ARCHIWUM MOTORYZACJI
1, pp. 149-171 (2011)

Driver Model for the analysis of pre-accident situations- similarities and differences of results on a track and in a simulator

RAFAŁ S. JURECKI, TOMASZ L. STAŃCZYK

Politechnika Świętokrzyska, Wydział Mechatroniki i Budowy Maszyn,
Katedra Pojazdów Samochodowych i Transportu, Al. 1000- lecia Państwa Polskiego 7 , 25-314 Kielce

The article presents pre-accident simulation tests conducted on a car track and in a simulator. The aim of the tests was to verify the correctness of a driver model worked out for such a type of analysis and the identification of its parameters. The article shows the comparison of parameters characteristic for driver behaviour in both testing environments. As the driver may have chosen the manoeuvre to defend – to brake or (and) to avoid an obstacle, the frequency of choosing the above - mentioned manoeuvres has been compared in each testing environment. The comparison of driver reaction time was carried out during braking as well as turning. Correlation coefficients between average reaction time were determined. The comparison of a manoeuvre realization method has been conducted. As a numerical measure of the manoeuvre realization method, the parameters of a mathematical driver model were taken into account. The correlation analysis of model parameters was realized on the example of selected drivers.

1. Introduction

The possibility of performing a computer simulation of the real vehicle movement depends not only on the quality and accuracy of the prepared dynamic vehicle models but also on the quality of modelling the driver behaviour (actions). Attempts to create a so-called driver model have been made for many years by many authors. However, due to the complexity of this problem the prepared driver models have been deliberately limited to a specific broad field of interest. In many articles [1-11] authors propose the concept of a driver models also for a particular, narrowed scope of application, i.e. for the analysis of pre-accident situations.

The model worked out by authors and described in articles [12-14], [4-7] has been tested for a selected scenario of a pre-accident situation. A manner of performing a given scenario during tests on the ‘Kielce’ track has been presented in article [13]. The estimation of frequency of particular driver behaviours and driver reaction time for turning manoeuvres, engine braking and using a service brake have been conducted. Linear regression equations that describe the relation reaction time in a risk time function that is a characteristic of an accident situation [12] were determined. On the basis of registered in function time values of the of wheel turning angle and deceleration, carried out identification procedure of a driver model parameters for research on the track.

As we are interested in so called “average driver”, despite the efforts to maintain various safety measures, pre-accident situation tests are connected with some level of risk. A safe alternative to carry out such test is a virtual environment, i.e. a driving simulator. To estimate whether it is possible and in what range to realize such tests in a virtual environment, tests of the same group of drivers and with the same scenario were conducted in the simulator. Then, the same conduct procedure was applied as in case of data obtained on the track. The comparison analysis of the results obtained on the track and in the simulator has been presented in the following article.

In some publications one may find, in a descriptive way, characteristic differences in the perception of a real road situation and its mapping in a virtual environment (in the driving simulator) [2], [15-16]. Thus, a particular advantage of conducted tests is the possibility for estimation of differences of various parameters values that are characteristic for driver behaviour in both environments.

2. Eksperimental tests on the track

The experimental tests have been conducted on the ‘Kielce’ track . The vehicle used for testing was a Ford Transit with appropriate measuring equipment. During tests many parameters were measured. Assignment of some of them was essential to delimit the parameters of a developed driver model (deceleration, angle of wheel turning). To carry out tests was selected a pre-accident situation that was a sudden obstacle in the form of a motor car driving form a side road. A more detailed scenario and tests method were presented in article [13].

The aim of a driver was to try to avoid the collision with an obstacle appearing on the road, however, the reaction method for a sudden risk was not imposed on the driver.

According to his individual, subjective assessment of a given road situation, the driver could only brake, make a passing manoeuvre or perform both types of actions at a desired level of intensity.

During tests and analysis the term 'risk time' was used [4], [6], [9], [12], [15], [17]. Risk time t_R has been defined as the time, which the driver has from the moment of noticing an obstacle to a potential collision with it, and it can be used by the driver to apply defensive measures. This parameter is calculated as relation of distance car from obstacle S, to his speed V (fig. 1) - (equation 1) (in some publication called TTC – Time To Collision [18-20]), as it has been shown by the authors in articles [5], [7], [13-14] becomes useful to assess an accident situation.

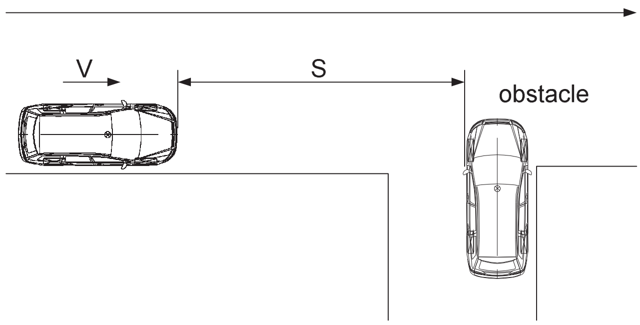

Fig.1 Diagram of calculation the risk time.

$$t_R = \frac{S}{V} \tag{1}$$

Thanks to its application, a particular situation is characterised (the above-mentioned car speed and the distance from an obstacle when it becomes visible) by this one parameter, i.e. risk time.

The tests have been conducted for the following parameters: driving speed characteristic for developed areas in cities: 40, 50, 60 km/h; distances from the vehicle at which the driver noticed the obstacle: 10, 20, 30, 40 and 50m. A combination of these parameters made it possible to obtain 15 different trials, characterized by initial risk time (this value be counted for moment when obstacle appears) of values in the range between 0.60 s to 4.5s.

3. Experimental tests in the simulator

The tests were conducted in a driving static simulator took place in a Simulation Tests' Laboratory of the Faculty of Transport of the Warsaw University of Technology. The construction and the simulator's possibilities have been described in the studies [21], [22]. Signals from the sensors have been processed by a set of three IBM PC computers and the effects of the simulation have been displayed on an HD overhead projector on a screen behind the car. The simulator software, which enables the analysis of different road situation scenarios contains a vehicle model [23] with the following parameters:

- 7 degrees of freedom (2 coordinates of the centre of mass of the vehicle movement in a earth fixed coordinate system, yaw angle, 4 rolling angles of road wheels),
- a quasi-static description of changes in the normal road reactions,
- flexibility of the steering system
- a complex non-linear model of contact forces and aligning moments.

The scenario implemented in the car driving simulator AutoPW was identical with the one used on the track. Owing to the graphic capabilities of the simulator, it was possible to reconstruct the scenery of the analysed situation in a more realistic way.

Fig. 2 presents a simulator reconstruction of the intersection in simulator. Fig. 3 shows the bird's eye view of subsequent phases of passage in a single trial.

Fig. 2. The view on real road crossing and his mapping in AutoPW simulator.

The tests have been made with a group of 30 drivers (males), in various age 20 of who were aged between 22 and 24, and 10 were aged between 30 and 67. The same group of drivers participated in both experiments (the track 'Kielce', driving simulator AutoPW). The simulator's software (car model) was loaded with Ford Transit parameters that was used on the track, so in the simulator, the driver was driving a motor car of the same parameters as on the track.

Fulfilling three conditions:

- the same group of drivers,
- the same scenario and test parameters,
- a motor car of the same suspension parameters,

the similarity of conducted tests in both testing environments has been guaranteed on the best possible level. Thus, possible differences in obtained tests results will be solely connected with the influence of a testing environment. Therefore, it will be possible to indicate, in which aspects drivers' behaviours in both environments are similar or identical, and in which they are different. The drivers before researches in simulator acquainted with specific this researches environment in time of tentative rides.

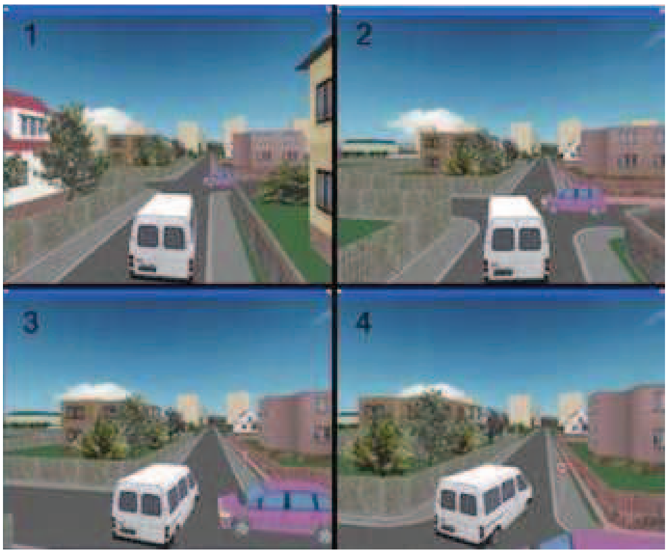

Fig. 3. Mapping one of the registered trials (a bird's-eye view).

4. Estimation of manoeuvre taking frequency

The studies have shown that the decision to take a particular action (turning, braking) depends on the value of risk time and not only on driving speed or distance from the obstacle [12]. For the purpose of further analysis, 'W' coefficient has been specified to describe the ratio of the number of people making a specific manoeuvre n_p to the number of all test participants n - that is frequency of occurrence of given defensive manoeuvre - expression (2).

$$W = \frac{n_p}{n} \cdot 100\,\% \tag{2}$$

The biggest likeness of behaviour in both types of environment was observed in the case of a decision to make a turning manoeuvre. Fig. 4 shows the value of the 'w' coefficient, specified for that manoeuvre. A clearly defined risk time value is visible (circa 1.2-1.5s), at which practically 100% drivers decide to make a turn manoeuvre. In the case of accident situations with risk time below that border, percentage of drivers who decide to make the turning manoeuvre drops rapidly but even for the shortest tested risk time t_{R0} = 0.6 s it does not drop to zero.

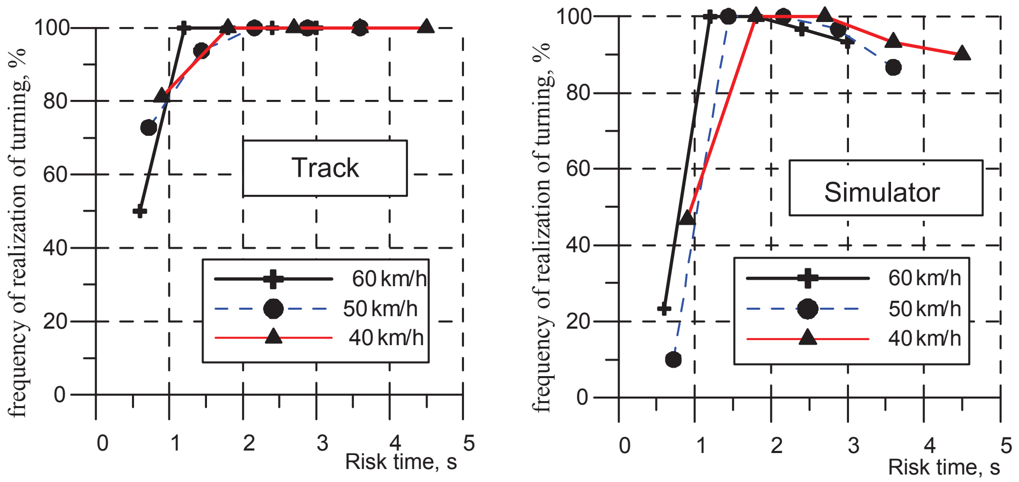

Fig. 4. The frequency of making decisions concerning the choice of a turning manoeuvre

The greater differentiation of behaviour types has been observed in the case of the braking manoeuvre. Fig. 5 shows the engine braking frequency in both types of test environment, and fig. 6 shows the frequency of braking with a service brake.

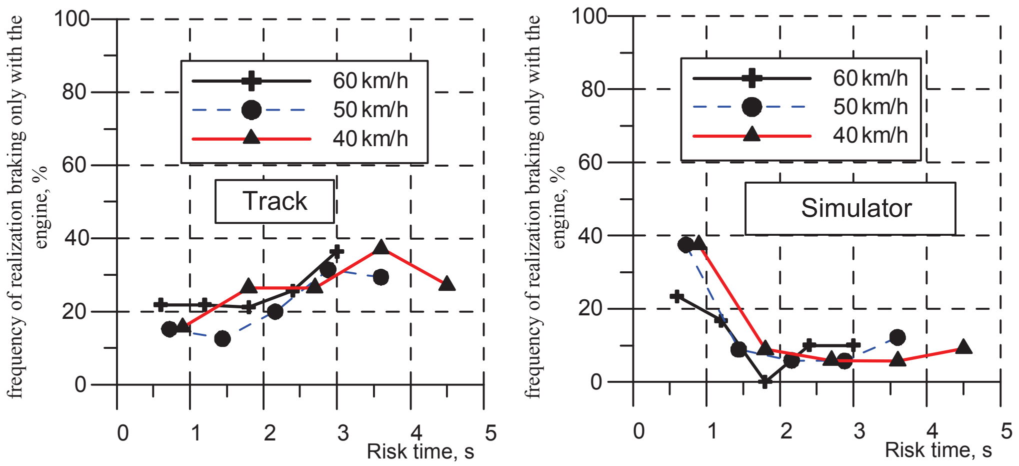

Fig. 5. The frequency of making decisions concerning the choice of a turning manoeuvre

Frequencies of making decisions to brake only with the engine (the tested persons stopped pressing the accelerator pedal in that case instead of pressing the brake pedal) were similar in both types of environment and ranged from ca. 0 to 40%. However, with the track tests there is a slight increase in the frequency of making this manoeuvre along with the increase of the initial risk time. In the simulator the frequency reaches the values between 30 and 40% only for small risk time values, and stabilizes at ca. 10% above 1.0-1.5s.

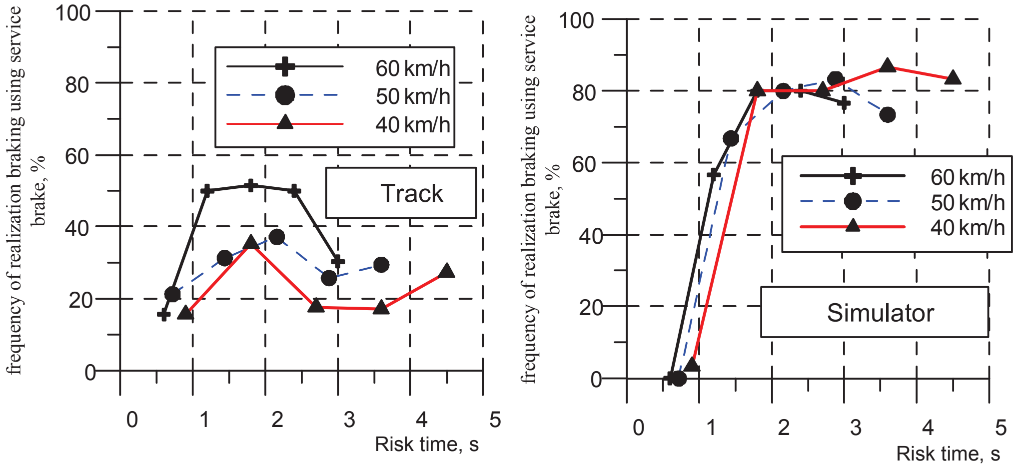

Fig. 6. The frequency of making decisions concerning the choice of a braking manoeuvre

The greatest differences in driver behaviour are visible in the case of braking with a service brake. During the track tests the biggest frequency of making this decision was ca. 40% for the risk time of ca. 2s. Above the risk time $t_{R0} \approx 3$s the percentage of drivers who decided to brake with the brake pedal fell to ca. 20 – 30%. In the simulator the situation was different. With risk time ranging from 0.6 to 2 s the percentage of drivers making that manoeuvre increased in an almost linear manner from 0 to 80%. and stayed at that level until the end of the tested range $t_{R0.}$ The behaviour similarities in two types of testing environment are bigger if considered together with the issue of driving speed reduction, regardless whether it takes place due to the engine or pedal braking - fig. 7.

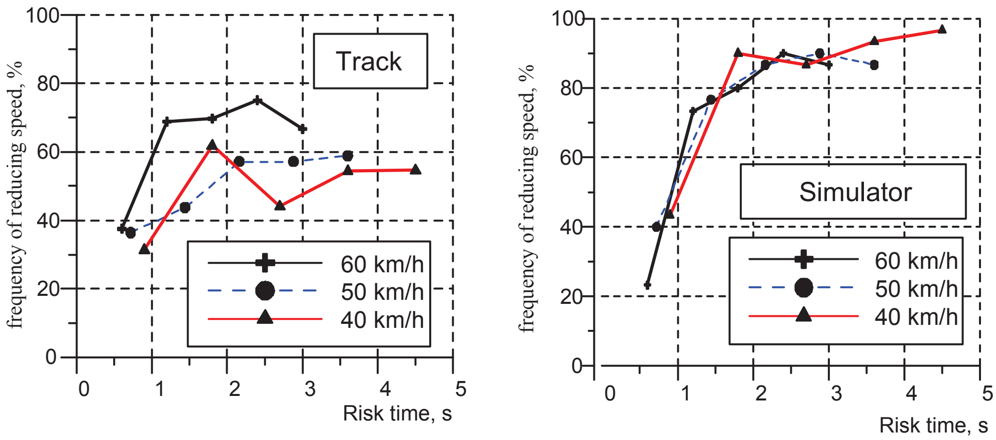

Fig. 7. The comparison of frequency reducing driving speed

Although in that case this decision was also more often made in the simulator, the variability - that is the increase in frequency of making decisions with the rising risk time - is the same in both types of testing environments. In the case of long risk time the above diagrams are similar (an approximately horizontal line) but they differ by a specific constant value of ca. 30%.

5. The analysis of reaction time correlation

Among the driver model parameters, reaction time were analysed particularly thoroughly [4], [7], [18], [24-27]. It results from the fact that the obtained reaction time values may be directly used in reconstructing the course of road accidents.

5. 1. Reaction time during turning

It has been found out that driver reaction time during test in the simulator is shorter than those on the track. However, it is impossible to indicate a fixed difference value of reaction time, as it is stated in some publication sources e.g. [25], [28].

Tests conducted by authors have shown however that obtained reaction time values, both on the track and in the simulator, is very much dependent on an initial risk time value which characterised a particular trial. Reaction time during turning be defines as time since moment appearing obstacle by driver to moment reaction through driver on the steering wheel.

The average driver reaction time, specified for the whole driver population for individual actions both for the track tests and in the simulator have shown a linear dependence on the initial risk time value t_{R0}. These characteristics are very similar for both types of environment. They are shown in the subsequent figures. Fig. 8 demonstrates the turning reaction time.

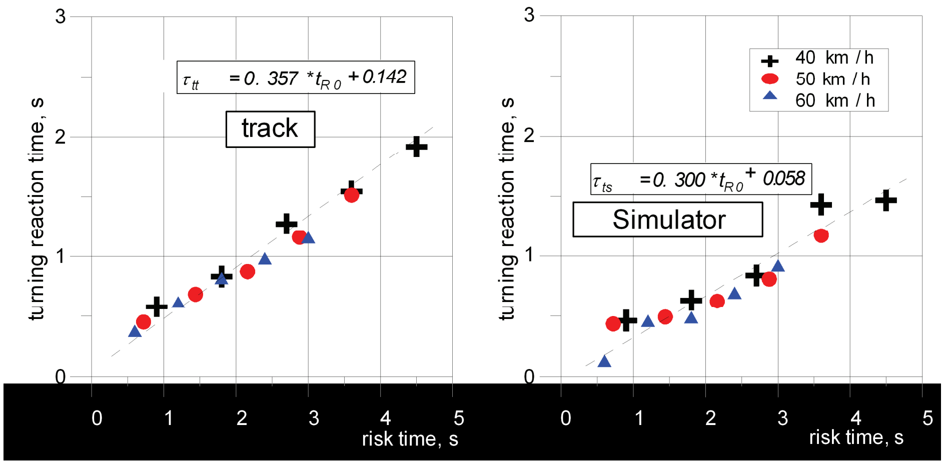

Fig. 8. Drivers' reaction time for turning in function t_{R0}

The presented diagrams allow us to formulate the following conclusions:

1. the reaction time obtained both on the track tests and in the simulator clearly depend on the risk time and do not depend only on speed at which the subsequent trials took place.
2. the reaction time vary broadly (from ca. 0.4 ÷ 1.9s on the track to ca. 0.15 ÷ 1.5 s in the simulator) and strongly depend on the risk time values t_{R0}- the relation is linear in character.

The first of the listed conclusions deserves stressing. Publications concerning accident analysis and different types of guides for experts contain recommendations as to the value of reaction time. In many cases they are relatively accurate, subject to statistical processing and are shown e.g. in the form of the distribution function. They do not make, however the recommended reaction time contingent on any parameters characteristic for the pre-accident situation. Consequently, the expert may assume the same reaction time both for a situation with the risk time of 0.6s and for a situation with much higher risk time - for example ca. 2.0s.

The diagrams presented in fig. 8 clearly prove that in both situations mentioned above significantly different reaction time should be assumed. Therefore, is the above conclusion justified or is it a randomly obtained result? Certainly the randomness of results can be ruled out. First: the relation between the reaction time and risk time has been confirmed by two independently conducted tests - on the track and in the simulator. Second: each of the points set on the diagrams is a average value of reaction time of 30 drivers tested in each trial. Each diagram was created on the basis of 450 measurements. Dependency of the reaction time from the risk time may be interpreted in the following way: when assessing the situation, the driver does not consider driving speed and distance from the obstacle separately but he is aware of the time available for making a decision and reacting._When he feels that there is more time

available, it takes longer for him to make the decision, and by all means it takes longer to react.
The confirmation of that thesis is the dependence of reaction time obtained on the track and in the simulator as well as the results of correlation analysis illustrated in fig. 9. The calculated linear correlation coefficient was very high at R = 0.97. For the relation shown in fig. 9 a linear regression equation (3) was estimated, which enabled the calculation of the average reaction time on the track τ_{tt} at a known value of the time on the simulator $\tau_{ts.}$ The each point on the figure 9 represent the average reaction time appointed in simulator and the track, for the same value risk time.

$$\tau_{tt} = 1.128 \cdot \tau_{ts} + 0,118 \tag{3}$$

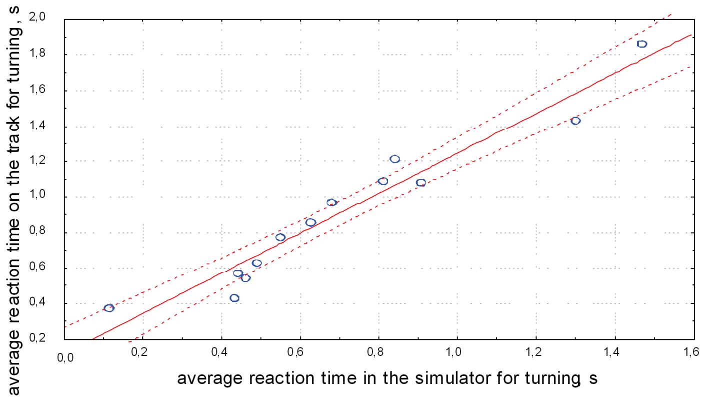

Fig. 9. The relationship of average reaction time (during turning) determined on the track and average reaction time determined in the simulator

5. 2. Accelerator pedal reaction time

Fig. 10 demonstrates the features of the accelerator pedal reaction time in the initial risk time t_{R0} function. Accelerator pedal reaction time be defines as time since moment appearing obstacle by driver to the action in the accelerator pedal.

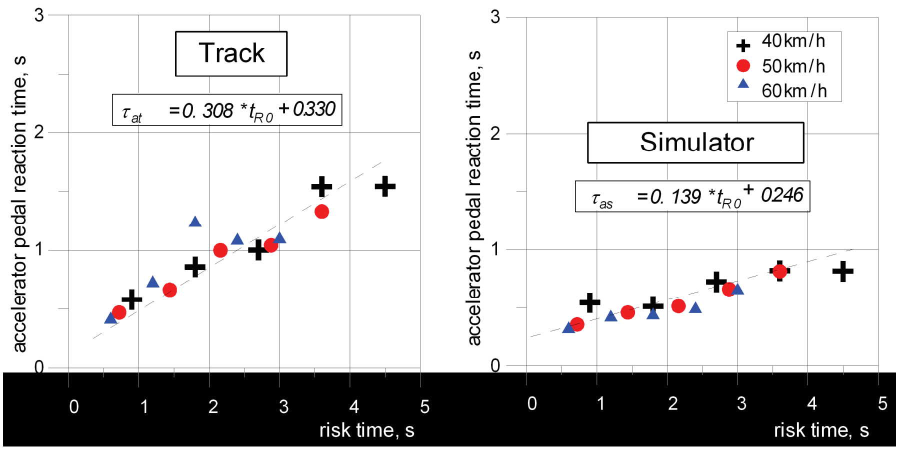

Fig. 10. Drivers' reaction time for accelerator pedal in function $t_{R0.}$

Since the interrelations between the accelerator reaction time determined on the track and in the simulator is also linear, it is possible that they are correlated. For the accelerator pedal reaction time determined in both environments a correlation coefficient has been specified at R=0.90 and the linear regression equation has been defined (4) for the relation shown in fig. 11.

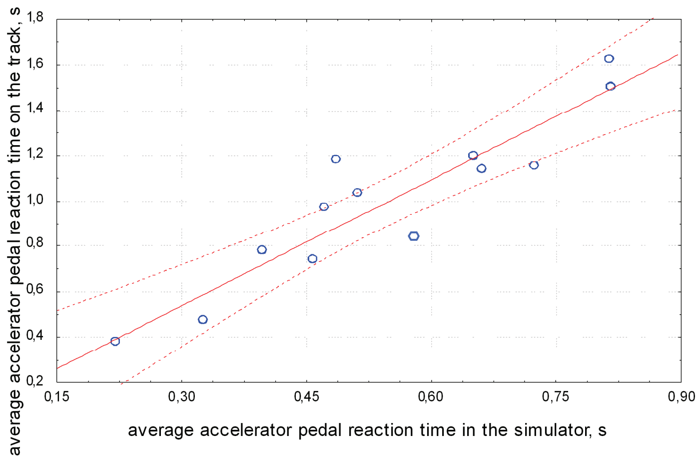

Fig. 11. The relationship of average reaction time (for accelerator pedal) determined on the track and average reaction time determined in the simulator.

$$\tau_{at} = 1.851 \cdot \tau_{as} + 0{,}016 \quad (4)$$

Using this relation average accelerator pedal reaction time on the track τ_{at} may be calculated at the known value of reaction time in the simulator τ_{as}.

5.3. Reaction time during braking with a service brake

The reaction time characteristics for braking with a service brake have been presented in fig. 12. As in the previous cases they show a clear linear dependence on risk time. The relation has been obtained both for the track and simulator tests. Braking reaction time be defines as time since moment appearing obstacle by driver to the action in the service brake pedal.

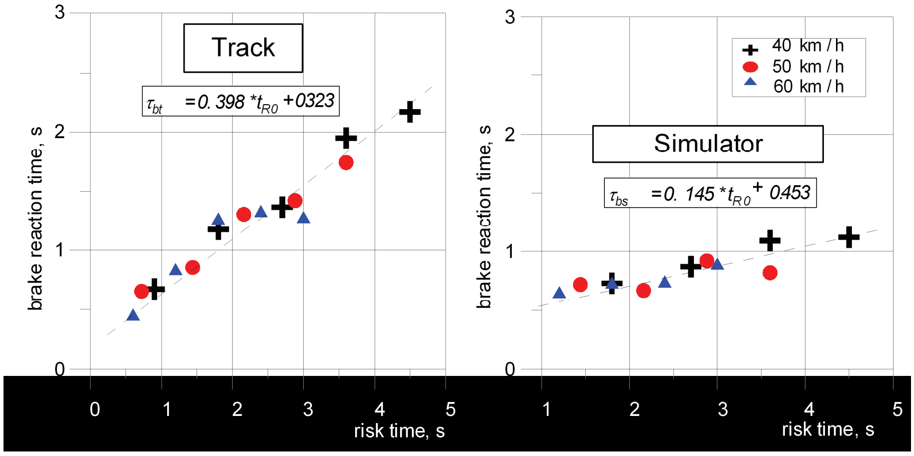

Fig. 12. Drivers' reaction time while using service brake in function t_{R0}

A linear correlation coefficient has been determined for the average reaction time values obtained on the track and in the simulator (for a specific risk time value). It was not significantly lower in comparison with the turning and acceleration pedal manoeuvres and its value R=0.88 can be described as high. The relation between average braking reaction time obtained in both testing environments has been rendered in fig. 13.

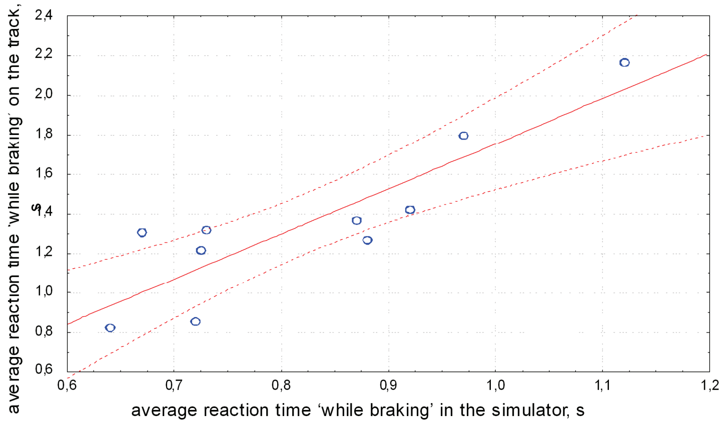

Fig. 13. Dependence of average reaction time (for braking using service brake) set on the track from average reaction time set in the simulator

The fixed regression dependence (equation 5) enables the calculation of average reaction time for braking on the track τ_{bt} at known average reaction time determined in the simulator τ_{bs}.

$$\tau_{bs} = 2.287 \cdot \tau_{bs} - 0{,}531 \qquad (5)$$

5.4. Summary of driver reaction time' comparison

For further comparison, table 1 shows the values of the differences of average reaction time for five selected trials characterised of different risk time values. The table presents differences only for two basic type of time used for accident reconstruction, i.e. reaction time during turning and reaction time during braking with a service brake.

Table 1. Comparison of reaction time obtained on the track and in the simulator

	Differences of average reaction time: track – simulator s. for five selected values of risk time t_{r0}				
	t_{r0} = 0,6 s	t_{r0} = 1,5 s	t_{r0} = 2,5 s	t_{r0} = 3,5 s	t_{r0} = 4,5 s
Difference of reaction time during turning	0,13	0,19	0,27	0,34	0,41
Difference of reaction time during braking with a service brake	- 0,01	0,24	0,52	0,79	1,07

Taking into consideration the above-mentioned comparison of reaction time, the following conclusions may be drawn:

- drivers' reaction time during turning as well as braking obtained during tests in the simulator is shorter that during tests on the track (fig. 8, 10 and 12);
- the difference of average time values obtained on the track and in the simulator is not fixed for a particular manoeuvre but it decreases linearly along with the decrease of risk time that characterises a particular trial, that is along with the increase of situation risk level (fig. 8, 10 and 12 and table 1);
- all the above-mentioned values of drivers' reaction time determined during tests on the track and in the simulator show a strong mutual correlation (fig. 9, 11 and 13).
- average reaction time values obtained in both environments take similar values for small value risk time (difference approaches zero – tab. 1)

The last conclusion is worth noting as it indicates that testing situation of the least risk time values, which realization on the track may be particularly dangerous, can be conducted in the driving simulator.

6. The analysis of model driver parameters (Ways of manoeuvres realization)

Measuring has shown that the registered characteristics of the wheel turning angle and vehicle deceleration are very different [5]. In some trials (predefined risk time values) the obtained of turning characteristics and deceleration characteristics were placed around the predefined average line, while the others showed stronger differentiation.

However, in the majority of trials the obtained characteristics indicated so large differentiation to make averaging pointless. Consequently, the results of tests on the track and in the simulator comprised a basis for dividing the whole population of tested drivers into four smaller groups with typical manners of behaviour [12]:

1. Very small deceleration (or does not occur), 'early' turn.
2. Very small deceleration (or does not occur), 'average' turn.
3. Small deceleration, 'average' turn.
4. Small deceleration, 'early' turn.

A mathematical driver model for the analysis of pre-accident situations has been worked out as to precisely (mathematically) characterise methods of manoeuvre realization. It has been assumed that the model will comprise two basic functions used by drivers as defensive manoeuvres in risk situations [12], [13]: decreasing the speed (braking) and steering (avoiding an obstacle).

In the prepared driver behaviour model described in [12-14] the braking model takes the form of equation (6):

$$b_b(t) + W_1\dot{b}_b(t) = W_2\left(y_{lat}(t-\tau_b) - y_s(t-\tau_b) \right) + W_3\left(\frac{1}{t_R} \right) \tag{6}$$

where: W_1, W_2, W_3 - braking model coefficients, b_b - vehicle deceleration, y_{lat} - obstacle lateral position, y_s – lateral position of the vehicle's mass centre, τ_b - reaction time for braking, t_R - risk time, S - distance from the obstacle, t - time, V - vehicle speed.

The steering model takes the form of equation (7).

$$\delta_t(t) + W_4\dot{\delta}_t(t) = W_5(y_{lat}(t-\tau_t) - y_s(t-\tau_t)) \qquad (7)$$

where: W_4, W_5 - steering model coefficients, δ_t - wheel turning angle, y_{lat} - obstacle lateral position, y_s – lateral position of the vehicle's mass centre, τ_t - reaction time for steering.

The identification of model driver parameters on the basis of tests in the simulator has been conducted similarly to the test results on the track [13]. For particular trials characterised by the value of initial risk time, t_{R0} characteristics with the division for groups of drivers were determined. Similarly to the presentation of results on the track [13], on the graphs apart from a wheel turning angle courses and a deceleration realized by particular drivers, are presented courses of average values (thick line), envelope of minimum values (broken line) and envelope of maximum values (dotted line). Furthermore, the field, with the characteristics of drivers from a particular group, has been marked. Example characteristics of a deceleration and wheel turning angle obtained during tests on the track and in the simulator for one selected trial characterised by the initial risk time value of 1.8s were presented in fig. 14… 15.

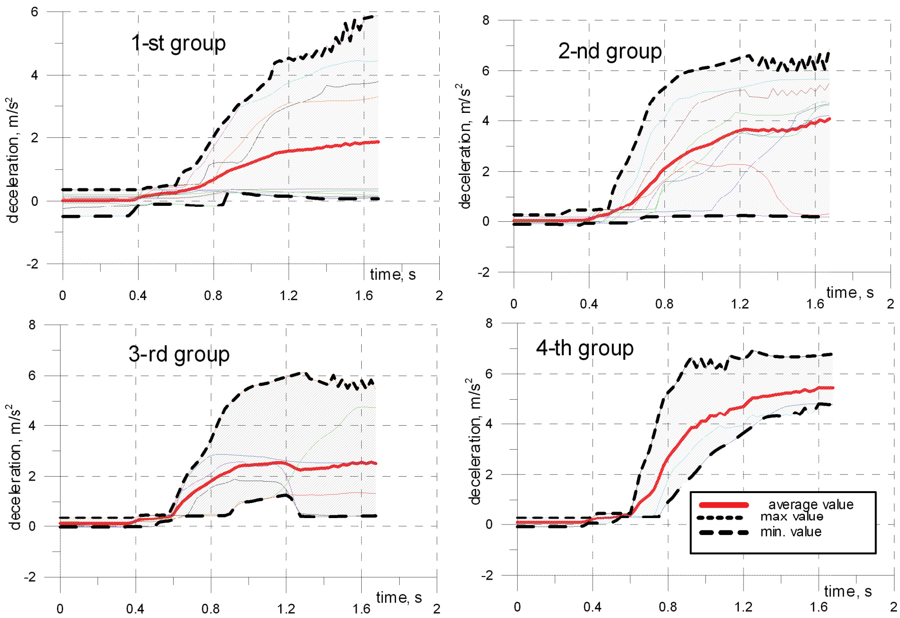

Fig. 14. The deceleration realised in the simulator for risk time t_{R0}=1.8s (v=60km/h, s=30m)

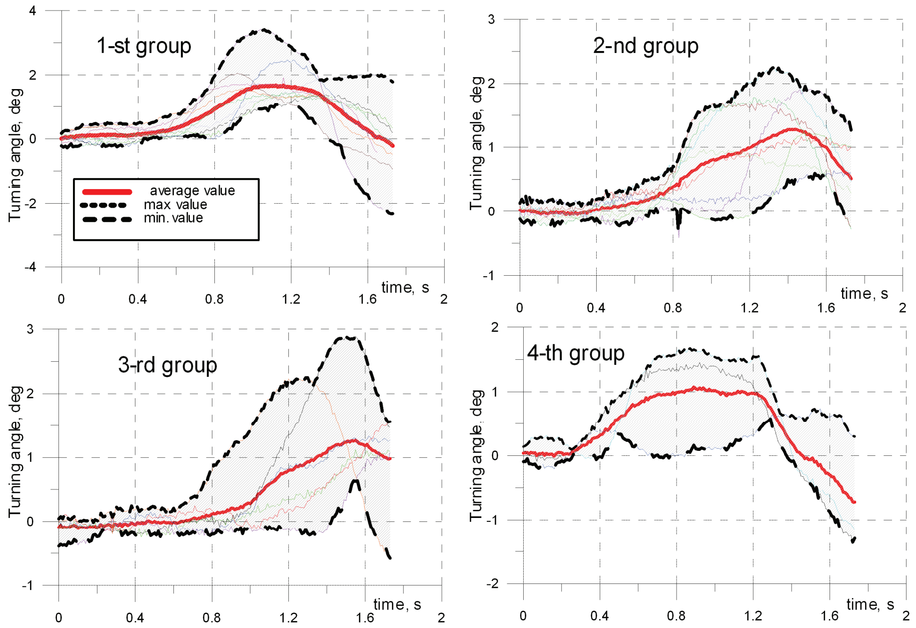

Fig. 15. The turning angle realised on the track for risk time t_{R0}=1.8s (v=60km/h, s=30m).

The above-mentioned characteristics illustrate that despite the division of drivers into four groups, the diversification of drivers' behaviours on the track and in the simulator is big. That is why, it is impossible to so clearly indicate similarities and regularities as it was analysed before in the case of probabilities of manoeuvre realization or reaction time. While analysing these characteristics it can only be pointed to the following regularities:

– on the characteristics are visible shorter reaction time in the simulator, both during braking and turning (confirmation of thesis from chapter 5);
– in the simulator all drivers braked with greater intensity – in some cases double or greater deceleration was obtained than on the track;
– in the simulator, all drivers performed stronger turnings during avoiding the obstacle – double or greater maximum values of turning angles than on the track.

With the aim to precisely quantitatively characterise the similarities or differences of the manoeuvre realization way, the identification of driver model parameters (described in equations (6) and (7)) has been conducted. The method of parameters identification on the basis of track test results has been described in detail in article [12]. In a similar way, the model parameter identification has been carried out on the basis of simulator test results.

The identification criterion was the compatibility of characteristics (in the time function) of the steered wheels' turning angle - equation (8) and deceleration - equation (9) obtained in experiments σ_{exper}, b_{exper} and obtained in a computer simulation of the driver model σ_{simul}, b_{simul}. A minimum criterion function value J_t, J_b, calculated between start time $t_1$and end time t_2 of a given manoeuvre $(T=t_2 - t_1)$ has been searched

for the turning angle $$J_t = \frac{1}{T}\int_{t_1}^{t_2}(\delta_{exper_i}(t) - \delta_{simul_i}(t))^2 dt \tag{8}$$

for deceleration $$J_b = \frac{1}{T}\int_{t_1}^{t_2}(b_{exsper_i}(t) - b_{simul_i}(t))^2 dt \tag{9}$$

A possible difference of model parameter values was the result of the fact that the proposed form of the driver mathematical model, described well the driver behaviour only in one testing environment. Article [13] illustrated high compliance of results obtained on the track and in the computer simulation with the use of the driver model and identified model parameter values.

To present that the proposed driver model well describes driver behaviour also in the simulator, there has been carried out the comparison of time courses of deceleration and turning obtained during simulator tests and computer simulation with the use of the mathematical driver model. At the same time, in this case the parameters of the model identified for tests in the simulator were used.

Fig 16 - 18 contain example results of simulations for different risk time values. In the selection process attention was drawn to the differentiation of turn and deceleration characteristics obtained in the simulator. Conducted simulations for identified model parameters on the basis of tests in the simulator point out that the mathematical driver model proposed by the authors does not concern solely one particular form of characteristics but well describes different forms of turning characteristics as well as deceleration obtained both on the track and in the simulator.

Since the proposed form of the mathematical driver model may be considered as adequate to describe driver behaviour both on the track and in the simulator, potential difference values of model parameters obtained in both environments shall be treated as the effect of differences in testing environments.

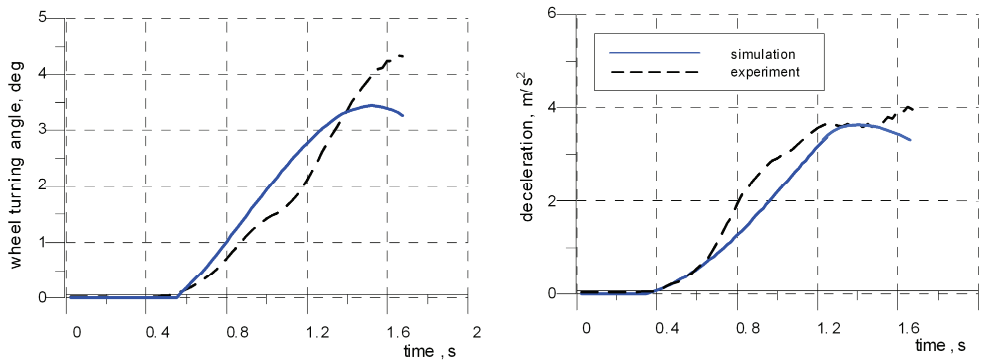

Fig. 16. Comparison of the turning angle courses and deceleration courses, obtained in simulation and registered in the experiment for risk time t_{R0}=1.2s (parameters for driver a 1st group)

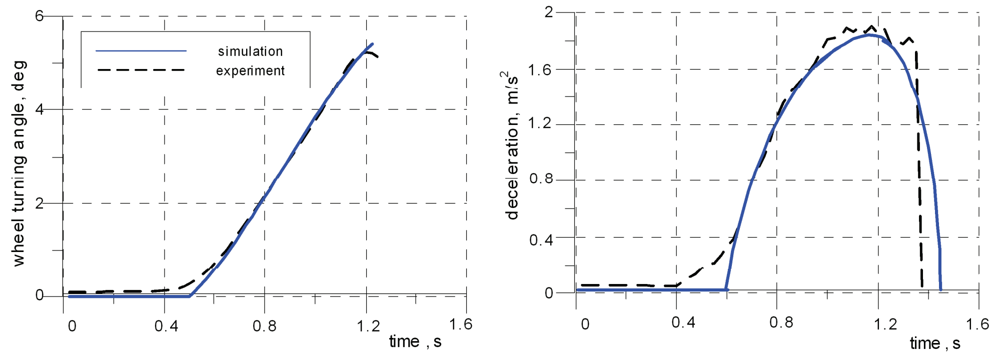

Fig. 17. Comparison of the turning angle courses and deceleration courses, obtained in simulation and registered in the experiment for risk time t_{R0}=1.8s (parameters for driver a 1st group)

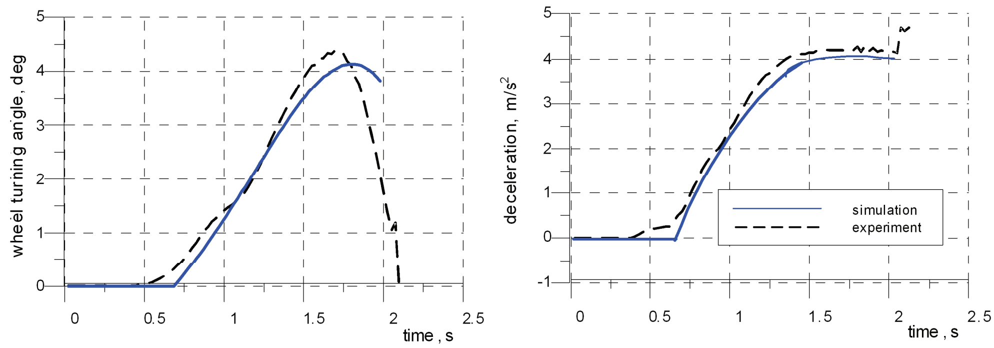

Fig. 18. Comparison of the turning angle courses and deceleration courses, obtained in simulation and registered in the experiment for risk time t_{R0}=2.16s (parameters for driver a 2^{nd} group)

For identified W1, W2, W3, W4, W5 coefficients, in most cases we did not succeed in establishing any regular form of organized value which allows for determination for them functional dependences. Well then, value ranges for those coefficients for particular groups of drivers were determined. Only in some cases, if it was possible, to determine linear regression equations [13].

To make comparisons and assessments easier, the analysis was limited exclusively to the comparison of average courses of deceleration and turning (thick line in fig. 14,15), for first two groups of drivers. Table 2 presents value ranges of identified model parameters for tests on the track and in the simulator. These ranges comprise all 15 trials of risk time values within 0.60s to 4.5s (see chapter 2).

Table 2. Values of driver model parameters identified on the basis of test on the track and in simulator

Coefficient		Group	Average characteristics deceleration and turning angle			
			track		simulator	
			min	max	min	max
Braking model – equation (6)	W1	1	-0,82	1,12	-1,5	-0,38
		2	-0,75	1.03	-2,0	-0,32
	W2	1	-0.91	1.21	-0,95	-0,35
		2	-0,45	0,45	-2,35	-0,98
	W3	1	0	0,9	0	0,9
		2	0	0,9	0	0,9
steering model equation (7)	W4	1	-0,31	2,82	-1,25	1,41
		2	0	2,5	-0,95	2,5
	W5	1	0,004	0,1	0,03	0,1
		2	0	0,056	0	1,11

Additionally, the results presented in table 2 are illustrated on the graphs – fig. 19 and 20.

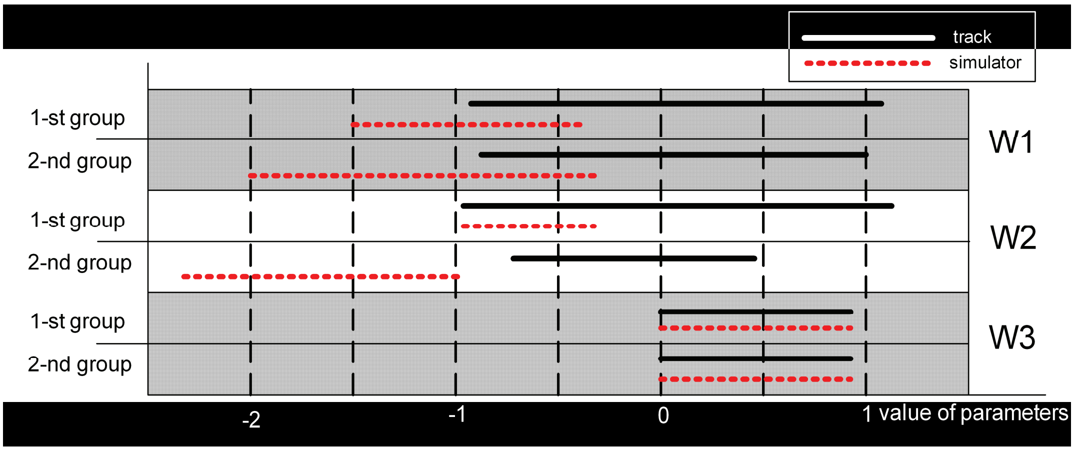

Fig. 19. Ranges for the values of braking model parameters for track and simulator tests

The analysis of W1 and W2 coefficient values did not allow to indicate, with reference to the whole group of drivers, either any functional dependence or correlation between values obtained on the track and in the simulator. Nonetheless, it can be stated that value ranges obtained on the track are moved towards positive values as compared to ranges obtained in the simulator.

Worth mentioning is the fact that W3 coefficient for both groups of drivers adopted values from the same range of variability, both during track and simulator tests. This coefficient occurs in equation (6) with an element being the inverse of a current risk time value. This means that, this element of the way a driver reacts during braking is approximately the same in both testing environments.

The analysis of W4 coefficient did not let to point out either any functional dependence in relation to the whole group of drivers or the correlation between values obtained on the track and in the simulator. It can only be stated that (similarly to W1 and W2 coefficients) the ranges of values obtained on the track are moved towards positive values in relation to the ones obtained in the simulator.

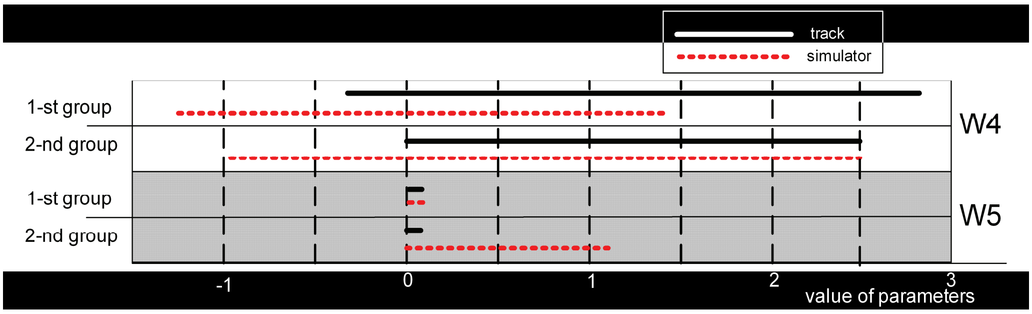

Fig. 20. Ranges of steering model parameters for track and simulator testing.

The analysis of W5 coefficient, however, leads to interesting conclusions. A bottom border of a value range, for both groups of drivers, and for both the track and the simulator, is more or less the same – close to zero. Whereas the upper border, for the first group of drivers is the same but for the second one is almost twice bigger in the simulator rather than on the track. W5 coefficient occurs in equation (7) with an element that described a current distance between the centre of a car and an obstacle, measured in lateral direction. This means that with a particular lateral distance between the car and the obstacle, for the drivers of the first group this element of driver behaviour during avoiding an obstacle is approximately the same in both testing environments, whereas for the drivers of the second group this element of driver behaviour in the simulator is nearly twice stronger than on the track. This has been quantitatively illustrated, through a mathematical model, confirmed above-mentioned descriptive difference between driver behaviour on the track and in the simulator.

7. The correlation analysis of driver model parameters obtained for individual drivers

While analysing driver behaviour on the track and in the simulator, it has been found out that there exists similarities and correlations for the whole tested population in relation to some parameters that characterise this behaviour. A strong correlation between reaction time on the track and in the simulator occurs. It was impossible to confirm the existence of correlation among model coefficients mentioned in chapter 6, yet the whole tested population was divided into smaller groups.

It occurred, however, that it is possible to observe the correlation among model parameters obtained in both testing environments, not in relation to average group behaviours but in case of the analysis of a single driver behaviour.

The analysis of correlations has been performed on 3 randomly selected drivers. The results are shown in table 3. Drivers A and B come from group ‘1’, whereas driver C comes from group ‘2’.

Table 3. Results of a correlation analysis of model coefficient

	LINEAR CORRELATION COEFFICIENT				
	W1	W2	W3	W4	W5
Driver ‘A’	0.824	0.896	0.658	0.925	0.899
Driver ‘B’	0.547	0.776	0.748	0.708	0.827
Driver ‘C’	0.663	0.620	0.786	0.901	0.804

The conducted correlation analyses of model coefficients (W1, W2, W3, W4, W5) show that the correlation between test results on the track and in the simulator is high. It needs to stated, however, that the correlation concerning reaction time and steering model coefficients (W4, W5) is much stronger than in the case of braking model coefficients (W1, W2, W3). Probably correlation between the steering model is stronger because drivers in both types of tests preferred that manoeuvre for the assumed accident scenario. In that case braking was regarded as a complementary action. We may presume that the situation may be different for other scenarios in which braking would be the dominant action.

8. Conclusion

In the following article there have been conducted the analysis of similarities and differences in drivers' behaviours in simulated accident situations on the car track and in the driving simulator. To enable this type of analysis, the similarity of experiments conducted in both testing environments has been guaranteed to the highest degree. This was achieved by fulfilling the following conditions: the same group of drivers was tested; the same testing scenario and parameters were applied, and finally the car with the same dynamic properties was used. It can therefore be stated that obtained differences in test results are solely the effect of testing environment influence.

High level of similarity accompanies the assessment of probability of turn taking decision in both environments, whereas decisions that concern braking, either with a service brake or an engine, are different in both environments.

The biggest similarity, represented by high values of correlation coefficients, are reflected in driver reaction time both during braking as well as turning. The similarity is also manifested in the fact that average driver reaction time determined for the whole tested population of drivers, both on the track and in the simulator, show linear dependence on the initial value of risk time.

It has been stated that driver reaction time during tests in the simulator are shorter that during tests on the track. However, the difference of the average values of time obtained in both environments is not fixed for a particular manoeuvre but decreases linearly with the decrease of risk time that characterises a particular trial, that is with the increase of the danger level of a situation. For the longest risk time, this difference exceeds 1 second during braking and reaches 0.4s while turning. For the shortest values of risk time this difference approaches zero.

The biggest diversity relates to the way of manoeuvre realization, represented as time courses of turning angle and braking deceleration. To illustrate this in a precise way (quantitatively), the authors used a driver model for the analysis of pre-accident situations.

The values of this model coefficients were identified and compared and on the basis of track and simulator tests. Despite the division of a tested driver population into four smaller groups, of similar reaction ways, it was impossible to obtain strong correlations or similarities. Among five identified coefficients, only one (for 1 and 2 groups of drivers shown in the article) took adopted the value from the same value range both for track and simulator tests.

It occurred, however, that it is feasible to observe the correlation among model coefficients obtained in both testing environments, not in relation to average group behaviours but in case of the analysis of individual drivers. It is true that the acquired correlation coefficients are not so high as in case of reaction time but can be treated as essential.

The above-mentioned similarities and differences of drivers' behaviours on the car track and in the driving simulator can be partly connected with a pre-accident scenario selected for the tests. One may suppose that for other scenarios, the situation may vary. It is therefore appropriate to carry out analogous comparisons for other scenarios of pre-accident situations (or generally speaking road situations). Only then it is possible to provide a complete answer for the question: in which aspects, drivers' behaviours in both environments are similar or identical, and in which they differ.

References

[1] GUO K.,GUAN H, *Modelling of Driver/Vehicle Directional Control System*, Vehicle System Dynamics 22(1993) 141-184

[2] REYMOND G., KEMENY A., DROULEZ J., BERHOZ Z., *Role of lateral acceleration in curve Driving: Driver model and experiments on a Real vehicle and a simulator*, Human Factors. The Journal of the Human Factors and Ergonomics Society, 43/2001, pp.483-495

[3] SHARP R.S., CASANOVA D., SYMONDS P., *A Mathematical Model for Driver Steering Control, with Design, Tuning and Performance Result,* Vehicle System Dynamics 33(2000) 289-326

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

[5] STAŃCZYK T. L., JURECKI R. S., *Modele kierowcy (możliwość ich wykorzystania do analizy sytuacji przedwypadkowych) (Driver models (possible uses in analyzing pre-accident situations)),* Zeszyty Naukowe Politechniki Świętokrzyskiej Kielce 2004, Zeszyt nr 79, 105-138. (in Polish)

[6] STAŃCZYK T. L., JURECKI R. S., *Identyfikacja parametrów modelu kierowcy dla sytuacji przedwypadkowych (w oparciu o wyniki badań eksperymentalnych na torze)* (*Identification of driver model parameters for pre-accident situations (based on results of experimental track tests)*, Teka Komisji Motoryzacji o/Kraków 2005, Vol. No. 29-30, 419-428. (in Polish)

[7] STAŃCZYK T. L., JURECKI R. S., *Precision in estimation time of driver reaction In car accident reconstruction*, Wydawnictwo IES, EVU Annual Meeting 8-10 November Kraków 2007, s. 325-334

[8] SZCZEPANIAK C., *Podstawy modelowania systemu człowiek – pojazd – otoczenie (Basics of modelling the system man - vehicle – environment),* Warszawa 1999, PWN. (in Polish)

[9] THAKUR K., *Simulation of Driver Behaviour as a Function of Driver error and Driver Daydream*, http://www.is.irl.cri.nz/pubdoc/1997/ILTSS.pdf

[10] WILLUMELT H. P., THOMAS JURGENSOHN T., Fahrer Modele- ein kritischer Uberblick, Teil 1 ATZ Automobilitechnische Zeitschrift 997/8/1997, 424-428

[11] WILLUMELT H. P., THOMAS JURGENSOHN T, Fahrer Modele- ein kritischer Uberblick, Teil 2 ATZ Automobilitechnische Zeitschrift 999/1997,552-560

[12] JURECKI R., *Modelowanie zachowania kierowcy w sytuacjach przedwypadkowych*, Rozprawa doktorska (*Modelling of driver behaviour in pre-accident situation, PhD thesis)*, Politechnika Świętokrzyska w Kielcach, Kielce Univesity of Technology, Poland.(in Polish), 2005

[13] JURECKI R., STAŃCZYK T. L., *Driver model for the analysis of pre-accident situations*, Vehicle System Dynamics, No.5, Vol. 47, 2009, pp. 589-612.

[14] JURECKI R., STAŃCZYK T. L., *Model matematyczny sposobu reagowania kierowcy w sytuacjach przedwypadkowych*, Zeszyty Naukowe Politechniki Warszawskiej, Nr. 4(67)/2007, str. 5-23 (in Polish)

[15] 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, October 2006.

[16] REED M., GREEN P., *Comparison of driving performance on rooad and in low – cost simulator using a concurrent telephone dialing task*, Ergonomics, 42/1999, pp.1015-1037

[17] WICHER J., *Bezpieczeństwo samochodów i ruchu drogowego (Safety of cars and Road traffic),* Warszawa WKiŁ 2002 (in Polish)

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

[19] HILLENBRAND J., *Fahrerassistenz zur Kollisionsvermeidung. PhD thesis*. Fortschritt-Berichte VDI, Reihe 12, Verkehrstechnik/Fahrzeugtechnik Nr.669, 2008.

[20] JANSSON J., JOHANSSON J., GUSTAFSSON F., *Decision Making for collision avoidance systems*. SAE Paper 2002-01-0403.

[21] CHODNICKI P., GUZEK M., LOZIA Z., MACKIEWICZ W., STEGIENKA I., 2004, *Statyczny symulator jazdy samochodem AutoPW wersja 2003 (Static driving simulator AutoPW, version 2003),* Zeszyty Naukowe Politechniki Świętokrzyskiej Kielce, Zeszyt nr 79, 157-164. (in Polish)

[22] LOZIA Z., *Symulatory jazdy samochodem*. WKŁ, Warszawa, 2008.

[23] LOZIA Z., *Model symulacyjny ruchu i dynamiki samochodu dwuosiowego, wykorzystywany w symulatorze (Simulatory model of movement and dynamics of a biaxial car used in a Simulator)*, Zeszyty Instytutu Pojazdów Politechniki Warszawskiej Warszawa, Zeszyt 4 (34)/99. 37-51(in Polish)

[24] DANNERT G.: *Grundprobleme der Reaktionzeit des Kraftfahrers*. Ferkehrsunfall und Fahrzeugtechnik, Nr 12/1998, S.328-334.

[25] GREEN M., *„How long does it take to stop?“ Methodological analysis of driver perception-brake times.* Transportation Human Factors No 2(3), 2000, pp. 195-216.

[27] TÖRNROS J.: *Effect of driving speed on reaction time during motorway driving*. Accident Analysis and Prevention, Vol. 27, No 4, 1995, pp. 435-442

[26] MAGISTER T., KRULEC R., BATISTA M., BOGDANOVIĆ L.: *The driver reaction time measurement experiences*. Innovative Automotive Technology – IAT'05, Bled,21st-22nd April 2005.

[28] MCGEHEE D.V., MAZZAE E.N., BALDWIN G.H.S.: *Driver reaction time in crash avoidance research: validation of a driving simulator study on a test track.* Proceedings of the 14th Triennial Congress of the International Ergonomics Association and the 44th Annual Meeting of the Human Factors and Ergonomics Society (IEA 2000), San Diego/USA, (6) 2000.