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Using Matlab-based Driving Simulator for Human Factor Assessment

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Abstract: We discuss the possibility of using simulation technologies for human factor assessment. In this context, a simple car-driving simulator was developed in MATLAB/Simulink. A human driver controls a simulated drive via an input HCI (Human-Computer Interface) device, i.e., a joystick or a steering wheel with pedals, exploiting the perception of the current situation in the visualized scene. To enable the human factor assessment, several testing scenarios were designed and implemented; some of these were subsequently used for measuring the driver's responses to the simple visual stimuli. We analyzed the acquired data and evaluated the basic parameters of the human operator, such as the reaction delay or the attitude to control. The results indicate the potential for more complex experiments in this field.

Keywords: human factor, human-machine interface, vehicle simulator, human model, reaction delay.

1. INTRODUCTION

At present, various processes and systems are frequently simulated and visualized. Various types of simulators are applicable in diverse areas where humans play an essential role. In this context, prominent tasks include flight or driving training and personal activities in critical industrial branches, such as chemistry and nuclear power plants. The importance of simulators lies in their capability of simulating complex systems under various conditions and situations, with a focus on realistic interpretation. In addition to training, the set of central goals includes also maintaining desirable habits and achieving better understanding of the safety and reliability. Due to this scenario, simulators are becoming an invaluable instrument in many areas.

One of the most significant domains is transportation (road and airborne), where safety and reliability are vital preconditions of successful operation. Efforts are made to increase safety by using various advanced driver assistant systems (ADAS), including automated driving as an instance of human-automation synergy. In spite of these systems, a human being still remains an integral part of the structure because he/she is responsible for the final control action (Roesener et al., 2018).

There are many researches in the field of human factor assessment in transportation based on use of simulation technologies, such as those presented in (Seppelt, B.D. & Lee, J.D., 2019) or (Macadam, 2003).

The goal of our research is to continue the mentioned researches and via finding new methods for an objective evaluation of driver abilities and limitations (within different conditions and influence factors) by using approaches based on measuring human responses on driving simulator. Thus, this paper presents verification of usability of the MATLAB-based driving simulator for evaluation of basic human driver parameters via measuring his/her response to different stimuli and discussion of its usability for more advanced tasks.

2. METHODOLOGY FOR HUMAN FACTOR ASSESSMENT

For the above reasons, the general aim consists in obtaining as much information about the human factor as possible in order to employ such data in developing various precautions intended to increase the safety and reliability.

Human factor assessment exploits the quantification of human behavior, cognition, and processes. This approach focuses on acquiring information related to human interaction with a device or a process and the prediction of probable human reactions within different conditions and associated factors. Such knowledge is useful for optimizing the human environment to ensure a higher effectivity or better performance and to eliminate or reduce human errors (Spurgin, 2010).

Intensive research into the proposed problems has resulted in several articles, including (Mulder et al., 2018), (Roesener et al., 2017), (Havlikova & Sediva, 2016), (Slanina et al., 2017) or (Jiang et al., 2019). However, despite this, the quantity of information regarding reliable description and prediction of human behavior remains insufficient.

A large group of the human factor assessment methods is based on modeling a human behavior. The basic human behavioral model representing a simple dynamic driving task can be defined as shown in Fig. 1 (Roesener et al., 2018). This model comprises three processes: perception, information processing, and action.

One of the most limiting parameters defining human behavior is response time, or reaction delay. This corresponds to perception and information processing and is a crucial factor,

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as, in the parameter, a value too high could lead to a failure of the human control capabilities and the subsequent destabilization of the controlled system. Such a situation might have disastrous consequences, especially in car driving. The fact that this parameter increases with rising driver fatigue only confirms this theory (McRuer & Krendel, 1974).

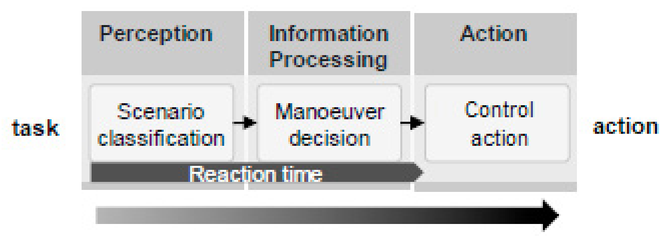

Fig. 1. The human driver performance model (Roesener et al., 2018).

Another aspect of the model rests in the form of the control action; this depends mainly on the complexity of the desired task. In a simple driving task, such as responding to sudden stimuli where feedback information is missing or insufficient, the control action can be basically described as open-loop control using feed-forward impulses (Roesener et al., 2018). The more complex tasks require addition of other control levels and human controllers (Mulder et al., 2018).

This paper evaluates the described basic parameters of a human driver by using data acquired of own driving simulator. At present, many different types of driving simulators are available at driving schools, research centers, or as a form of entertainment. Although most of these provide wide setting and customization options, the design is usually commercial and intended for specific tasks, meaning that defining one's own scenarios or initial measurement conditions is not allowed. Moreover, some of the software tools do not facilitate data acquisition in all required parameters or sample time setting. Another disadvantage then rests in the actual cost. Based on the above reasons, we developed a specific simple car driving simulator.

The possibility of defining customized testing scenarios with data acquisition in selected parameters within a pre-defined sample time together with detailed information about controlled dynamics constituted the basic requirement. Further, data processing in MATLAB was a desired functionality, and therefore MATLAB/Simulink was chosen to facilitate implementation of the car driving simulator.

3. SIMPLE CAR DRIVING SIMULATOR UTILIZING MATLAB/SIMULINK

MATLAB/Simulink provides a wide spectrum of tools for the modeling and simulation of different systems. One of these tools is Simulink 3D Animation, which includes several functions (blocks) for graphically effective, VRML (Virtual Reality Modeling Language)-based 3D visualization of modeled processes and comprises a block for joystick input data processing (Khaled, 2012).

The idea exploits the model described in (Hahn, 2016); this concept was expanded via the HCI, real-time synchronization, and definition of suitable scenarios. The resulting simulator consists of five or six main parts, as illustrated in Fig. 2.

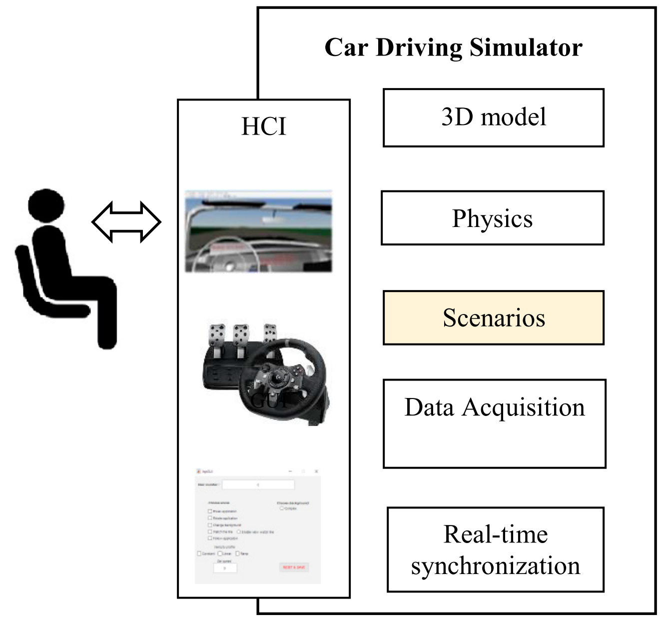

Fig. 2. The basic concept of the MATLAB-based car driving simulator.

The 3D vehicle model is based on a model of the 1957 Bel Air Chevrolet car (Cabrio), freely available on the websites listed in the source (Ocnus, 1996). The car was modified and adjusted for use in the related scene of the simulator by utilizing V-Realm Builder software. Loading this model into Simulink is possible via the VR sink function.

The dynamic model is relatively simple: It corresponds to the basic motion equations enhanced with the transfer characteristics, emphasizing available information on the parameters of the real Bel Air Chevrolet car, i.e., nominal power 160 hp, weight 1,550 kg, max. speed 160 km/h, and acceleration from 0 to 100 km/h in 18 s. The kinematic (rotation) system corresponds to the standard Ackermann steering geometry (Prokop, 2001). The complete physical model is rendered from standard Simulink libraries via functional blocks and then adapted to the most realistic possible behavior of the car.

The data acquisition function is implemented in the form of cyclical time-synchronized data saved into the workspace and into the .mat file defined via the GUI. The function exploits data logging of selected driving parameters, such as the steering wheel angle or pedal pressing, which represent human control actions in relation to various visual stimuli, actual car position, current velocity, time stamp, and other aspects.

The soft real-time synchronization is implemented by using the real-time synchronization block with the sampling period of 50 ms.

The last (but not the least) part of the concept rests in the HCI. The human driver controls the car via a joystick control input, namely, through a Logitech G920 steering wheel with pedals. The maximal rotation of the steering wheel is 900°, and the resolution corresponds to about 0.1°. The car driving control actions are based on visual perception of the simulated scene; this is mediated by a 49” Samsung CHG90 QLED gaming display. The simulator software is also equipped with a GUI for defining the initial parameters and choosing the appropriate driver testing scenario.

The resulting simulated scene view is illustrated in Fig. 3.

4. DESCRIPTION OF THE SCENARIOS

The final part of the Car Driving Simulator concept rests in implemented scenarios, designed and developed considering the possibility of measuring and evaluating suitable human driver parameters presented in, e.g., (Jirgl et al., 2016).

There are four available scenarios: Follow a car; Brake reaction; An Object in the path and Follow a line. Each of these was designed to model a different situation and can be chosen and parameterized by the instructor via the GUI.

4.1 Follow a car

This scenario comprises following a car driving along a defined path and changing its velocity. The velocity profiles can be set by instructor as the random changing velocity, the constant velocity, linearly increasing velocity, and ramp – gradually linearly increasing and decreasing velocity. The tested subject does not know the driving configuration in advance.

The recorded parameters include the current time, velocity, position, steering wheel angle, and pressure on the pedals. This data can be used for evaluating the driver’s ability to adapt to the control of unknown dynamics and to a changing situation. The scenario, however, is primarily used to initial driving and adopting habits for another testing cycle.

4.2 Brake reaction

In order to obtain a record of the braking response measurement, a simulator application was created that starts during the vehicle control simulation. The task of the driver is to follow the instructions given in the simulator window (the braking instruction "STOP" is displayed at random moments). The principle of this scenario is shown in Fig. 4 - a).

Advantageously, it is possible to set the maximum velocity or to change the complexity of the background, including the addition of buildings, trees, cars, and other elements. The recorded parameters subsume time, with the time stamp signalizing the STOP sign appearance and the rate of the brake pedal pressing action.

4.3 An Object in the Path

This scenario is relatively similar to the previous one: In order to obtain information about the response to an obstacle, an application has been created and is triggered during the vehicle control simulation. A driving cycle thus involves an object (a deer) showing at the distance of 20 m in front of the car, and the driver’s task is to pass by, using only the steering wheel. As in the previous case, there is also the possibility of setting the maximum speed and changing the complexity of the background. The recorded parameters comprise time, with the time stamp signalizing the deer, recording of the steering wheel angle, and the car’s position in time. The principle of this scenario is presented in Fig.4 – b).

In this scheme, we can evaluate the reaction delay and also the driver’s reaction or control action embodied in the steering wheel angle. These data provide information about the driver’s attitude and ability to respond to unpredictable situations.

4.4 Follow a Line

The application (scenario) is based on measuring the driver’s response to a random step change of a line visualized within a pre-defined maximum speed; the task is to follow the line and to process the change in the shortest time and at the maximum accuracy possible. The distance from the line is also displayed in the simulator window. The recorded parameters are the current time and speed, with the time stamp signalizing a line change, the steering wheel angle, and the distance between the car and the line.

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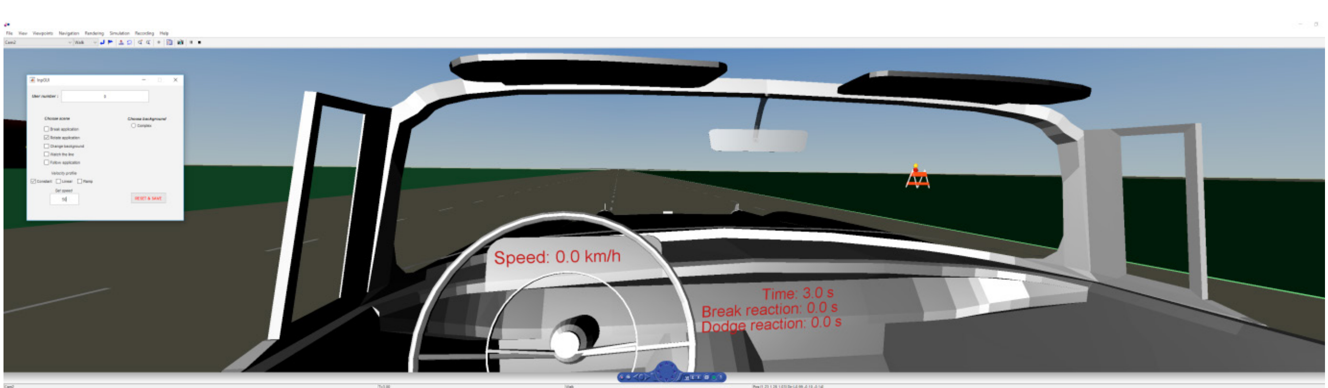

Fig. 3. The driver’s view in the simulator.

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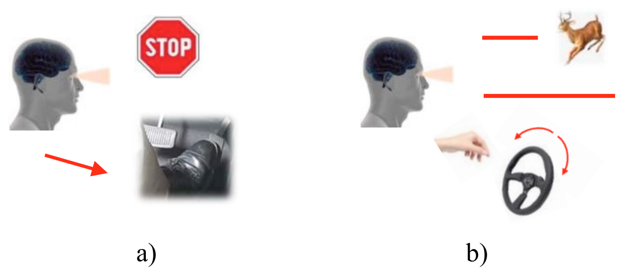

Fig. 4. The principle of the "Brake reaction" scenario – a), and the "An object in the path" scenario – b).

The measured data can then be processed via the methods presented in, e.g., (Jirgl et al., 2016). The resulting driver-related parameters include the reaction delay, prediction ability, driving attitude (a passive or an aggressive driver), and other aspects. This type of task requires also another description of the human behavior, namely, one consisting in in the actual form of the feedback controller and its properties (McRuer & Krendel, 1974).

5. RESULTS

As an example of using the proposed driving simulator for human factor assessment, evaluation of the basic driver's parameters, such as reaction delay, which embodies one of the main relevant behavior parameters, is presented through the selected scenarios.

A set of 20 people aged 22 to 25 were tested during the initial phase; all of the participants had a driving license and were active drivers. Each person was subjected to a warm-up lap using the first scenario – following a car for 5 minutes to get used to the controlled vehicle dynamics; after this stage, 10 repeated Brake response tests were performed, and An Object in the Path scenario was run.

5.1 Evaluating the driver reaction delay via the Brake response scenario

Using the Brake reaction scenario provides information on the reaction delay related to the processing of the given visual stimuli in the human brain and selection of an appropriate control action. The configuration of this process is eye – foot.

The driver's task consisted in reaching the defined speed limits (50 km/h or 90 km/h, corresponding to the values specified in the Czech Republic for roads inside and outside built-up areas, respectively) and keeping straight on the road. At random moments (pre-defined by the instructor), the STOP sign would appear to make the driver stop the car in the shortest time possible. The difference between the sign displayed and the brake pedal pressing moments observable in the measured data was then evaluated as the reaction delay, Fig. 5.

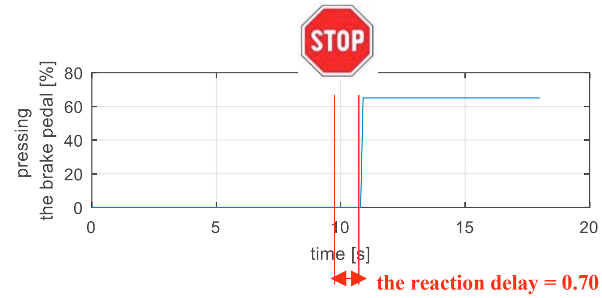

Fig. 5. The brake response evaluation.

The resulting histograms showing the distribution of the measured reaction delays in individual subjects as related to 10 repeated testing cycles and the maximum speeds of 50 km/h and 90 km/h are indicated in Fig. 6.

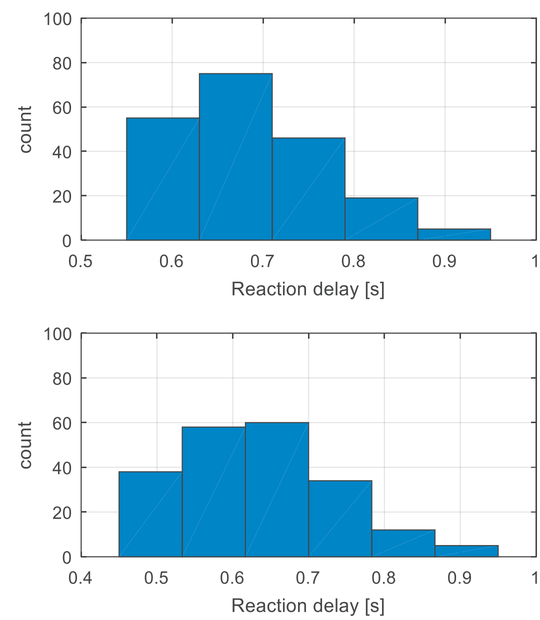

Fig. 6. The histogram of the reaction delay for the eye-foot configuration (the Brake response scenario), with the maximum speeds of 50 km/h (up) and 90 km/h (bottom).

The results obtained from the eye-foot configuration range the reaction delay values between 0.45 s and 1 s. The most frequently observed value is about 0.6 - 0.7 s in both cases, correlating to relevant theoretical expectations. There is also certain similarity in both distributions, corresponding to the log-normal distribution, which is characteristic of the parameters relating to the human factor.

5.2 Evaluating the driver reaction delay using An Object in the Path Scenario

This scenario was executed with the same group of people as in the previous case but included also the information about the reaction delay, albeit in the eye – hand configuration. Based on this scenario, there is also a possibility of evaluating the form of the control action in individual drivers. The driver's task was similar to that of the previous scenario, namely, reaching the defined speed limit (50 km/h or 90 km/h) and keeping straight on the road. At random moments (pre-defined by the instructor), an object (a deer) would appear, and the driver was made to bypass the obstacle by using only the steering wheel, without engaging the brake pedal. The measured data and the evaluated drivers' responses are displayed in Fig. 7.

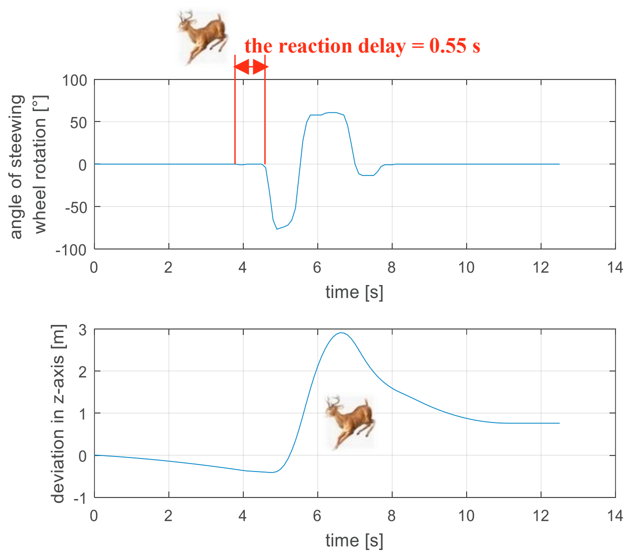

Fig. 7. The "An Object in the Path" scenario and an example of reaction delay evaluation.

The resulting distribution of the measured reaction delays in individual subjects as related to 10 repeated testing cycles and the speed limits of 50 km/h and 90 km/h are shown in Fig.8.

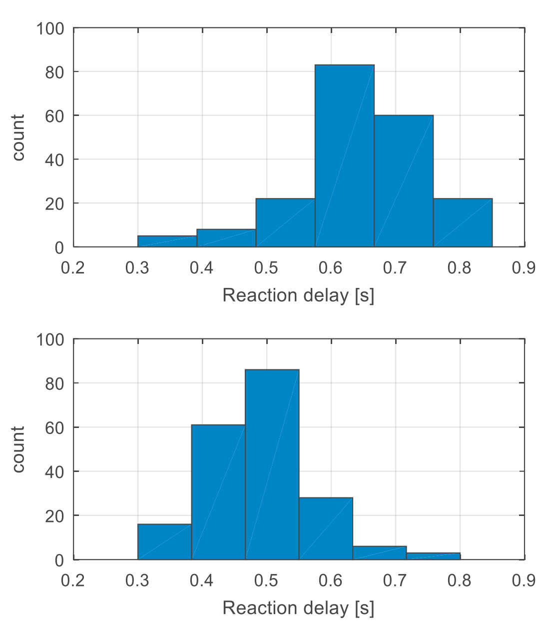

Fig. 8. The histogram of the reaction delay for the eye-hand configuration (the An object in the path scenario), with the maximum speeds of 50 km/h (up) and 90 km/h (bottom).

Figures 9 and 10 present the average control action qualities (with the steering wheel angle normalized to the interval of <-1;1>) characterizing the selected two drivers (driver no.2 and driver no.7) exhibiting the most varied responses for demonstrating the drivers' control attitude. The gray-scale curves represents the reaction within individual tests, the red curve the average control action of the driver.

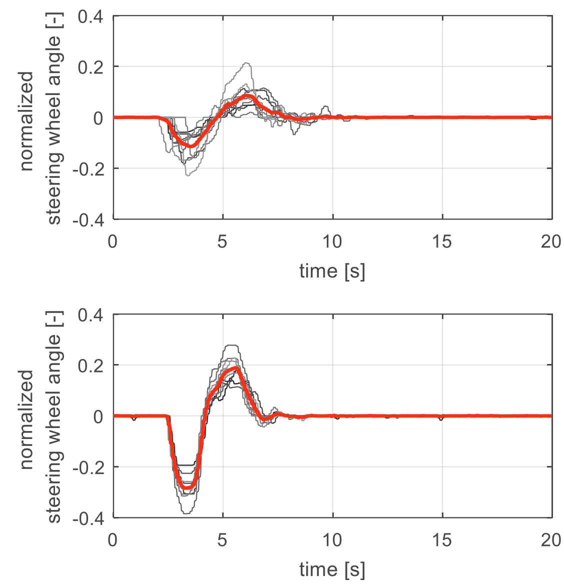

Fig. 9. The control actions (An object in the path scenario) related to the maximum speed of 50 km/h for the driver no.2 (up) and the driver no.7 (bottom).

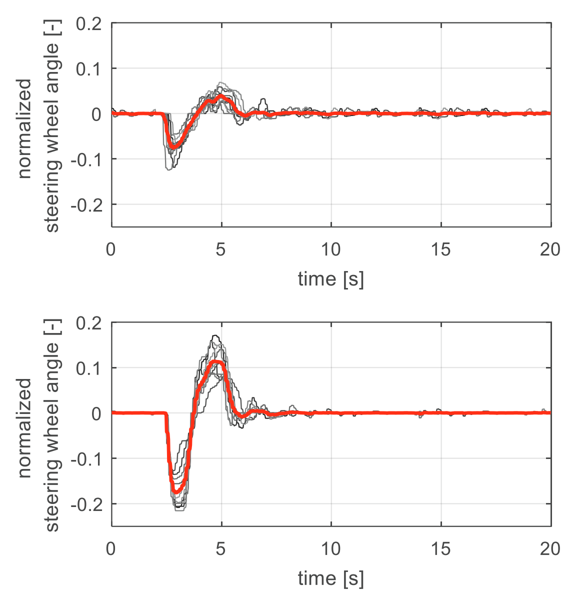

Fig. 10. The control actions (An object in the path scenario) related to the maximum speed of 90 km/h for the driver no.2 (up) and the driver no.7 (bottom).

Except for the different amplitudes corresponding to the velocities, we can also observe certain behavioral patterns in the individual drivers during the repeated testing cycles. Most of the patterns are very similar in both cases (50 km/h and 90 km/h) and indicate the strategy or attitude to control, e.g., responses of driver no.7 are in contrast to those of driver no.2 as regards the speed and accuracy.

Moreover, the average reaction delay of the driver no.2 was 0.60 s in case of maximum speed of 50 km/h and 0.45 s in case of 90 km/h. The reaction delay of the driver no.7 was 0.5 s for 50 km/h and 0.45 s for 90 km/h. These results represents the drivers' abilities and corresponds to the behavioral patterns discussed above.

These characteristics also match the results presented in the literature, e.g., by (Roesener et al. 2018), and confirm the correctness of the employed approach, together with the possibility of using the proposed simulator for research purposes within assessment of the basic parameters of the human driver.

6. CONCLUSION

The aim of this paper was to demonstrate the possibilities of using simulation technologies to assess the human factor. For these purposes, a basic car driving simulator was designed and implemented in the MATLAB/Simulink tool. The main reasons for such a choice were discussed in chapter 2. Even though the adopted solution cannot be described as advanced, the obtained results correlated with those acquired from more complex simulators, published in relevant sources; this outcome suggests that a correct approach had been selected. The main advantages of the technique consist in its possibility of easy implementation of the required testing scenarios; and the conditions' and direct data processing by using MATLAB.

Future research into the problem is expected to evaluate the data measured in the individual scenarios, proposing more difficult options and also evaluation of the drivers' responses to various influences during the driving cycle. This information can be utilized for recognition of human-driver's behavioral patterns or developing more advanced assistant systems to improve reliability and safety in transportation.

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