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Meritve voznikovega odzivnega časa

Measuring a Driver's Reaction Time

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Odzivni čas voznika, udeleženega v prometni nesreči, je za izvedenca, ki rekonstruira prometno nesrečo, vedno in vsakokrat neznana veličina. Baze podatkov odzivnih časov voznikov, objavljene v literaturi, so postale že sila nepregledne, pogoji, pri katerih so bili ti odzivni časi izmerjeni, pa težko primerljivi s pogoji prometne nesreče, ki je predmet rekonstrukcije. V Laboratoriju za varnost v prometu so se zato začele raziskave voznikovega odzivnega časa, metodologij in tehnik merjenja voznikovega odzivnega časa ter razvoj simulatorja za merjenje voznikovega odzivnega časa. Predstavljene so komponente, struktura in merilni algoritem omenjenega simulatorja. Pojasnjeni so rezultati odzivnih časov voznikov na resnična nevarna stanja, ki so bili izmerjeni v stvarnih razmerah vožnje. Primerjava rezultatov merjenj odzivnih časov voznikov v simuliranem in resničnem voznem okolju pa je namenjena za kakovostno oceno simulatorja ter načrtovanje njegovega prihodnjega razvoja.

(Ključne besede: nezgode prometne, časi odzivni, meritve, simuliranje, stanja nevarna)

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 relevant literature have become almost obscure and hard to compare with the everyday practice of accident reconstruction, an expert decision was made at the Transport Safety Laboratory to investigate a driver's reaction time and reaction-time measurement techniques as well as to develop a PC-based simulator for measurements of a driver's reaction time. The driver-reaction-timer simulator's structure and its components are described together with its measuring algorithm. The measurements of the driver's reaction time in real and simulated driving environments were performed, and the results obtained are discussed. By comparing these results, a quality evaluation of the current stage of development of the simulator is addressed and the necessary further development of the simulator is defined.

(Keywords: traffic accident, reaction times, measurements, simulations, dangerous situations)

0 UVOD

Pri rekonstrukciji prometnih nezgod se pogosto pojavljajo primeri, ko mora izvedenec cestnoprometne stroke v svojih izračunih upoštevati odzivni čas voznika. Odzivni čas voznika je pri tem mišljen kot čas, ki preteče od trenutka, ko voznik zazna nevarnost in do trenutka, ko se voznik bodisi z izmikanjem ali zaviranjem odzove na okoliščine ([8] in [11]).

Resnični odzivni čas voznika v dejanskih okoliščinah, ki so privedle do nezgode, bo za izvedenca vedno neznanka. Prav zato je ocena edini način za določitev odzivnega časa voznika. Za pravilno oceno vrednosti odzivnega časa so

0 INTRODUCTION

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

The real driver's reaction time in the circumstances that led to the accident will always be unknown to reconstruction experts. For that reason the only way to obtain this value is by an estimation. For the purpose of a correct estimation, values relating običajno na voljo različni eksperimentalni podatki, dostopni v ustrezni literaturi. Kratek povzetek uporabe znanih podatkov o odzivnih časih voznikov v vsakdanji izvedeniški praksi zlahka pokaže, kako različni so ti podatki. Slovenska izvedeniška praksa najpogosteje uporablja povprečni odzivni čas 0,6 s; tuja literatura, zlasti anglo-ameriška, pa za odzivni čas voznikov navaja čas 1,0 s. Na to, da so te vrednosti dostikrat nekritično uporabljene, kažejo različni preizkusi, katerih namen je bil ugotoviti dejanski odzivni čas voznikov v primeru pojava nenadne ovire. V laboratoriju Calspan so leta 1974 izvajali preizkuse, pri katerih so pred vozila metali sode. Srednji izmerjeni odzivni čas med trenutkom meta soda in trenutkom zaznavanja prvega odziva voznika (zaviranje ali izmikanje) je bil pri teh poskusih 0,65 s, razpon pa je znašal med 0,40 s in 1,70 s. Pri teh preizkusih se je v primeru nenadne ovire 75 odstotkov voznikov odzvalo z zaviranjem [7]. Leta 1989 je Olson objavil rezultate preizkusov, ki so bili izvedeni podobno kakor tisti v laboratoriju Calspan. Izmerjeni odzivni čas voznika (v primeru pojava nenadne ovire) je znašal med 0,80 s in 1,8 s, pri tem pa je imelo 85 odstotkov voznikov odzivni čas 1,4 s [8]. R. Limpert v najnovejši izdaji svoje knjige navaja, da je v normalnih razmerah (suha cesta, dnevna svetloba itn) odzivni čas voznika med 1,0 in 1,5 s, poleg tega pa navaja, da se lahko ta čas v primeru noči ali trka s pešcem poveča do 3 s [5].

Da odzivni čas voznika ni samo podatek v izračunih, ampak lahko vpliva na odgovornost udeležencev nesreče, kaže preprost vsakdanji primer prometne nesreče, pri katerem se vozilo zaleti v mirujoče vozilo.

Iz poškodb vozila se je dalo oceniti, da je naletna hitrost znašala 18 km/h. Glede na to, da na vozišču ni bilo vidnih sledi zaviranja, voznik pa je trdil, da je pred trkom zaviral, je bil pojemek njegovega vozila pri zaviranju največ 0,5g. Ogled kraja nezgode je pokazal, da je voznik gibajočega se vozila lahko zagledal mirujoče vozilo 30 m pred mestom trčenja. Naj bo hitrost vožnje na obravnavanem odseku ceste omejena na 50 km/h. Naloga izvedenca je bila ugotoviti hitrost vozila pred zaviranjem. Naj zgolj za pojasnilo uporabimo sila poenostavljen postopek izračuna hitrosti vožnje vozila, ki je trčilo. Pot, ki jo je vozilo opravilo do trka, določa enačba:

to the driver's reaction time obtained experimentally are available in literature. A short resume of the usage of values for the driver's reaction time in everyday reconstruction practice can easily show how different those figures are. In Slovenia, reconstruction experts mostly use a value in the range from 0.6 s to 1.0 s for the mean reaction time, while foreign literature (especially Anglo-American) suggests a 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 sudden appearance of an 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 first driver's reaction (braking or avoidance) had a 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 by braking (in the case of the sudden appearance of an obstacle) [7]. In 1989, Olson published the results of experiments that were similar to those recorded by the Calspan laboratory. The driver's measured reaction time (in the case of the sudden appearance of an obstacle) was between 0.80 s and 1.8 s. Eighty-five percent of the drivers had a reaction time of 1.4 s [8]. In the latest edition of R. Limpert's book a reaction time in the range between 1.0 and 1.5 s under normal conditions (dry road, daylight etc.) is suggested. It is also indicated that special conditions (e.g., night or impact) can increase a 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 that influences the feelings of guilt of the participants in the accident.

From the damage to the vehicle an 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 0.5 g is estimated. At the accident spot a visibility of 30 m, for the driver to observe an obstacle, is measured. Furthermore, the speed limit of 50 km/h is ascertained. The task of the reconstruction experts is to establish the vehicle's speed before braking. For the sake of simplicity a very basic calculation procedure will be used. The distance covered by the vehicle before impact is determined by the equation:

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

kjer so a srednji pojemek, s pot ustavljanja, v hitrost pred zaviranjem, v_n hitrost vozila ob trku in t_R odzivni čas voznika. Iz te enačbe sledi hitrost vozila pred zaviranjem:

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

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

Če v zgornjo enačbo vstavimo navedene podatke, dobimo, ob upoštevanju odzivnega časa voznika 0,6 s, da bi hitrost vozila pred zaviranjem znašala 55 km/h, pri odzivnem času 1,0 s, bi bila ta hitrost 49 km/h, pri odzivnem času 1,8 s pa 40 km/h. Če torej izvedenec 'vztraja', da je imel v obravnavani nezgodi voznik odzivni čas pod 1 s, bi to pomenilo, da je bila njegova hitrost večja od dovoljene hitrosti 50 km/h.

Pri obravnavi dejanskih nesreč se torej očitno lahko pojavljajo različna vprašanja v zvezi z odzivnim časom voznika. Prometna situacija, razmere pri vožnji in voznikovo psihofizično stanje (npr. neprespanost, treznost, odvračanje voznikove pozornosti itn.) so trije poglavitni dejavniki, ki vplivajo na odzivni čas voznika. Vsakdanja izvedeniška praksa pri rekonstrukciji prometnih nesreč kaže na to, da je odzivni čas voznika pri različnih voznih razmerah obsežno popisan v literaturi ([1], [5], [8], [11] in [12]), vendar pa so postale objavljene baze podatkov o odzivnih časih voznikov sila nepregledne. Pogost problem se pojavlja zaradi neprimerljivosti dejanskih razmer pri prometni nesreči, ki je predmet rekonstrukcije, z razmerami preizkusnih meritev odzivnih časov voznikov, objavljenih v literaturi. Izbran odzivni čas voznikov zato ni povsem zanesljiv.

Za celovito razumevanje problematike odzivnih časov voznikov v dejanskih prometnih razmerah in zlasti za praktično določanje odzivnih časov voznikov, udeleženih v značilnih prometnih stanjih pred nesrečo, ki je preiskovana in rekonstruirana, so v Laboratoriju za varnost v prometu na Fakulteti za pomorstvo in promet, Univerze v Ljubljani stekle:

a) raziskave odzivnih časov voznikov,
b) raziskave tehnik merjenja odzivnih časov in
c) razvoj simulatorja na osnovi osebnega računalnika za meritve odzivnih časov voznikov.

Poudarek pri raziskavah je predvsem na simulacijah kakršnihkoli dejanskih stanj pred

With regard to the described values of the variables the above equation provides us with 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's speed before braking was 55 km/h. For reaction times in an interval from 1.0 s to 1.8 s, the vehicle's speeds before braking will be within the interval from 49 km/h to 40 km/h. Thus if the reconstruction expert 'persists' in values of the driver's reaction time under 1 s, then it follows that the vehicle's speed before braking was over the speed limit of 50 km/h.

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

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

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

The focus is on the simulation of an actual traffic situation preceding a road accident, based on cestnoprometnimi nesrečami; simulacije naj pri tem temeljijo na skicah prometnih nesreč, izjavah prič in udeležencev, znanih odločujočih parametrih in terenskih meritev. Cilj Laboratorija za varnost v prometu je, da bi simulator zagotavljal zmožnost določanja stvarnih odzivnih časov voznikov, udeleženih v prometnih nesrečah glede na dejanske okoliščine odvijanja prometa, vozne razmere, vidljivost in vidno polje.

the accident-scene diagram, accident-eyewitness 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 the final objective of the Transport Safety Laboratory.

1 SIMULATOR ZA MERJENJE ODZIVNIH ČASOV

Simulator za merjenje odzivnih časov, ki ga je zasnoval R. Krulec v Laboratoriju za varnost v prometu na Fakulteti za pomorstvo in promet [4], je sestavljen iz dveh podsistemov: podsistema za navidezno simulacijo vožnje in sprožanje vidne spodbude ter podsistema za merjenje ukrepov oziroma odzivov voznika. Podsistema povezuje zaporedje faz odzivnega časa (sl. 2).

1.1 Navidezna simulacija vožnje in sprožanje

Podsistem za navidezno simulacijo vožnje in sprožanje vidnih spodbud v postopku merjenja odzivnega časa voznika predvaja vnaprej pripravljen videoposnetek vožnje in s tem pridobi pozornost voznika. Med časoma, ki sta v programu določena kot “najkrajši čas do naslednje spodbude“ in “najdaljši čas do naslednje spodbude“, v sekundah, program sproži vidno spodbudo vozniku. Vidno spodbudo predstavljajo štirje kvadrati – luči, ki se lahko obarvajo v štirih mogočih kombinacijah. Vsaka od njih pomeni drugačno reakcijo voznika (sl. 1): delno (tj. blago) zaviranje, ki zahteva delni pritisk zavorne stopalke, skrajno zaviranje do zaustavitve vozila in spodbudo za izmikanje levo ali desno. V

1 THE 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 Transport [4], is composed of two subsystems: one for virtual driving simulation and stimulation, and the other for measuring the driver’s actions and reactions; the two subsystems are connected via a sequence of reaction-time phases (Fig. 2).

1.1 The virtual drive simulation and stimulation of the driver

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 that are referred to in the program as the ”Minimum time to next stimulus“ and the “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 colour themselves in four possible combinations. Each of them represents a different driver’s reaction (Fig. 1): partial (i.e., light) breaking, which requires that the brake pedal is partially applied, extreme breaking until the vehicle stops, and stimulus for avoidance to the left or right. In the

Sl. 1. *Štiri mogoče spodbude*[1]
Fig. 1. *The four possible visual stimulations*[1]

[1] Voznik je v simuliranem okolju spodbujen vidno enako kakor v resničnem voznem okolju z enakim pomenom posamezne spodbude.

[1] The driver is stimulated visually in the simulated environment in the same way as in the real driving environment with the same meaning of the particular stimulus.

grafičnem vmesniku lahko izberemo skupino spodbud, ki se bodo izvajale.

Poleg omenjenih parametrov, lahko v podsistemu za navidezno simulacijo vožnje in sprožanje spodbud izbiramo želeni posnetek vožnje. Hitrost predvajanja posnetka (v km/h) je sinhronizirana s hitrostjo, ki jo dosega voznik z dejanskim pritiskom na stopalko.

1.2 Zaznavanje ukrepanja voznika

Voznikovi ukrepi na določeno spodbudo so zaznani, ko se le-ta odzove (pričakovano) s svojimi rokami in deluje na krmilni obroč v primeru spodbude za izogibanje, oz. ko se odzove (pričakovano) s svojimi nogami in deluje na stopalko za plin ali zavorno stopalko v primeru spodbude za zaviranje. Voznikovi ukrepi s krmilnim obročem ter stopalko za plin in zavorno stopalko vplivajo na analogno-digitalni (A/D) pretvornik.

Podatki pretvornika so računalniško zajeti in obdelani. Analogno digitalni pretvornik ponuja 10-bitno ločljivost, kar pomeni 1024 različnih vrednosti za stanje krmilnega obroča in 1024 za obe stopalki. Ker pretvornik sporoča signale prek programskega vmesnika vsako milisekundo, nastanejo hitra nihanja oz. šum v vrednostih stanja pretvornika, zato ima podsistem vpeljan tudi preprosti časovni filter, ki te vrednosti stabilizira.

Za vsak odziv lahko določimo tudi območje veljavnosti odklona krmilnega obroča ali pritiska na stopalko, izraženo v odstotkih. Privzete vrednosti za odklon krmilnega obroča so od 50 do 100 odstotkov in prav take tudi za polno zaviranje. Za delno zaviranje je privzeto območje veljavnosti od 20 do 90 odstotkov pritiska na stopalko. Pri zaviranju lahko določimo tudi najmanjši čas pritiska “z zadržkom“, v milisekundah, na stopalko, ki določi, ali je odziv veljaven. Določimo lahko tudi največjo hitrost, ki jo dosežemo pri 100-odstotnem pritisku na stopalko za plin.

Programski vmesnik mmsystem na podlagi opravilnega sistema Windows 2000/NT/XP ponuja funkcijo timeGetTime(), ki vrne natančen čas v milisekundah, odkar se je zagnal opravilni sistem. Vrednost je tipa DWORD in obsega 32 bitov, kar pomeni, da se obrne na približno vsakih 49,71 dni. Veliko ločljivost in natančnost merilnika časa zagotavlja opravilni sistem in je v programu nastavljena na največjo napako 2 milisekundi s

graphical user interface a group of stimulations that will be performed can be chosen.

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

1.2 Perceiving the driver’s actions

The driver’s reactions to the applied stimulus are perceived when he/she reacts (as expected) with his/her arms, and acts on the steering wheel when the avoidance stimulus is applied, or when he/she reacts (as expected) with his/her legs and applies on the accelerator and brake pedals when the braking stimulus is applied. The driver’s actions with the steering wheel and the accelerator and brake pedals influence the A/D converter.

The corresponding data produced by the converter is acquired and processed with the aid of a computer. The A/D converter offers a 10-bit resolution, what 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 via a program interface are sent every millisecond, 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’s declination and the pedal’s push can be defined in percentiles. The default values for the steering wheel’s declination and also the extreme braking are between 50% and 100%. For partial braking, the validity range is between 20% and 90% of a pedal’s push. During braking, a minimum push time of the brake pedal ”the Hold Time”, in milliseconds, can be set, which determines if a reaction is valid. Also the maximum speed ”Max Speed“, which is reached when the accelerator pedal is applied 100%, can be set.

The program interface mmsystem based on the Windows 2000/NT/XP operating system 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. The high resolution and accuracy of the time measuring is ensured by the operating system. A maximum error of 2 milliseconds in the program is set pomočjo funkcij timeBeginPeriod() in timeEndPeriod(), kar zagotavlja natančnost tudi pri hitrih zaporednih klicih funkcije timeGetTime().

1.3 Meritve odzivnih časov voznikov

Podsistema sta povezana s programskimi merilniki, ki merijo (sl. 2):

- začetek vidne spodbude,
- čas odziva (tj. voznikovo delovanje na spodbudo) in
- celotni odzivni čas.

Iz diagrama poteka meritve, ki je prikazan na sliki 3, je razvidno, da so upoštevane tudi neveljavni odzivi, do katerih lahko pride ob nezadostnem pritisku

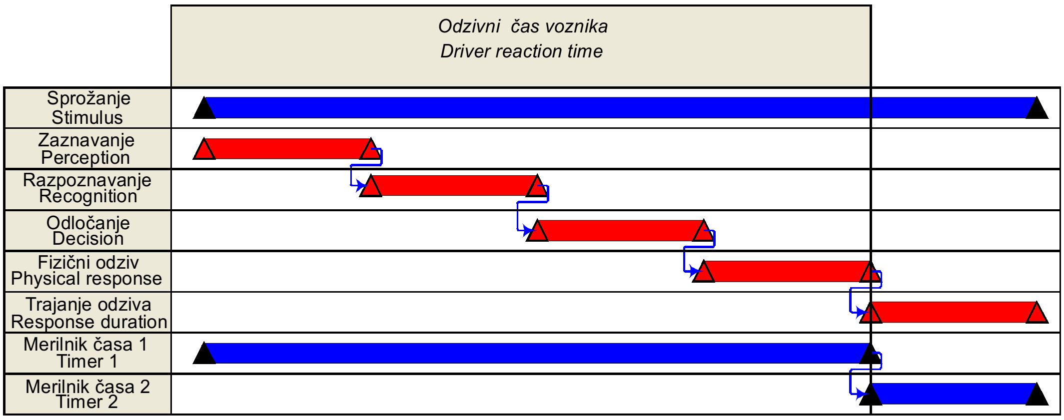
via the functions timeBeginPeriod() and timeEndPeriod(), which also ensures accuracy with fast successive calls of the function timeGetTime().

1.3 The driver's reaction time measurements

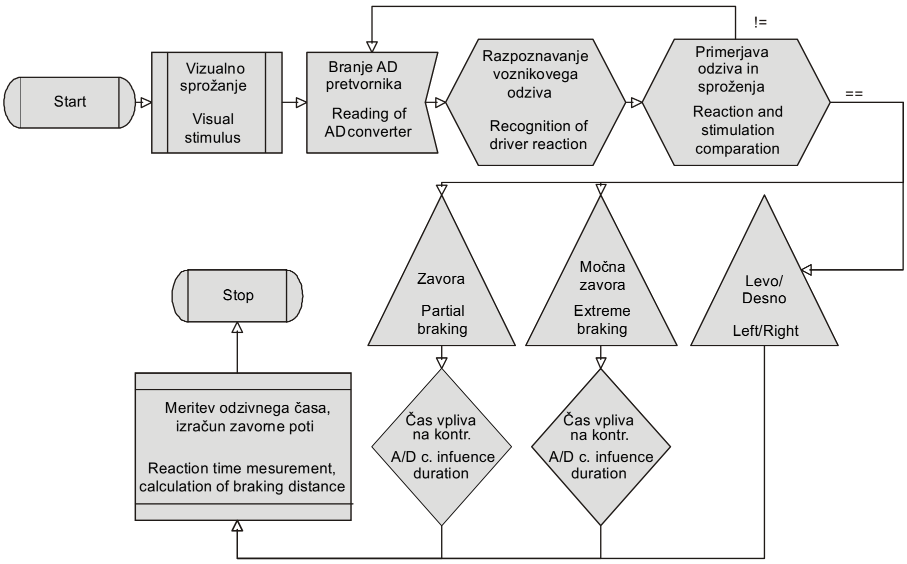
The two subsystems are connected with the program's measuring modules, which measure (Fig. 2):

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

The flow chart of a measuring course is shown in Fig. 3. It can be seen that the algorithm also considers invalid reactions, which can occur if the pedal is not



Sl. 2. *Pasovni diagram programskih merilnikov*
Fig. 2. *Gantt diagram of the program's measuring modules*



Sl. 3. *Logični potek meritve*
Fig. 3. *Flow chart of a measuring course*

na stopalko, zaradi česar ne pride do zaviranja, in če krmilni obroč ni zadostno obrnjen oz. je obrnjen v napačno smer.

sufficiently applied and thus braking is not achieved; and the same goes if the steering wheel is rotated insufficiently or in the wrong direction.

2 PREIZKUSNO DOLOČANJE ODZIVNIH ČASOV

Za določanje odzivnih časov voznikov so bili izvedeni preizkusi v stvarnem in simuliranem voznem okolju.

V simuliranem voznem okolju so bili odzivni časi voznikov merjeni s:

1. simulatorjem Vericom Stationary Reaction Timer (Preglednica 1.B) [13] in
2. simulatorjem FPP Driver Reaction Timer (sl. 4 - desno; Preglednici 1.B in 1.C) [4].

V resničnem voznem okolju so bili odzivni časi voznikov merjeni neposredno in posredno.

Neposredne meritve odzivnih časov voznikov so bile izvedene z merilnikom pospeškov Vericom VC3000 z dodatno opremo, ki spodbuja voznikov odziv in jo je mogoče namestiti na poljubnem mestu v voznikovem vidnem polju (sl. 4 - levo, sl. 7) [9]. Meritve so bile izvedene podnevi ob dobrih vremenskih razmerah (preglednica 1.A) in z vidno opremo za spodbujanje, nameščeno v smeri pogleda voznika naravnost naprej (sl. 4 - levo, sl. 7 - levo) ter zunaj smeri pogleda voznika (sl. 7 - desno). Dobre vremenske razmere pomenijo takšne razmere, pri katerih vidljivost ni omejena in koeficient trenja ni izpostavljen spremembam.

2 THE 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 (Table 1.B) [13],
2. the FPP Driver Reaction Timer (Fig. 4 right; Tables 1.B) [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 the experiments. Those were performed in daylight in good (Table 1) weather conditions with the 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.

Sl. 4. *Meritve reakcijskega časa voznika v dejanskih voznih razmerah (oprema za vidno spodbudo je nameščena v smeri pogleda voznika naravnost naprej) in v simuliranih voznih razmerah na simulatorju PC osnove (vidna spodbuda je na robu zaslona)*

Fig. 4. *Measurements of the driver's reaction time in the 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 the visual stimulus is located on the side of the screen)*

Preglednica 1. *Primerjava rezultatov odzivnih časov voznikov iz preizkusov v dejanskem voznem okolju z rezultat,i dobljenimi v simuliranem voznem okolju[2].*
Table 1. *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[2].*

** Oprema za vidno spodbudo voznika je bila nameščena v smeri voznikovega pogleda naravnost naprej.*
** The visual stimulus equipment was arranged in the direct line of sight of the driver.*
*** Oprema za vidno spodbudo voznika je bila nameščena zunaj smeri voznikovega pogleda.*
*** The visual stimulus equipment was arranged off–centre to the direct line of sight of the driver.*

		Odzivni čas voznika The driver's reaction time [s]				
		skrajno zaviranje extreme braking	blago zaviranje light braking	izmikanje - levo avoidance - left	izmikanje - desno avoidance - right	
Mesto namestitve vidne spodbude Placement of the visual stimulation	v smeri pogleda in the line of sight	0,79	0,95	0,87	0,77	**A**
	zunaj smeri pogleda off–center to the line of sight	1,14	1,54	1,07	1,55	
	razlika difference	0,35	0,59	0,20	0,78	
	stvarno vozno okolje (1)* real driving environment (1)*	0,91	0,97	0,87	0,83	**B**
simulirano okolje simulated environment	Vericom (2)	0,64	0,71	0,72	0,83	
	Reaction Timer (3)	0,63	0,72	0,75	0,80	
	razlika (3)–(1) difference (3)–(1)	–0,28	– 0,25	– 0,12	– 0,03	
	približna srednja vrednost razlike: orientation mean value of difference:	*– 0,2*				
	stvarno vozno okolje (4)** real driving environment (4)**	1,14	1,54	1,07	1,55	**C**
	razlika (4)–(1) difference (4)–(1)	– 0,51	– 0,82	– 0,32	– 0,75	
	približna srednja vrednost razike: orientation mean value of differece:	*– 0,6*				

Odzivni čas voznika na pričakovano nevarnost je bil določan posredno z:
1. analizo časa med zaporednimi slikami videoposnetka vožnje vozila; posnetek je bil narejen s tržno digitalno kamero (sl. 5) in
2. analizo časa med značilnimi skrajnostmi pospeškov vozila in diagramov kotne hitrosti, ki so bili posneti s trirazsežnim merilnikom pospeškov Crossbow in merilnikom kotne hitrosti Horizon (sl. 6).

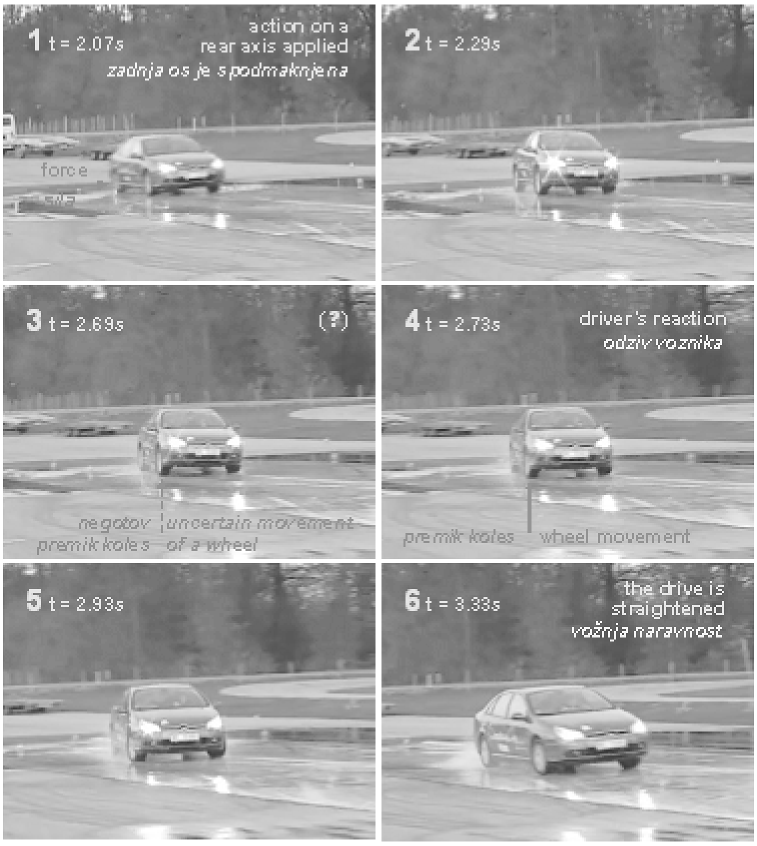
Slika 5 prikazuje način in trenutek voznikovega odziva potem, ko je sila vzdolžno na

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 a ordinary, off-the-shelf digital camera (Fig. 5),
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 the Horizon rotational gyro (Fig. 6).

Fig. 5 shows how and when the driver reacted when a force applied to the rear axis of a vehicle

[2] Ponovljivost vseh izvedenih preizkusov je bila zagotovljena glede na gostoto prometa, voznih odsekov, vidljivosti, razmer na cestišču ter navedenega psihofizičnega stanja voznikov in sovoznikov.

[2] The uniformity of all the experiments performed in the real driving environment was ensured with regard to the density of traffic, the route taken, the lighting, the visibility, the surface conditions, and the reported psychophysical state of the drivers and co-drivers involved.



Sl. 5. *Analiza časa med zaporednimi slikami videoposnetka vožnje vozila pri hitrosti približno 25 km/h (s primerjavo slik 3 in 4 je moč opaziti, kako negotov je trenutek premika koles)*

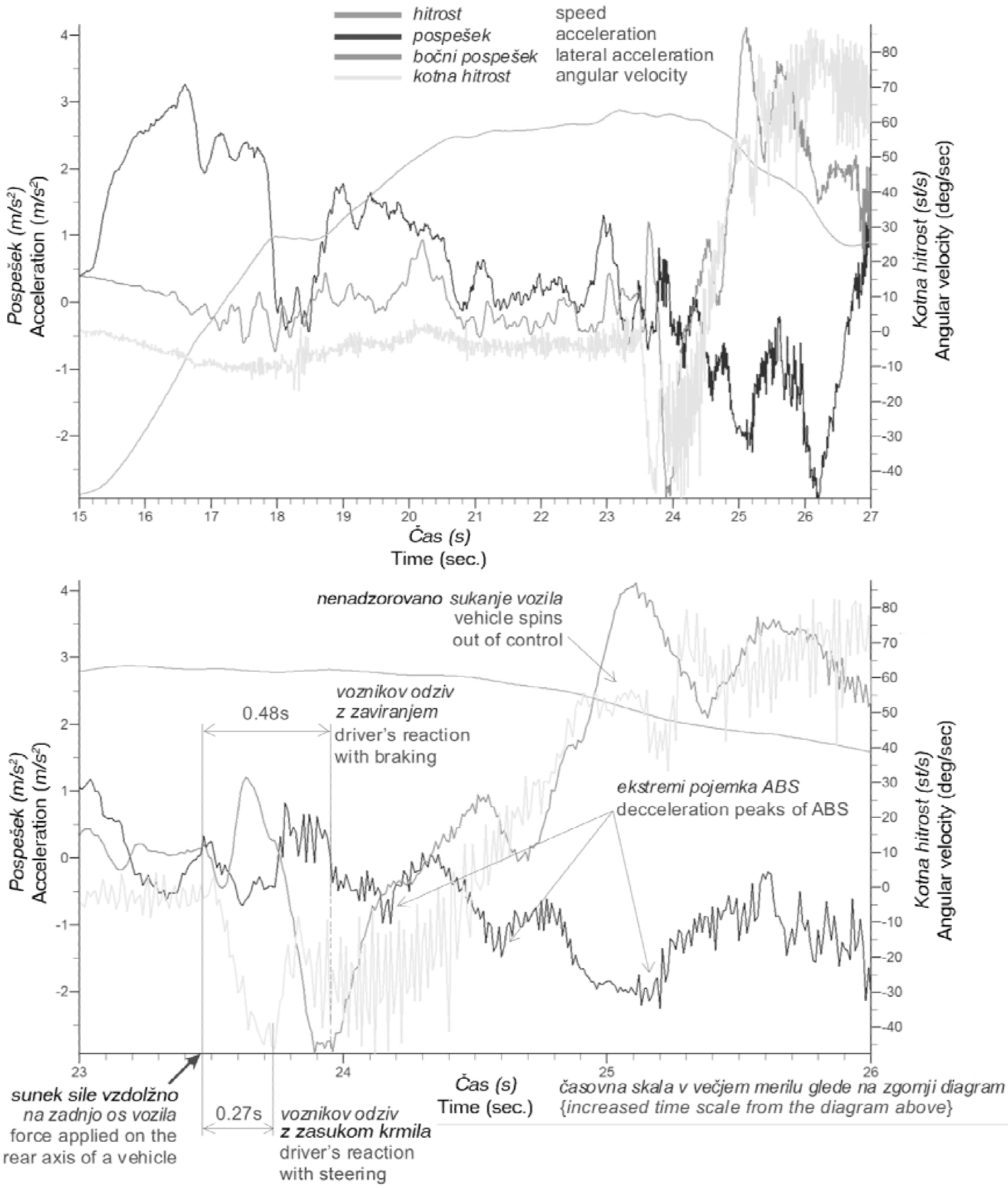
Fig. 5. *A study of the intra-frame time of the consecutive frames of a film of a vehicle driving at approximately 25 km/h (note how uncertain is the moment of a wheel movement, comparing frames 3 and 4)*

zadnjo os vozila povzročila njegovo zavrtitev. Seveda je na podlagi analize video posnetka mogoče ugotoviti samo tiste odzive voznika, ki so vidni zunanjemu opazovalcu in še to le z omejeno natančnostjo. Pri taki metodi je določanje odzivnega časa voznika vedno izpostavljeno subjektivni presoji opazovalca o tem, kdaj je voznikov odziv opazen navzven (primerjava posnetkov št. 3 in št. 4 na sl. 5). Vsekakor taka metoda lahko poda vrednost odzivnega časa voznika, toda le z nezanemarljivimi odmiki. Statistična analiza je pokazala, da so vrednosti odzivnih časov voznikov na pričakovano nevarnost normalno porazdeljene s povprečjem 0,42 s in standardnim odmikom 0,14 s s stopnjo zaupanja 95 odstotkov (stopnja značilnosti 5 %).

Analiza diagramov tangentnega pospeška, bočnega pospeška, hitrosti in kotne hitrosti je prikazana na sliki 6. Trenutek delovanja sile vzdolžno na zadnjo os vozila, posledica katere je njegova zavrtitev, je na grafih bočnega pospeška in kotne

caused its rotation. Clearly, from studying a motion picture, only the reactions of a driver visible to an 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 always be present (compare frames no. 3 and no. 4 of Fig. 5). This means that the method can provide the reaction time of a driver but with non-negligible deviations. A statistical analysis shows that the values of the reaction times of drivers to an anticipated danger is normally distributed with a mean value of 0.42 s and a standard deviation of 0.14 s at a confidence level of 95 % (significance level of 5 %).

A study of the diagrams of tangential acceleration, lateral acceleration, speed and angular velocity is presented in Fig. 6. From the graph of lateral acceleration and angular velocity the action on the rear axis of a vehicle causing it to rotate (as



Sl. 6. *Čas odziva voznika na pričakovano nevarnost, določen iz diagramov pospeška, bočnega pospeška, hitrosti in kotne hitrosti*

Fig. 6. *The time of reaction of a driver to an anticipated danger deduced from diagrams of acceleration, lateral acceleration, speed and angular velocity*

hitrosti izražen kot nenaden padec (sl. 6). Ta točka v času na diagramu je uporabljena kot primerjava, po kateri so podrobneje analizirani odzivi voznika. Voznikov odziv z zaviranjem je razviden iz diagrama tangentnega pospeška vozila, na katerem je moč

shown in Fig. 5) is distinguishable as an abrupt plunge. This point in time on the diagram is used as a reference from which the reactions of a driver are closely examined. The driver's reaction with braking is seen from the diagram of tangential acceleration opaziti pojemek, ko se zavore odzovejo na voznikovo delovanje. Voznikov odziv z obračanjem krmilnega obroča je razviden iz diagramov bočnega pospeška in kotne hitrosti, saj ti kažejo na točko v času, pri kateri se smer zavrtitve vozila spremeni.

Seveda tak postopek ne more dati odgovora na to, kdaj se je voznik dotaknil zavorne stopalke, ali kdaj je voznik dejansko začel vrteti krmilni obroč. Rezultati, ki so dobljeni na podlagi opisane metode in so prikazani na sliki 6 so namreč seštevek odzivov voznika in vozila. Kljub temu je ta raziskovalna metoda uporabna, ko sta tip in zaporedje voznikovih odzivov temeljito preučena.

3 VREDNOTENJE SIMULATORJA

Že prvi testi, v katerih so bili vozniki spodbujeni za delno in skrajno zaviranje ter za izmikanja levo ali desno, so pokazali nezanemarljive (glej razloge v uvodu) odmike med odzivnimi časi, ki so bili dobljeni v stvarnem voznem okolju in tistimi, ki so bili dobljeni v simuliranem okolju na simulatorju. Primerjava rezultatov simulirane vožnje in rezultatov preizkusov iz stvarnega voznega okolja pri vidni spodbudi voznika v smeri njegovega pogleda naravnost naprej izkaže srednji odmik z vrednostjo do 0,2 s (preglednica 1.B). Odmiki se povečajo do 0,8 s (preglednica 1.C), ko je v stvarnem voznem okolju vidni stimulator nameščen zunaj voznikovega neposrednega pogleda, premeščen je v smeri proti robu njegovega vidnega polja. Odzivni čas voznika je v stvarnem voznem okolju v splošnem daljši kot v simulacijah.

Razvidno je (preglednica 1.B), da se rezultati, dobljeni v simuliranih voznih okoljih z uporabo simulatorja Reaction Timer in simulatorja Vericom Stationary Reaction Timer, bistveno ne razlikujejo.

Predstavljeni rezultati izkazujejo očitno pomanjkljivost simulacijskih voznih okolij; ni namreč mogoče simulirati vpliva vremenskih razmer na vozne pogoje.

Prvi razlog za opisane razlike med odzivnimi časi na spodbujeno skrajno ali delno zaviranje, dobljenimi na simulatorju in tistimi, dobljenimi v stvarnem voznem okolju, je ta, da je pri preizkusih v stvarnem voznem okolju, poleg časa odziva voznika, upoštevan še odzivni čas zavornega sistema vozila, simulator pa meri samo čas odziva voznika. Literatura ([3], [6] in [10]) navaja, da znaša

of the vehicle, on which deceleration is observed when the brakes respond to the driver's input. The driver's response with steering is seen from the diagrams of lateral acceleration and angular velocity, since these are showing the point in time when the rotation of the vehicle changes direction.

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

3 THE EVALUATION OF THE 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 (see the introduction, as to why) deviations between the reaction times obtained in the real driving environment and those in the simulated environment on the simulator. The mean deviation amounts to 0.2 s (Table 1.B) when the results from the simulator are compared to the experimental results from the real driving environment with the visual stimulation of a driver in his/her direct line of sight. The deviations increase up to 0.6 s (Table 1.C) 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 the simulations.

Note (Table 1.B) 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 the impact of the weather 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 breaking was stimulated is that the experiment in the real driving environment accounts for, in addition to the time of the driver's reaction, also for the time in which the vehicle's brake system reacts, while the simulator measures just the time needed for the driver to react to the stimulus. According to the literature ([3], odzivni čas hidravličnega zavornega sistema osebnega vozila približno najmanj 0,1 s. Posledično so seveda odzivni časi voznika, dobljeni v stvarnem voznem okolju, primerno daljši od tistih pri preizkusih v simuliranem voznem okolju.

Drugi zelo pomemben razlog za omenjene odmike, predvsem pri spodbujanju izmikanja, pa je ta, da se voznik zaveda dejstva, da med potekom simulacije ni izpostavljen nikakršni dejanski nevarnosti. Poleg tega se s časom voznik popolnoma zave, da dejansko sploh ne vozi in se zato lahko osredotoči zgolj na luči, ki posredujejo spodbudo. Smer voznikovega pogleda med preizkusi namreč ni bila nadzirana, njegov pogled pa ni bil na nikakršen način pritegnjen oz. prisiljen slediti videoposnetku vožnje vozila. Zato še posebej, ko vozniki spoznajo, da je na preizkušnji njihova sposobnost, se v simuliranem voznem okolju zelo agresivno odzovejo na posredovano spodbudo, celo bistveno bolj kakor v dejanskih voznih razmerah (da niti ne omenimo njihove tekmovalnosti za čim boljši rezultat). Sunkoviti premiki krmilnega obroča in zavorne stopalke, izvedeni v simulaciji, so bili tolikšni, da bi v stvarnih voznih razmerah za povprečnega voznika pomenili veliko nevarnost. V simuliranih razmerah vožnje so se sodelujoči vozniki odzvali v pičlih 0,4 s. To je skoraj vrednost odzivnega časa voznika na pričakovano nevarnost (sl. 5 in 6) in je primerljiva z refleksnim časom voznika [2].

V stvarnem voznem okolju je bil opažen značilen vpliv mesta namestitve luči, ki posredujejo spodbudo na odzivni čas voznika. Če so bile luči sbodbujevalnika nameščene zunaj smeri voznikovega pogleda (sl. 7), je bil njegov odzivni čas značilno daljši kakor tedaj, ko je bila oprema za vidno spodbudo nameščena tik pred voznikom oziroma v smeri njegovega pogleda (preglednici 1.A in 1.B). Opisana razlika je v območju med 0,2 in 0,8 s, kar kaže na pomembnost mesta, od koder prihaja spodbuda do voznika. Na osnovi istih rezultatov (preglednici 1.A in 1.B) je moč sklepati, da je eden od razlogov za razliko med odzivnimi časi, dobljenimi v dejanskem voznem okolju in tistimi, dobljenimi v simuliranem voznem okolju (preglednici 1.B in 1.C), neprimerno mesto vidne spodbude na zaslonu glede na videoposnetek vožnje. Odzivni časi voznikov v simuliranih voznih okoljih torej niso dejanski, kakor je bilo pričakovati.

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

The second most important reason for the mentioned deviation, especially when avoidance is stimulated, is that the driver is conscious of the fact that he is not exposed to any real danger during simulations. Furthermore, with time the driver became fully aware that he/she is not actually driving and therefore during a simulation the driver can focus only on the lights that provide the stimulus. In other words, during the experiments the direction of the driver's vision was not controlled and his/her eye was not attracted by any means or forced to follow the video of the vehicle's driving. Consequently, especially when they realized that their pride is at stake, the drivers in the simulated environment reacted very aggressively to the stimulus, even more than in real driving conditions (in fact they competed to post the best reaction time result). The jerkiness of the steering wheel and of the brake pedal during the simulations was such that it would be very dangerous for a mediocre driver in real driving conditions. The results from the simulated driving environment were "as good as" 0.4 s for the reaction time. That is almost the reaction time of a driver anticipating danger (Fig. 5 and 6), and it closely resembles the reflex time of a driver [2].

In the real driving environment the influence of the position of the lights that provide the stimulus on the driver's reaction time was observed to be significant. If the lights were positioned off-centre to the direct line of sight (Fig. 7) of the driver his or her reaction time was significantly longer than when the visual stimulus equipment was in his or her direct line of sight, observing the traffic situation in the frontal area of the vehicle (Table 1.B and 1.C). The described difference in the range from 0.2 to 0.6 s indicates the importance of the location of the driver's visual stimulation. From the same findings (Table 1) a deduction can be made that one of the reasons for the difference between the reaction times obtained in the real driving environment and those in the simulated environment on the simulator 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 as realistic as expected.

Sl. 7. *Namestitev vidnega spodbujevalnika v smeri voznikovega pogleda (levo, spodbuda izmikanja v levo) in zunaj smeri voznikovega pogleda, vendar v njegovem vidnem polju (desno, spodbuda skrajnega zaviranja) pri preizkusu v dejanskem voznem okolju*

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

Resničnost, v katerih so izvedene meritve v dejanskem voznem okolju, je prepuščena sovozniku, ki nadzira luči spodbujevalnika. Če je sovoznik okoren s svojimi gibi, lahko voznik ugane trenutek naslednje spodbude in celo vrsto same spodbude. Ni treba posebej poudariti, da se v takšnih primerih odzivni čas skrajša in zato rezultati niso dejanski. Interpretacija rezultatov, merjenih v dejanskih razmerah je zelo pomembna. Posebno pozornost je treba nameniti rezultatom v tistih prometnih situacijah, ki povečujejo koncentracijo in osredotočenost voznika na vožnjo.

4 SKLEP

Prvi preizkusi so pokazali, da je simulator FPP Driver Reaction Timer, ki ga je zasnoval R. Krulec v Laboratoriju za varnost v prometu na Fakulteti za pomorstvo in promet, po svojih zmožnostih primerljiv s tržno dostopnimi simulatorji.

Preizkusi, v katerih so bili vozniki spodbujeni za delno in skrajno zaviranje ter za izmikanja levo in desno, so pokazali nezanemarljive razlike med odzivnimi časi v simuliranem okolju in tistimi v dejanskem voznem okolju, pa tudi časi, objavljeni v ustrezni literaturi.

Po opravljenih preizkusih je moč sklepati, da je vzrok za opažene razlike neprimerno mesto vidne spodbude na zaslonu računalniškega simulatorja glede na videoposnetek, ki je predstavljal simulirano vožnjo. Edino primerno

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 increases the concentration and focus of the driver while driving.

4 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 simulators.

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 the reaction times obtained in the simulated environment compared to those experimentally obtained in the real driving environment or compared to the driver's reaction times published in the relevant literature.

From the experiments performed it can be concluded that the recorded difference results from the inappropriate location of the visual stimulus on the mesto vidne spodbude bi bilo takšno, da bi bil videoposnetek simulirane vožnje predvajan kot ozadje. Zagotovljeno mora biti, da je oprema za vidno spodbudo nameščena v vidnem polju, v katerem voznik pregleduje okolico pred vozilom in opazuje odvijanje prometa ter moteče nepremične in premikajoče se ovire. Ni potrebno, da je vizualni stimulator nameščen v smeri voznikovega pogleda naravnost naprej. Če je nameščena zunaj smeri neposrednega pogleda, je mogoče meriti odzivni čas voznika na predmete, ki se približujejo od strani, vendar le tedaj, ko je vidna spodbuda nameščena v voznikovem resničnem vidnem polju.

Nadaljnji razvoj simulatorja FPP Driver Reaction Timer bo osredotočen na dopolnitev baze videoposnetkov resničnih voženj ter na vključitev resničnih dejavnikov ogrožanja varnosti prometa, vključujoč motenje voznika. Posebna pozornost bo namenjena nadzoru dejanske smeri pogleda voznika. Pričakovati je, da bo na ta način dosežena bolj dejanska slika vplivov na odzivni čas voznika.

Posebej velja poudariti izsledek preizkusov merjenja odzivnih časov voznikov v dejanskem voznem okolju: gre za ugotovitev, da je odzivni čas voznikov na nepričakovano oviro ali nevarnost v povprečju 10% daljši od ene sekunde. Ta ugotovitev je pomembna predvsem zato, ker slovenski izvedenci cestnoprometne stroke uporabljajo eno sekundo kot standardni odzivni čas voznika, ki je udeležen v prometni nesreči. Za določitev natančnih vrednosti odzivnih časov voznikov ob različnih okoliščinah bi bile bržkone potrebne nadaljnje raziskave, vendar bi morali biti že pričujoči rezultati skupaj z bogato literaturo na to temo dovolj, da izzovejo odgovor strokovnjakov.

PC-based simulator screen with regard to the video representing the simulated driving. The only appropriate position of the visual stimulus is such that the video of the simulated driving is played as a background. It must be ensured 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 looking for traffic and for impeding fixed and movable obstacles. It is not necessary that the visual stimulus is placed in the line of direct sight. If it is placed broadly off-centre to the line of sight the driver's reaction time on the objects closing from the side can be measured, as long as the visual stimulus is placed within the 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 the real driving environment and simulations. Special focus will be devoted to the control of the actual driver's direction of vision. It is expected that a more realistic picture of the influences on the driver's reaction time will be gained in this way.

In conclusion, another finding should be emphasized and is derivable from the driver's reaction-time experiments in the real driving environment, i.e., the reaction time of a driver to unknown and unexpected obstacles or danger in front of a vehicle is on average of the order of 10% longer than one second. This finding is important since Slovenian accident reconstruction experts are using one second as the standard reaction time of a driver involved in an accident. Certainly, further investigations should be made to find the exact values of the reaction time of a driver in different circumstances, but the results presented in this article together with the abundant existing literature on this subject must be enough to challenge the response of the expert community.

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