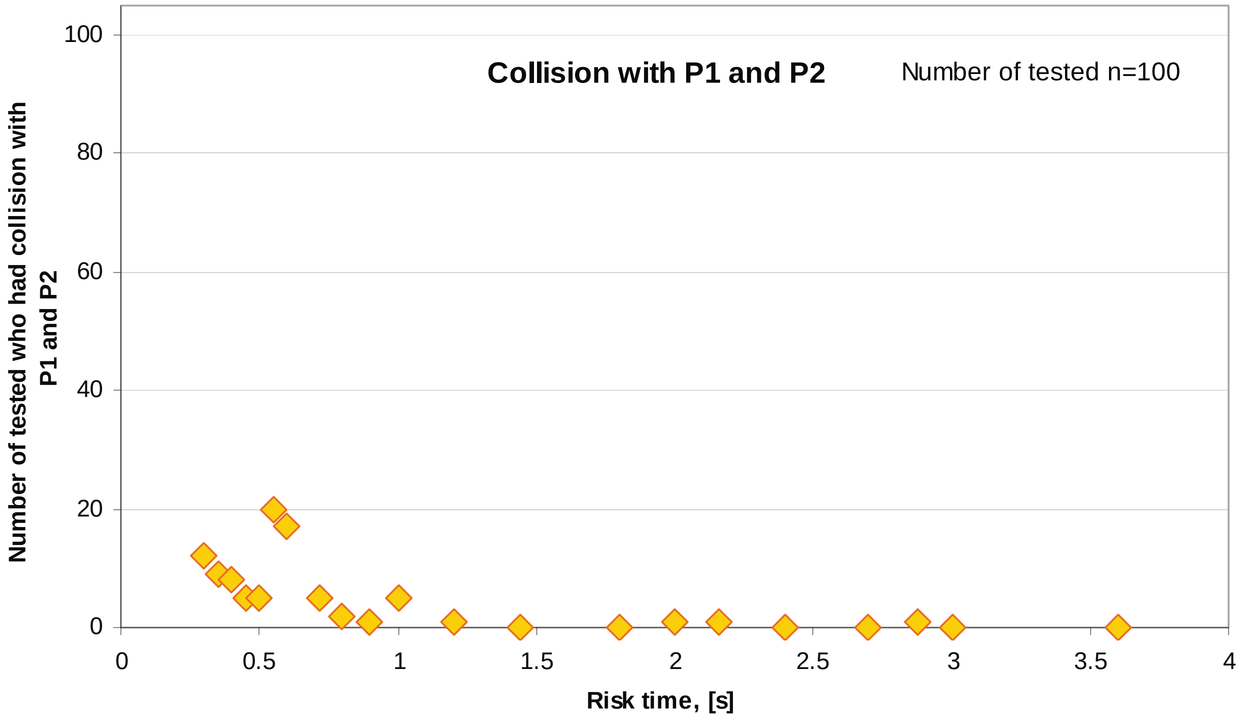

Fig. 10. Number of drivers who had collisions with both roadblocks P1 and P2

6. Conclusions

The driving simulator can be a good tool to assess behaviour of drivers in dangerous traffic situations. Despite its many disadvantages (animated image, no inertia stimuli in static simulator *autoPW*, „artificiality of the situation", no intensive feeling of danger), the results that are generated via the simulator may become a serious source of information serving a behaviour of drivers in dangerous situations. Unlike the road experiments, the research studies that are conducted using the simulator allow for much wider scope of tests of the parameters values that describe a given situation, e.g. at high driving velocities, in complex scenarios defining the accident situation, or in situations when performance of such tests would pose high threat on participants of the tests. The obtained results of frequency to make specific manoeuvres prove that a decision to make them depends on risk time. The drivers' response times, obtained through tests, have confirmed in qualitative aspect the results, obtained by the authors in their previous works (realised on a smaller group of drivers and for another scenario). Their dependence on risk time characterising the accident situation has also been confirmed.

References

[1] Chodnicki, P., Guzek, M., Lozia, Z., Mackiewicz, W., Stegienka, I., *Static driving simulator autoPW, Version 2003,* Scientific Booklets of the Kielce University of Technology, Mechanics. Booklet No. 79 Kielce, pp. 157-164 (in Polish language), 2004.

[2] Fröming, R., *Assesment of Integrated Pedestrian Protection System,* PhD thesis. Fortschritt-Berichte VDI, Reihe 12, Verkehrstechnik/Fahrzeugtechnik r.681, 2008.

[3] Guzek, M., Jurecki, R., Lozia, Z., Stańczyk, T. L., *Comparative analyses of driver behaviour on the track and in virtual environment,* Driving Simulation Conference Europe, DSC 2006 Europe, Paris, 2006.

[4] Guzek, M., Jurecki, R., Lozia, Z., Stańczyk, T. L., *Drivers research on the track and in the virtual reality,* Scientific Booklets of the Kielce University of Technology, Booklet No. 84, pp.195-206, Kielce (in Polish language), 2006.

[5] Guzek, M., Jurecki, R., Lozia, Z., Stańczyk, T., *Drivers behaviour research in pre-accident situation realized in the driving simulator*, Proceedings of X Conference "Problems of Road Accidents Reconstruction", Institute of Forensic Research, Szczyrk (in Polish language), 2006.

[6] Guzek, M., Lozia, Z., Pieniążek, W., *Experimental verification of simulation model applied in the driving simulator*, Scientific Booklets of the Vehicles Institute, Warsaw University of Technology, Booklet No. 4 (34)/99, pp. 69-87, Warsaw (in Polish language), 1999.

[7] http://www.it.pw.edu.pl/autopw/

[8] Jurecki, R. S., *Modelling of driver behaviour in pre-accident situations*. PhD thesis. Kielce University of Technology, Faculty Of Mechatronics and Machine Building, Kielce (in Polish language), 2005.

[9] Jurecki, R. S., Stańczyk, T. L., Lozia, Z., *Research on the emerging roadblock passing-by manoeuvre in conditions of test track research and in the driver simulator,* Scientific Booklets of the Vehicles Institute, Warsaw University of Technology, Booklet No. 1(56)/2005, pp. 65-78, Warsaw (in Polish language), 2005.

[10] Kończykowski, W., *Reconstruction and analysis of road accident*, Info-Ekspert, Warsaw, 1993.

[11] Lozia, Z., *Double-axle vehicle motion and dynamics model used in the simulator,* Scientific Booklets of the Vehicles Institute, Warsaw University of Technology, Booklet No. 4 (34)/99, pp. 37-51, Warsaw (in Polish language), 1999.

[12] Lozia, Z., *Driving simulators*, WKŁ, Warsaw (in Polish language), 2008.

[13] Stańczyk, T. L., Jurecki, R., *Response times of drivers in accident danger states*, Proceedings of II Conference "Vehicle technique development vs. communication insurance policies", Higher Business School named after J. Chrapek in Radom, pp. 321-348 (in Polish language), Radom, 2006.

[14] Stańczyk, T., Jurecki, R., *About causes of differences in published values of drivers response times,* Proceedings of X Conference " Problems of Road Accidents Reconstruction", Institute of Forensic Research (in Polish language), Szczyrk, 2006.

[15] Stańczyk, T. L., Jurecki, R., *Precision in estimation time of driver reaction in car accident reconstruction,* Proceedings of EVU Annual Meeting 8-10 November 2007, Institute of Forensic Research Publishers, pp. 325-334, Cracow, 2007.

[16] Stańczyk, T. L., Jurecki, R., *Fahrereaktionszeiten in Unfallrisikosituationen – neue Fahrbahn- und Fahrsimulatorversuche,* Verkehrsunfall und Fahrzeugtechnik , pp. 235 – 246, 07-08/2008.

[17] Weir, D. H., Clark, A. J., *A survey od mid-level driving simulators,* SAE TP 950172.

[18] *Road accidents. Vademecum of forensic expert*. Joint work. Institute of Forensic Research Publishers (in Polish language), Cracow, 2002.