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MEASUREMENT OF THE DRIVER RESPONSE TIME IN THE SIMULATED AND REAL EMERGENCY DRIVING SITUATIONS

ABSTRACT

Since the real reaction time of a driver involved in an accident will always be unknown to reconstruction experts, and because the driver's reaction time databases published in the respective literature have become almost obscure and hard to compare with the everyday practice of the accident reconstruction, expert decision was made at Transport Safety Laboratory to engage in research of the driver's reaction time and in the reaction time measurement techniques as well and to develop a PC–based simulator for measurements of the driver reaction time. The structure of the Driver Reaction Timer simulator and its components are described as well as its measuring algorithm. The measurements of the driver's reaction time in the real and simulated driving environment were performed, and the results obtained are discussed. By comparing these results, the quality evaluation of the current stage of development of the simulator is addressed and the necessary further development of the simulator defined.

KEYWORDS

reaction time, measurement, simulation, emergency situations

1. INTRODUCTION

When road accidents are being reconstructed the accident reconstruction experts are almost without exception confronted with the determination of driver's reaction time. The driver's reaction time is defined as the time which runs from the moment of driver's perception of danger to the moment of driver's reaction to the circumstances either by steering or braking ([8], [11]).

The real driver's reaction time in the circumstances which led to the accident will always be unknown to reconstruction experts. Because of that reason the only way to obtain this value is estimation. For the purpose of correct estimation, the values regarding the driver's reaction time obtained experimentally are available in literature. A short resume of usage of values for the driver's reaction time in everyday reconstruction practice can easily show how different those figures are. In Slovenia the reconstruction experts use mostly the value of 0.6 s for the mean reaction time, while foreign literature (especially Anglo-American) suggests the value of 1.0 s for the driver's reaction time. The fact that these values are often used uncritically was confirmed by several experiments, the purpose of which was to determine the real reaction time of drivers in the case of the appearance of a sudden obstacle. In 1974 in the Calspan laboratory experiments were performed, in which barrels were thrown in front of the vehicles. The mean measured reaction time after the barrel was thrown and the moment of perception of the first driver's reaction (braking or avoidance) had the value 0.65 s, while the total range was between 0.40 s and 1.70 s. In these experiments 75% of the drivers reacted with braking (in case of appearance of a sudden obstacle) [7]. In 1989 Olson published the results of experiments, which were similar to those performed by the Calspan laboratory. The measured driver's reaction time (in case of appearance of a sudden obstacle) was between 0.80 s and 1.8 s. 85% of the drivers had a reaction time of 1.4 s [8]. In the latest edition of R. Limpert's book the reaction time in the range between 1.0 and 1.5 s in normal conditions (dry road, daylight etc.) is indicated. It is also indicated that special conditions (e. g. night or impact) can increase driver's reaction time up to 3 s [5].

A simple everyday accident case in which one vehicle hits another vehicle at rest can show us that the reaction time is not only a variable in calculations, but also a factor which influences the guilt of the participants in the accident.

From vehicle damage the impact speed of 18 km/h is estimated. Since no skid marks were discovered on the road and according to the driver's statement that braking was actually done before impact, a maximum deceleration of 5 g is estimated. At the accident site the visibility of 30 m is measured, the distance at which the driver cannot fail to observe another vehicle at rest down the road. Furthermore, the speed limit of 50 km/h is ascertained. The task of the reconstruction experts is to establish the vehicle speed before braking. For the sake of simplicity a very basic calculation procedure will be used. The distance covered by the vehicle until impact is determined by the equation:

$$s = v t_R + (v^2 - v_n^2) / 2a \qquad (1)$$

where a is the mean deceleration, s is the braking distance, v is the vehicle speed before braking, v_n is the vehicle speed at impact and t_R is the driver's reaction time. From this equation the vehicle speed before braking is:

$$v = -a t_R + \sqrt{v_n^2 + 2as + a^2 t_R^2} \qquad (2)$$

With regard to the described values of concerned variables the above equation yields different results when different values for the driver's reaction time are considered. If the driver's reaction time is 0.6 s, then the vehicle speed before braking was 55 km/h. For reaction times in an interval from 1.0 s to 1.8 s, the vehicle speeds before braking will be within the interval from 49 km/h to 40 km/h. Thus, if the reconstruction experts 'persist' in values of the driver's reaction time under 1 s, then it follows that the vehicle speed before braking was over the speed limit of 50 km/h.

Clearly, the reconstruction of an accident requires consideration of different issues regarding the driver's reaction time. The traffic situation, the driving conditions and the driver's psychophysical state (e. g. sleeplessness, sobriety, distraction, etc.) are the three major contributing spheres which influence the driver's reaction time. The everyday accident reconstruction practice indicated that the reaction time of the driver driving in different driving conditions is well described in literature ([1], [5], [8], [11], [12]). However, the driver's reaction time databases published in the respective literature became almost obscure. Furthermore, comparing the driving conditions with the known (i. e. published) conditions, the reaction time with the real case being subject of reconstruction become untrustworthy.

To gain a thorough insight into the subject of the driver's reaction to the real traffic situation, and especially for determination of the reaction time of drivers involved in the particular traffic situation preceding the accident under investigation and reconstruction the Transport Safety Laboratory at the Faculty of Maritime Studies and Transport, University of Ljubljana, decided to engage in:

a) the research of the driver's reaction time,
b) the reaction time measurement techniques, and
c) development of a PC–based simulator for the measurement of the driver's reaction time.

The focus is on the simulation of any actual traffic situation preceding the road accident, based on the accident scene diagram, accident eyewitnesses and participant statements, reported decisive parameters and field measurements, with the ability to determine the reaction time of drivers involved in the accident with regard to the actual driving conditions, visibility and the view field from such a simulation as a final objective of the Transport Safety Laboratory.

2. DRIVER REACTION TIMER

The FPP Driver Reaction Timer simulator, designed by R. Krulec at the Transport Safety Laboratory of the Faculty of Maritime Studies and Transportation [4] is composed of two subsystems: one for virtual driving simulation and stimulation, and the other for measurement of driver's actions and reactions; the two subsystems are connected via the sequence of reaction time phases (Fig. 2).

2.1. Virtual drive simulation and stimulation

The subsystem for virtual drive simulation and stimulation plays a video of driving. In this way the driver's attention is focused on the simulated driving. Between the times which are referred to in the program as the »Minimum time to next stimulus« and »Maximum time to next stimulus« in seconds, the program launches a stimulus to the driver. The visual stimulation is represented by four lights which can be coloured in four possible combinations. Each of them represents a different driver's reaction (Fig. 1); partial (i. e. light) braking which requires that the brake pedal is partially applied[1], extreme braking until vehicle's stop, and stimulus for avoidance to the left or right. In the graphical user interface a group of stimulations can be chosen which will be performed.

In the subsystem for virtual drive simulation and stimulation (beside the mentioned parameters) also the desired video and its speed (in km/h) can be set. In this way the video is synchronized with the speed obtained by pressing the driver's accelerator pedal.

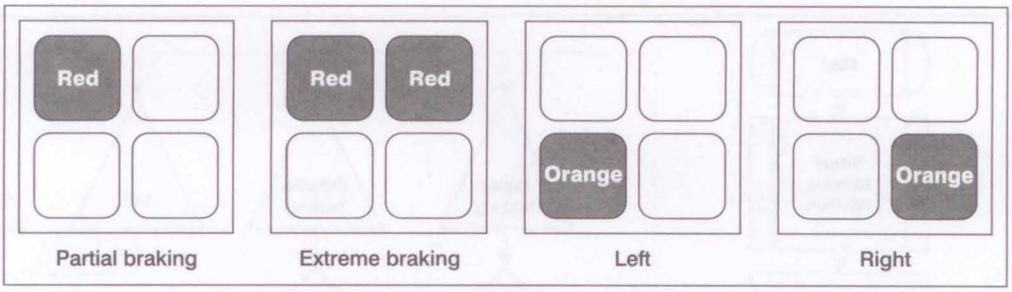

Figure 1 - The four possible visual stimulations[2]

2.2. The perceiving of driver's actions

The driver's reactions to the applied stimulus are perceived when they react (as expected) with their arms and act on the steering wheel when avoidance stimulus is applied, or when they react (as expected) with their legs and apply the accelerator and brake pedals when braking stimulus is applied. The driver's actions with the steering wheel and accelerator and brake pedals influence the A/D converter.

The corresponding data produced by the converter are acquired and processed by the aid of a computer. The A/D converter offers a 10-bit resolution, which means 1024 different values for the state of the steering wheel and another 1024 for both pedals, the accelerator and the brake. Because the signals from the converter are sent via a program interface every millisecond, the noise occurs in the values of the converter's state due to fast oscillations. The implementation of a simple filter into the subsystem, which stabilizes the values overcomes the problem.

For every reaction the validity range of the steering wheel declination and pedal push can be defined in percentiles. The default values for the steering wheel declination and also extreme braking, are between 50% and 100%. For partial braking the validity range is between 20% and 90% of a pedal push. At braking a minimum push time of the brake pedal »Hold Time«, in milliseconds, can be set, which determines if a reaction is valid. Also a maximum speed »Max Speed«, which is reached when the accelerator pedal is applied 100%, can be set.

The program interface mmsystem based on the operating system Windows 2000/NT/XP offers the function timeGetTime(), which returns the exact time (in milliseconds) from the start of the operating system. This value is a DWORD type and comprises 32 bits, which means that it turns around approximately every 49.71 days. A high resolution and accuracy of time measuring is ensured by the operating system. A maximum error of 2 milliseconds in the program is set via the functions timeBeginPeriod() and timeEndPeriod(), which ensures accuracy also with fast successive calls of the function timeGetTime().

2.3. Driver's reaction time measurements

The two subsystems are connected with the program measuring module, which measure (Fig. 2):

- the beginning of visual stimulation,
- the reaction time (i. e. the driver's action to a stimulus), and
- the total reaction time.

The flowchart of a measuring course is shown in Figure 3. It can be seen that the algorithm considers also invalid reactions, which can occur if the pedal is not sufficiently applied and thus braking is not achieved; and the same holds if the steering wheel is rotated insufficiently or in the wrong direction.

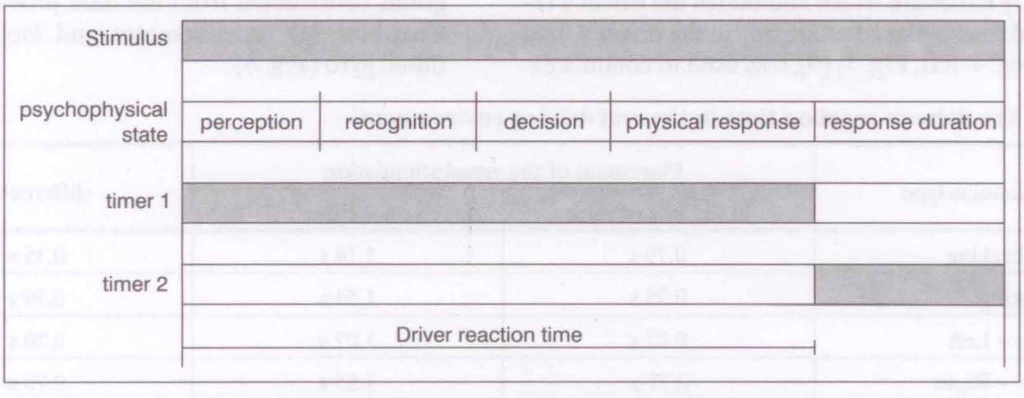

Figure 2 - Gantt diagram of program measuring modules

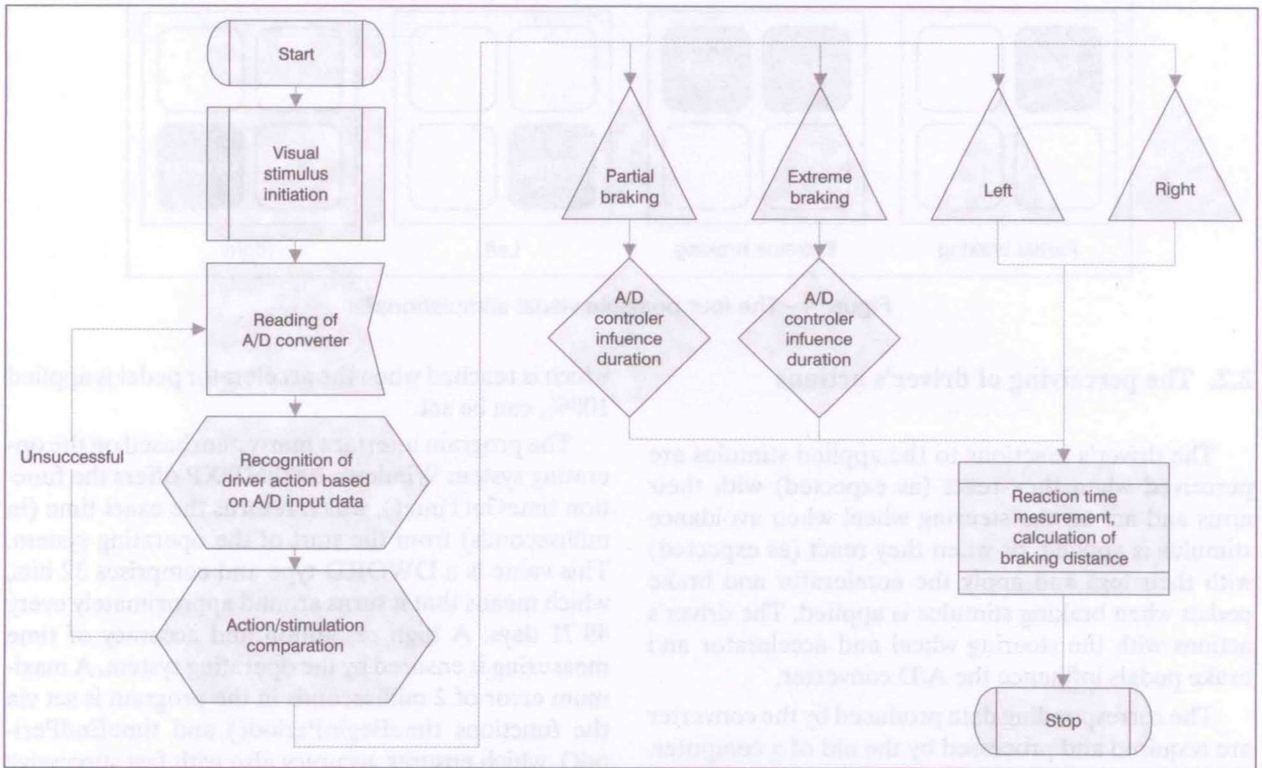

Figure 3 - Flowchart of a measuring course

3. REACTION TIME EXPERIMENTS

For the measurement of the driver's reaction time, experiments in the real and simulated driving environment were performed.

In the simulated driving environment the driver's reaction time was measured with:

1. the Vericom Stationary Reaction Timer (Tab. 2 and Tab. 3) [13], and
2. the FPP Driver Reaction Timer (Fig. 4–right; Tab. 2 and Tab. 3) [4].

In the real driving environment the driver's reaction time was measured directly and indirectly.

When the driver's reaction time was measured directly the Vericom VC3000 accelerometer with supplementary hardware which stimulates the driver's reaction and can be placed arbitrarily in the driver's field of view (Fig. 4–left, Fig. 7) [9], was used to conduct experiments. These were performed in daylight in good weather conditions (Table 1) with visual stimulus equipment arranged in the direct line of sight of the driver (Fig. 4–left, Fig. 7–left) and off–centre to the driver's direct line of sight (Fig. 7–right). The weather is considered good when the visibility is not obscured and the coefficient of friction is not affected.

The driver's reaction time to the anticipated danger was measured indirectly by means of:

1. studying the intra–frame time of the consecutive frames of a movie of a driving vehicle taken with the (ordinary off–the–shelf) digital camera (Fig. 5), and
2. studying the time between the characteristic peaks of vehicle acceleration and angular velocity diagrams constructed from the data provided by the Crossbow 3D accelerometer and Horizon rotational gyro (Fig. 6).

Table 1 - The driver's reaction time in the real driving environment[3]

Stimulus type	Placement of the visual stimulation		difference
	in the line of sight	off–center*	
Extreme braking	0.79 s	1.14 s	0.35 s
Light braking	0.95 s	1.54 s	0.59 s
avoidance – Left	0.87 s	1.07 s	0.20 s
avoidance – Right	0.77 s	1.55 s	0.78 s

* to the line of sight

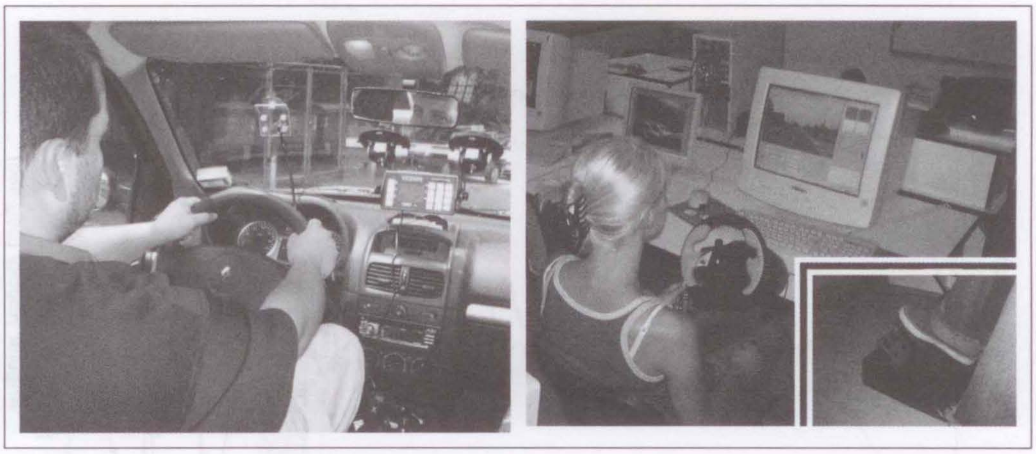

Figure 4 - Measurements of the driver's reaction time in real driving environment (visual stimulus equipment is placed in the direct line of sight of the driver) and in the environment simulated on the PC-based simulators (note how visual stimulus is located on the side of the screen)

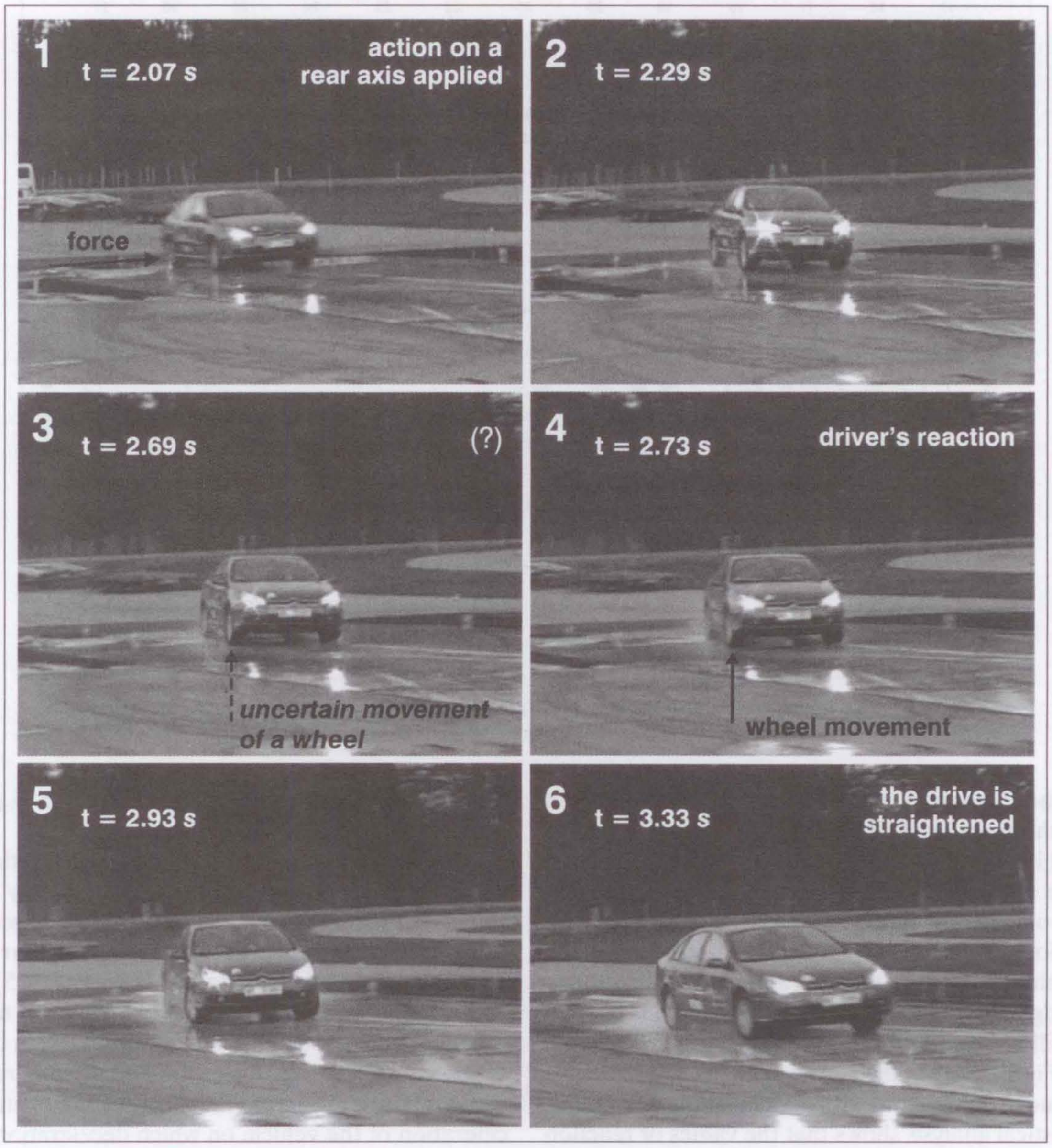

Figure 5 - A study of the intra-frame time of the consecutive frames of a movie of a vehicle driving at approximately 25 km/h (note how uncertain the moment of wheel movement is comparing frames 3 and 4)

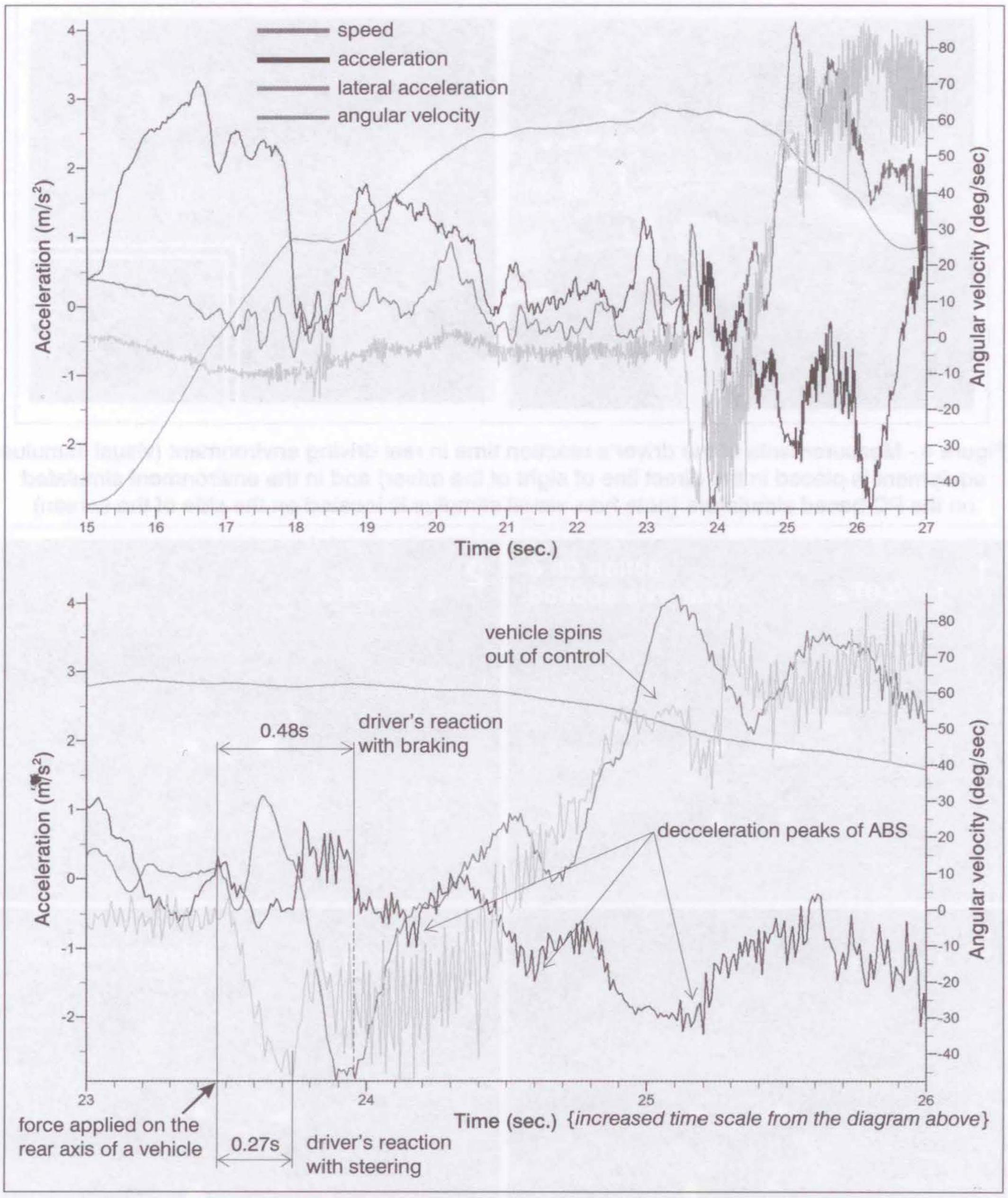

Figure 6 - The driver's reaction time to an anticipated danger deduced from diagrams of acceleration, lateral acceleration, speed and angular velocity

Figure 5 shows how and when the driver reacted when the force applied on the rear axis of a vehicle caused its rotation. Clearly, from studying the motion picture only reactions of a driver visible to the observer outside the vehicle might be investigated with conditional reliability. Using such a method for the determination of the driver's reaction time the subjective judgment of when the driver's reaction is observable will be always present (compare frames #3 and #4 of Fig. 5). Surely, the method can provide the reaction time of a driver but with no–negligible deviations. A statistical analysis shows that the values of reaction times of drivers to an anticipated danger are normally distributed with the mean value of 0.42 s and standard deviation of 0.14 s at a confidence level of 95 % (significance level of 5 %).

A study of diagrams of tangential acceleration, lateral acceleration, speed and angular velocity is presented in Figure 6. From the graph of lateral acceleration and angular velocity the action on the rear axis of a vehicle causing it to rotate (as shown in Fig. 5) is distinguishable as abrupt plunge. This point in time on the diagram is used as a reference from which driver's reactions are examined closely. The driver's reaction with braking is seen from the diagram of tangential acceleration of the vehicle on which deceleration is observed when brakes respond to the driver's input. The driver's response with steering is seen from diagrams

Table 2 - Comparison of the driver's reaction time results from the experiments in the real driving environment with the results obtained in the simulated driving environment

Visual stimulus type	Driving environment			
	Real*	Simulated		difference
	(1)	(2)	(3)	
		Vericom	Reaction Timer	(3) – (1)
Extreme braking	0.91 s	0.64 s	0.63 s	– 0.28 s
Light braking	0.97 s	0.71 s	0.72 s	– 0.25 s
avoidance – Left	0.87 s	0.72 s	0.75 s	– 0.12 s
avoidance – Right	0.83 s	0.83 s	0.80 s	– 0.03 s
Orientation mean value:	– 0.2 s			

*The visual stimulus equipment was arranged in the direct line of sight of the driver.

Table 3 - Comparison of the driver's reaction time results from the experiments in the real driving environment with the results obtained by the Driver Reaction Timer simulator developed

Visual stimulus type	Driving environment		
	Real*	Simulated	difference
	(1)	(2)	
		Reaction Timer	(2) – (1)
Extreme braking	1.14 s	0.63 s	– 0.51 s
Light braking	1.54 s	0.72 s	– 0.82 s
avoidance – Left	1.07 s	0.75 s	– 0.32 s
avoidance – Right	1.55 s	0.80 s	– 0.75 s
Orientation mean value:	– 0.6 s		

* The visual stimulus equipment was arranged off–centre to the direct line of sight of the driver.

of lateral acceleration and angular velocity since those are showing the point in time when the rotation of the vehicle changes direction.

Clearly, such an approach cannot provide an answer to when the driver touched the brake pedal or when they actually started to rotate the steering wheel. The results obtained from the method described and presented in Figure 6 are, namely, combined reactions of the driver and the vehicle. However, this investigation method can be of use when type and sequence of the driver reactions are scrutinized.

4. THE EVALUATION OF A SIMULATOR

The first tests where drivers were stimulated for partial and extreme braking and for avoidances to the left and right already showed non-negligible (note the introduction why) deviations between reaction times obtained in the real driving environment and those in the simulated environment on the simulator. The mean deviation amounts to 0.2 seconds (Table 2) when results from the simulator are compared to the experimental results from the real driving environment with the visual stimulation of a driver in their direct line of sight. Deviations increase up to 0.8 seconds (Table 3) when experimental results from the real driving environment with the visual stimulation installed off–centre to the driver's direct line of sight are compared. The driver's reaction time is longer in the real driving environment than in simulations.

Note (Table 2) that the results obtained in the simulated driving environment using the developed Reaction Timer and the Vericom Stationary Reaction Timer do not differ significantly.

From the presented results one drawback of the simulated driving environment became evident: it cannot simulate weather impact on the driving conditions.

The first reason for the described difference between the values of the reaction time obtained on the simulator and in the real driving environment when extreme or partial braking was stimulated is that the experiment in the real driving environment, apart from the driver's reaction time accounts also for the time in which the vehicle brake system reacts, while the simulator measures just the time needed for the driver to react to stimulus. According to literature

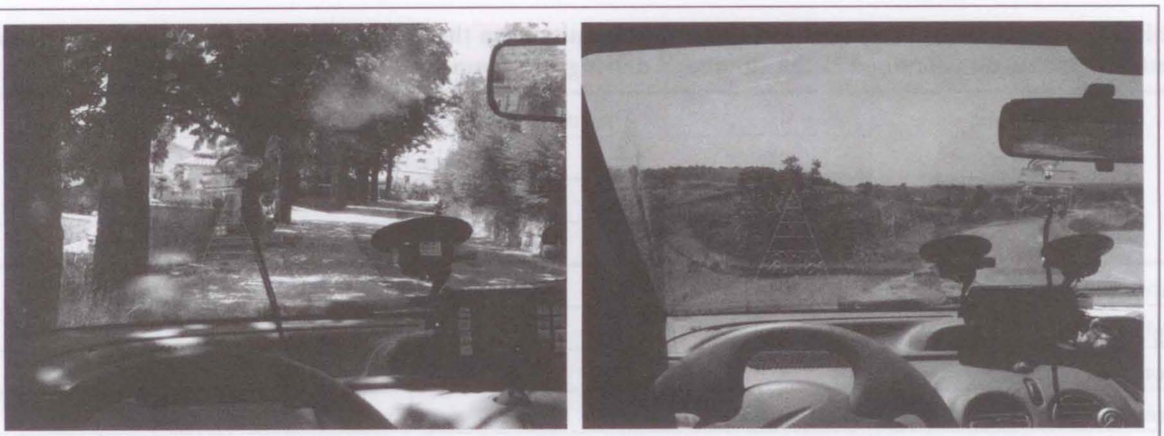

Figure 7 - The installation of a visual stimulator in the direct line of sight (left, avoidance to the left is stimulated) and off-center to the line of sight (right, extreme braking is stimulated) for the real driving environment experiment

([3], [6], [10]) the hydraulic brake system response time in a passenger car amounts to approximately at least 0.1 s. In consequence, the driver's reaction time results obtained in the real driving environment are therefore naturally significantly longer than those found from experiments in the simulated driving environment.

The second most important reason for the mentioned deviation, especially when the avoidance is stimulated, is that the driver is conscious of the fact that they are not exposed to any real danger during simulations. Furthermore, because with time the driver became fully aware that they are not actually driving and therefore during a simulation the driver can focus only on the lights which provide the stimulus. During the experiments, namely, the direction of the driver's eyes (the look) was not controlled and it was not attracted by any means or forced to follow the video of the vehicle driving. Consequently, especially when they realized that their aptness is at stake, the drivers in the simulated environment reacted very aggressively to the stimulus, even more so than in real driving conditions, not to mention that they were racing for the best reaction time result. The jerkiness of the steering wheel and of the brake pedal, done in simulations, was such that this would be very dangerous for a mediocre driver in real driving conditions. Frankly, the results from the simulated driving environment were "as good as" 0.4 seconds of reaction time. That is almost the driver's reaction time to the anticipated danger (Fig. 5 and Fig. 6), and it closely resembles the driver's reflex time [2].

In the real driving environment the influence of the position of the lights which provide the stimulus on the driver's reaction time was observed as significant. If the lights were positioned off-centre to the direct line of sight (Fig. 7) of the driver their reaction time was significantly longer than when the visual stimulus equipment was in their direct line of sight observing the traffic situation in the frontal area of the vehicle as presented in Tables 1 and 2. The described difference in the range from 0.2 to 0.8 seconds indicates the importance of the location from which the visual stimulation comes to the driver. From the same findings (Tables 1 and 2) it can be deduced that one of the reasons for the difference between reaction times obtained in the real driving environment and those in the simulated environment on the simulator (Tables 2 and 3) is the inappropriate location of the visual stimulation on the screen compared to the video presentation of driving. Therefore, the driver's reaction time results obtained in the simulated environment are not realistic as expected.

The reality, in which the measurements are performed in the real driving environment is left to the co-driver who controls the lights of the stimulator. If the co-driver is clumsy in his movements, the driver can guess the moment of the next stimulus or even the type of stimulus. It is not necessary to stress in particular that the reaction time is shortened in this way and the results are not realistic. The interpretation of the results measured in real conditions is very important. Attention should be paid only to those results in traffic situations which increase concentration and driver's focus on driving.

5. CONCLUSION

The first tests show that the FPP Driver Reaction Timer simulator, designed by R. Krulec at the Transport Safety Laboratory of the Faculty of Maritime Studies and Transport, is comparable in its abilities to commercial ones.

However, the first tests where drivers were stimulated for partial and extreme braking and for avoidances to the left and right also showed non-negligible deviations between reaction times obtained in the simulated environment compared to those experimentally obtained in the real driving environment or compared to driver's reaction times published in the respective literature.

From the experiments performed it can be concluded that the recorded difference results from inappropriate location of the visual stimulus on the PC based simulator screen with regard to the video representing simulated driving. The only adequate position of the visual stimulus is such that the video of the simulated driving is played as background. It must be assured that the location of the visual stimulation light is within the area through which the driver performs the scan of the surroundings of the vehicle observing traffic and impeding fixed and movable obstacles. It is not necessary that the visual stimulus is placed directly in the line of sight. If it is placed broadly off-center to the line of sight the driver's reaction time to the objects closing from the side can be measured, as long as the visual stimulus is placed within the mentioned driver's real scanning area.

Further development of the FPP Driver Reaction Timer will be focused on the completion of the video database and on the inclusion of real disturbances and burdening of the driver, based on the comparison between real driving environment and simulations. Special focus will be devoted to the control of the actual driver's direction of looking. It is expected that this will provide a more realistic picture of the influences on the driver's reaction time.

Finally, another finding should be emphasized and can be derived from the driver's reaction time experiments in the real driving environment. Namely, the driver's reaction time to unknown and unexpected obstacle or danger in front of a vehicle is on the average in the order of 10% longer than 1 (one) second. This finding is important since the Slovenian accident reconstruction experts use 1 (one) second as a standard reaction time of the driver involved in an accident. Further investigations should be made to find the exact values of driver's reaction time in different circumstances, but the results presented in this article together with the abundant existing literature on this subject must be sufficient to challenge a response of the expert community.

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POVZETEK

MERJENJE VOZNIKOVEGA ODZIVNEGA ČASA V SIMULIRANIH IN REALNIH NEVARNOSTNIH STANJIH

Reakcijski čas voznika udeleženega v prometni nesreči je za izvedenca, ki rekonstruira prometnmo nesrečo vedno in vsakič neznana veličina. Ker so baze podatkov voznikovih reakcijskih časov, objavljenih v merodajni literaturi, postale že sila nepregledne in zlasti, ker so pogoji pri katerih so bili objavljeni reakcijski časi izmerjeni težko primerljivi s pogoji prometne nesreče, ki je predmet rekonstrukcije, je bila v Laboratoriju za varnost v prometu sprejeta odločitev za začetek raziskav voznikovega reakcijskega časa, metodologije in tehnik merjenja voznikovega reakcijskega časa ter razvoj simulatorja za merjenje voznikovega reakcijskega časa. Predstavljene so komponente, struktura in merilni algoritmom omenjenega simulatorja. Pojasnjeni so rezultati odzivnih časov voznikov na realna nevarnostna stanja, ki so bili izmerjeni v realnih pogojih vožnje. Primerjava rezultatov merjenj odzivnih časov voznikov v simuliranem in realnem voznem okolju pa služi v pričujočem prispevku kot osnova za kvalitativno oceno trenutne stopnje razvoja simulatorja ter za njegov prihodnji razvoj.

KLJUČNE BESEDE

reakcijski čas, merjenje, simulacija, nevarna stanja

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1. In the real driving environment experiment when the partial (i.e. light) braking is stimulated the driver is expected to apply brake in such a manner that the speed of a vehicle is reduced by at least 50%, but the vehicle must not come to rest.
2. The driver is stimulated visually in the simulated environment in the same way as in the real driving environment with the same meaning of particular stimulus.
3. The uniformity of all experiments performed in the real driving environment was assured with regard to the density of traffic, route taken, lighting, visibility, surface conditions, and the reported psychophysical state of drivers and co-drivers involved.

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