System with driving simulation device for HMI measurements

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Abstract: - Investigation of Human Machine Interface (HMI) is on the top level of the interest when studying the reliability of the human operators. We do this investigation using a complex measuring system involving a realistic Car Driving Simulators. The first part of this paper gives an overview of requirement on design of such an experimental laboratory equipped with driving simulator. Our research is mainly focused on the reliability of the interaction processes between the driver and vehicles so main part of the article deals with examples of usage and development of the methodology which we apply on experimentations on vehicle simulators.

Key-Words: - HMI, EEG, Car Simulation, Driver-Car Interaction, Research Laboratory Design

1. Introduction

The measurements of HMI (specifically Car-Driver Interaction) require fulfilling of very specific conditions [3] [7]. Fortunately there is a general concern about the look and functions of car operator workplace. Of course there are attempts to change the look of car cockpit dramatically, but the car market is very conservative. From this point it is not hard to define in details all the necessary functional blocks of car cockpit system. If those are know and well described than the task of measurements of reliability between them and the human operators is almost straightforward. For tests of suitability of different HMI devices the usage of car simulator is very popular in this field [5]. It helps not only for training and design purposes but it also helps with analysis of driver behavior using several different investigation methods [4]. The most sever requirement on HMI devices is that they should not take too much part of driver's attention [1].

2. Laboratory with Car Simulator

To solve different tasks of the car-driving safety it is necessary to investigate the behavior of the driver when driving the moving car [9]. Though the contemporary electronic and information technologies allow the development and construction of measuring systems which can be used for monitoring of certain driver functions while driving on the road, there are lots of necessary measurements which are hardly possible to do in real cars.

There are following main fields of the applications of adaptive driving-car simulators:

a. *The optimization of the car cockpit*
b. *The analysis of the driver behavior, especially as concerns the investigation of influences of alcohol, nicotine and other important drugs on his/her attention*
c. *The development of artificial systems warning against decreases of driver attention*
d. *The training for improvement of driver resistance against decreases of their attention.*

Such simulators represent the considerably complicated laboratory systems (we shall call them as Laboratory Adaptive Driving-Car Simulators – LAD-CS) and must correspond to the whole set of requirements, discussed in the next paragraph.

Driving-car simulators designed for applications in the above mentioned fields have to fulfill following requirements:

a. *Their usage must be able without any (or even with minimal) invasive impacts on the tested person (proband).*
b. *They must simulate the satisfactory rich set of stimuli, influencing the driver senses and coming from inside and outside the car, like when driving the real car on the road, in satisfactory wide set of driving situations.*
c. *They must allow the satisfactory fast and accurate measurement of proband reactions and storing the obtained data in respective parts of specialized databases.*
d. *They must allow that the proband controlling the driving control instruments installed in the simulator cockpit in same (or at least very similar) manner like in the real car. The same requirements are on control and use of car assistance systems, communication and radio systems.*

e. The driving-car simulator system must be adaptive in such manner, that it can be used without necessity of significant changes for wide variety of probands and wide variety of driving situations. Except some necessary changes in cockpit hardware, the well-designed system of laboratory adaptive driver-car simulator has to be applicable also for different types of cars.

To be able to fulfill these requirements it is necessary to create considerably complicated laboratory system. The system has been developing in the period 2002 – 2005 in the Laboratory of System Reliability, Department of Control Engineering and Telematics, Faculty of Transportation Sciences, Czech Technical University. Picture Fig. 21 presents the rough structure of the laboratory adaptive driver-car simulator (LAD-CS) which was developed by our team respecting the above-mentioned requirements.

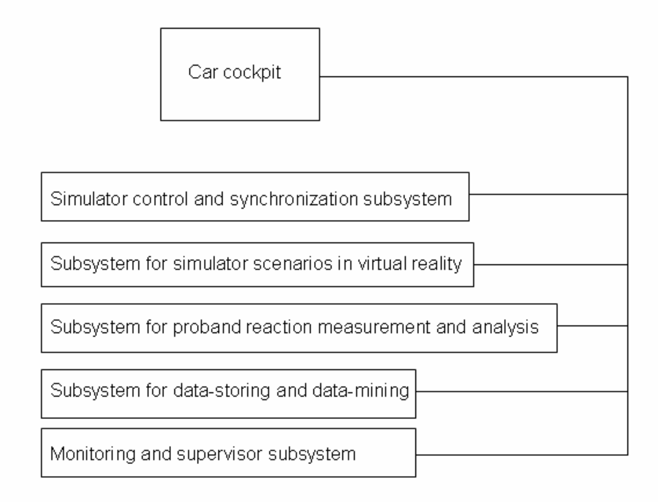

Fig. 1 The rough block-structure of the laboratory adaptive driver-car simulator

All these functional blocks have to cooperate under control of the simulation supervisor and his/her team. This group must be composed from skilled and well trained people, having the necessary knowledge not only in the simulator structure and functions, but also in respective transportation and car design problems and in driving neurology, physiology and psychology. The simulator control team influences the LAD-CS function through special monitoring and supervisor subsystem.

Because the set of functions, realized by LAD-CS is considerably wide and these functions have to be done in proper sequence in proper time, it appeared to be useful, if the responsibility of the simulation performance is upon one person only.

The members of the simulator control team have to deal with living people as tested and measure objects. Therefore, they must be able to communicate with various kinds of probands (each proband is individual) in well and gentle form, they must be able to reflect on their individual moods and wishes,

The whole system of the measurement device is very complex [10]. It consists from many particular devices which need to be synchronized. The next picture (Fig. 2) sketches a general view on it.

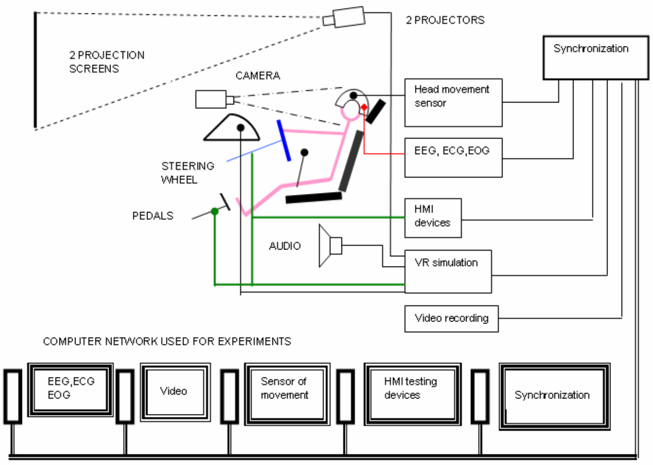

Fig. 2 Basic structure of the simulator laboratory

The next figure (Fig. 3) introduces the functional structure of our equipment from the point of view of the simulator. The whole system can be divided into four layers (they are separated with green lines on the picture). The first layer represents the simulator device itself. It consists of software and hardware parts. As the hardware of our "light" simulator we consider cockpit which is composed from parts of a real car and PCs connected to a network. I/O carts (like CAN bus to PC interface) are also included in this layer. Software of the simulator consists of Virtual Reality engine (generation of 3D graphics and spatial sound) and physical engine. The real behavior of the simulated car is a necessary condition for good results of experiments. For that reason it is necessary to pay big attention on the realistic behavior of the car. The physical engine is a compromise between a very accurate physics and a very fast (real-time) response.

The next layer represents a database of testing tracks (sometimes called scenarios) and cars. Each experiment requires more or less different scenario. To get objective results it is necessary to have precisely defined difficulty of the scenario. Sometimes we need a curveted road to study driver's ability to keep the car on the road while he/she is forced to do some additional work. On the other hand a scenario for investigation of driver's drowsiness and fatigue is recommended to have a very boring (almost straight) highway road which cannot divert him/her but it let the driver get into relaxation state. Similar rules hold for database of cars. Strong engine with automatic gearbox is suitable for measurement of drowsiness meanwhile car with manual gearbox and weaker engine with worthier grip serves better for classification of one's driving style.

The last layer represents tools for creation of assets constituting scenarios. Those are mainly modeling of 3D objects and tools for automation of such a process [11] and databases (storages) of modeled objects [12]. Each object in virtual reality is accompanied with a texture. The texture is a picture which simplifies the 3D object creation in following manner: The geometry of any real object is very complex, on the other hand it is possible to replace it with a very simple geometry covered by a worked out digital photography (texture) [13]. The textures can be of different types; general which are tillable (i.e. repeatable - like grass, road surface…) and the unique ones (houses, signs….). The amount of textures over one scenario could be very high but lots of them could be reused on several different pieces of geometry. For that reason it is also very practical to have beside the database of 3D models (objects) also a database of textures.

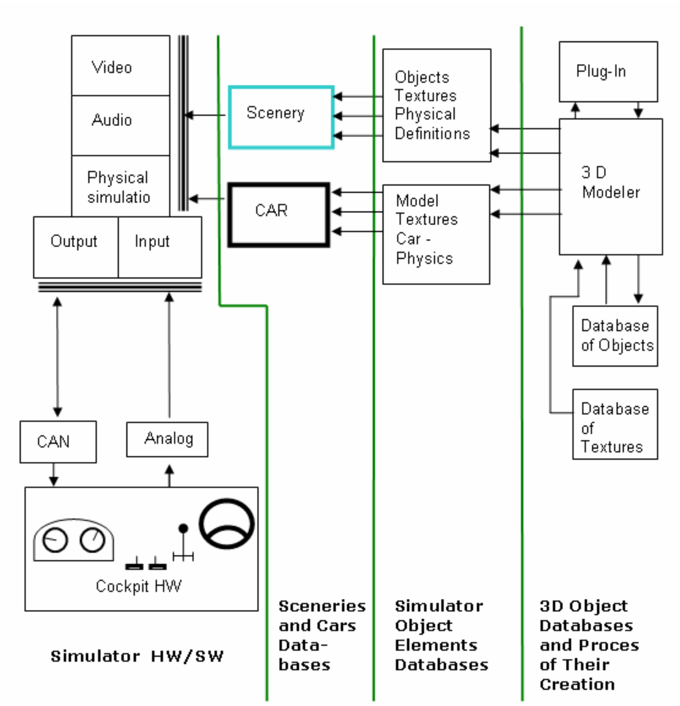

Fig. 3 Functional structure of the simulator laboratory

3. Measurements of tasks of HMI

From the point of view of objectivity it is possible to subdivide measurement in to two parts objective measurement and subjective measurement. The situation is illustrated on a following picture (Fig. 4). Outputs from the simulator are included in set of objective measurement. It is possible to record mainly the speed of the car (simulator), the trajectory, deviation from proper lane (to border or to contra-flow-line). These three outputs combined with reaction time are basic outputs for analysis of the effect different physical or mental strains during the process of driving the car simulator). On the simulator it is possible to measure also movements of pedals (throttle, brake) and movements of steering wheel. In addition to these simulator outputs it is possible to place additional devices in the simulator or on experimental driver (proband). Outputs from these devices are also included in set of objective measurement. For example measurement of reaction time to different stimuli, movement of head of the experimental driver or camera record. The outputs, which appear very important, are measurements of EEG signal or ECG signal.

Subjective measurements are represents for example by the analysis of subjective questionnaires, where the experimental driver describes own status before measurement, after measurement or during the process of driving the car / simulator. Also he/she subjectively evaluates different aspects of tested devices.

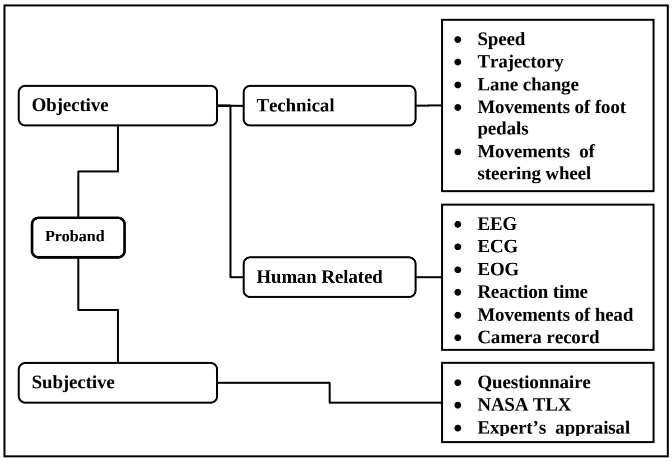

Fig. 4 Hierarchical structure of measurements

Following paragraphs should sketch possible methods of analysis of above described measured data and consequent methodology of classification of driver's performance.

3.1 Reaction Time experiments

The experiments which takes into account a time needed to perform certain desired tasks are very common in the field of HMI investigation. Such an approach is very straightforward, since it directly correlate with time cost demanded which are very important mainly in systems requiring time critical reaction of the operator. In comparison with questionnaires it is objective and they are not so affected by actual driver's mood. Their results are then affected mainly by learning procedure which is possible to derive from longer time measurement. But unfortunately in fact it deals much more with ergonomics than with a complex view on HMI discipline. It is possible to say that the reaction time test should not ever stay alone when classifying quality and suitability of a particular device.

3.2 Speed Measurements

One of the essential factors of drivers' ability of safe and responsible driving is his/her attention. Attention can be defined as driver's ability to react promptly and safely to standard and nonstandard situations. We made several different experiments on the car simulator. The attention of the experimental drivers is purposely decreased by means of the standard activities in the car. (Manipulating with car equipments, listening the radio, phoning…). One of the factors, which could be easily monitored, is a speed of the car.

Speed of the virtual car is recorded in m/s each "visual time step". The visual step was chosen because of that fact that the driver can only react on the changes in the scene (there is no feedback for the driver in between two successive frames). Unfortunately it causes that the time steps of the record are of "floating base" (i.e. the sampling rate is not constant over the whole record). From that reason it is necessary to interpolate the values in the record. A linear interpolation appeared to be sufficient foe all our analysis but more correct should be to use spline interpolation in some cases. Our scenery which the virtual car drives trough is divided into two sections. First part represents a demanding road (it is full of curves) and the second is an easy road (contains only very week curves and straight road segments).

Probands are instructed to keep predefined speed – 50 km/h for demanding road and 100 km/h for easy road. During driving the probands are asked to do certain action (manipulating with some in-car devices). During this action the driver should split his/her attention between the task and driving itself. Due to this fact he/she looses the correct control and we can find lots of correction actions in his/her behavior. One of them is correction of the appropriate speed (which is usually lost when fulfilling the given task). From this we can derive that demanding task causes more variations in the car speed (comparing to the parts when the driver is not disturbed).

On the next pictures there is depicted a histogram of speed measured from virtual drives. The first graph (Fig. 5) represents spectra of speeds in time when the driver was not disturbed and could focus all his/her attention on driving. The driver was instructed to keep a speed of 50 km/h. From the graph it is possible to see that he/she drove in between 43 and 48 km/h without significant differences.

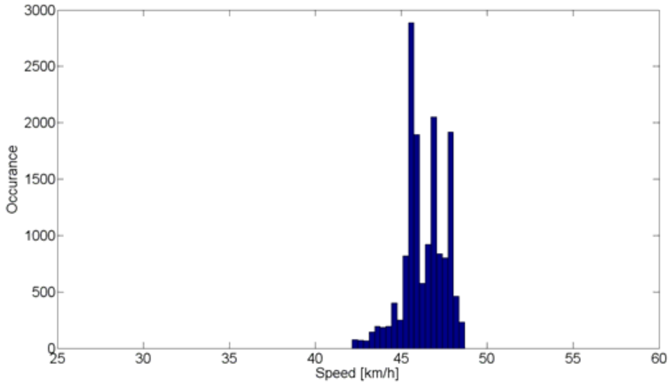

Fig. 5 Histogram of speed without disturbing

The next graph (Fig. 6) shows the situation when the driver was asked to manipulate with a little complex device while driving (all the other requirements on driving were the same as in the previous case). For a first look it is possible to say that the speed varies significantly, speed ranges in between 26 – 52 km/h. It is mainly due to the fact that the driver cannot put his/her attention on driving and he/she do many corrections. We can also see that the average velocity drops to 40 km/h.

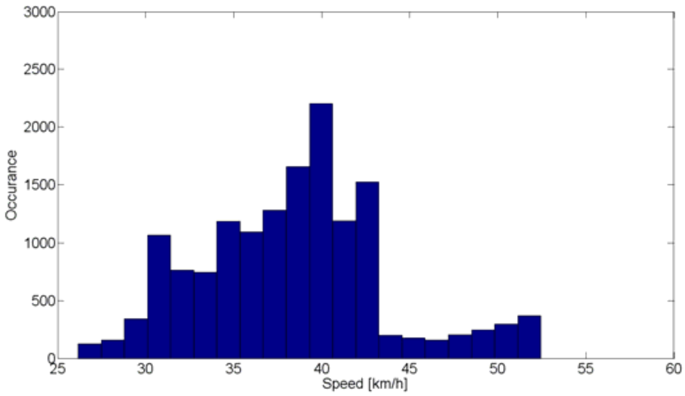

Fig. 6 Histogram of speed with disturbing

3.3 Deviation from an Appropriate Lane

One of the most important markers of the driver's ability to cope with difficult conditions is to monitor the deviation of the car's ideal path on the road. For our initial experiments we simplified this condition to a simple check if the car persists in the corresponding lane. The number of unmeant crossings of the border or dashed line is marked in the EEG recording and evaluated with respect to the time spent in the 'error state'.

This marker is very rough one. It is suitable mainly for measurements where the testing scenario is easy to drive and therefore driving out of the lane means very serious fault. This is successfully used when measuring drivers micro-sleeps (drive out of the lane there testifies that the driver is no more able to control the car).

3.4 Deviation from an Ideal Path

To do more precise classification of driver's behavior of the car we need to find a finer measure than described in upper paragraph. Analyzing of car trajectory seems to be very promising. We decided to base our classification on studying differences between the car trajectory and geometrically ideal path. Ideal path is a curve copying the middle of the road that experimenting person drives on. Discrete points of trajectory are interpolated so that they are of equidistant distribution. From these data a statistical analysis is derived.

The next graphs show histograms of differences of the trajectory of the driven virtual car and the geometrically ideal path. The first picture (Fig. 7) shows an analysis from the part of the measurement where the driver was not disturbed. A road width is 3.5 m and reference curve is a middle of the road so the correct trajectory should be around 1.75m (i.e. in a center of right lane). This is most occurred value as can be seen from the graph.

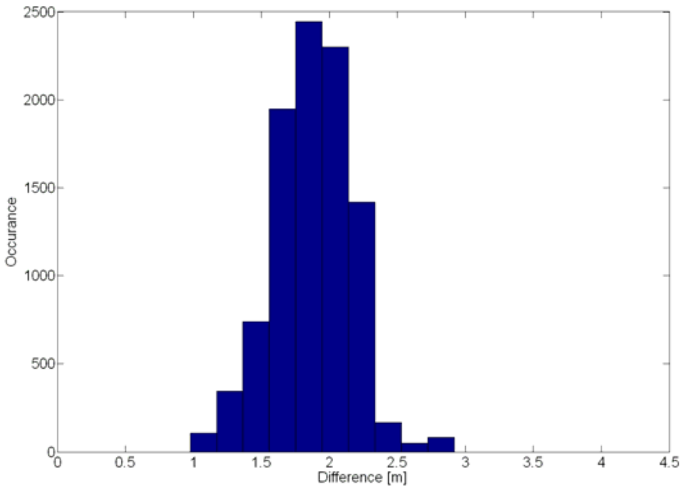

Fig. 7 Histogram of deviation from ideal path without disturbing

The picture (Fig. 8) shows the same proband driving on the same part of the track (road) but loaded with manipulation with car assistance device. It is possible to see significant variations in distance from controlling curve. Values near to 0 and over 3.5 mean that the car was out of its lane with at least 50% of its body.

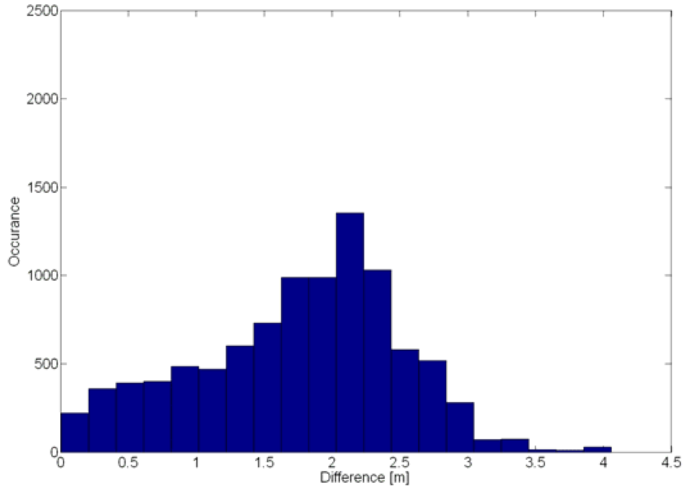

Fig. 8 Histogram of deviation from ideal path with disturbing

3.5 Driver's Correction Movements

From research done already before [14] it is proven that driver's correction movements are tightly coupled with his/her drowsiness. When the driver is drowsy he cannot pay enough attention on driving tasks. As a result we notice more corrections in his/her behavior. The most significant marker of the driver's attention decrease seems to be a set of steer wheel corrections [8]. Breaking and correction of the speed with gas pedal can be also testifying but those are already encoded in the car speed.

We suspect that such marker testifying about drivers attention decrease could be successfully used for investigation in HMI task as well. It is due to the fact that we also look for if the driver's attention decrease (not due to fatigue but by focusing on manipulating with car equipments) in place of controlling correctly the car.

3.6 EEG Measurements

EEG signals arise from an activity of neurons of the thalamus and cortex. A normal EEG signal is quasi-periodic, but they are approximately of a sinusoidal shape. The amplitude of the EEG signal is usually between 10 and 100, which varies with frequency. The frequency range is from 0 Hz to 80 Hz, the effective range is limited approximately to 30 Hz. It's measured on the scalp of the driver's head.

There exist several types of brain waves and they are classified into several categories. From our point of view, the most important are the following [2]:

- *Delta - (0.5 - 4 Hz) - It can be found in a deep sleep. It is also typical for analytical thinking. Occurrence during adult's vigilance is pathological. The amplitude is usually between 10 and 200.*
- *Theta - (4 - 8 Hz) - It can be found together with delta activity in certain phases of sleep. Theta activity also increases during psycho-tests, even with open eyes.*

- *Alpha - (8 - 13 Hz) - The most apparent is with closed eyes. It is damped by an intellectual activity and opened eyes. Its amplitude is usually between 30 and 70.*
- *Beta - (13 - 30 Hz) - It is typical for uneasiness.*
- *The amplitude is up to 30. The maximum of beta activity is in the frontal part of the brain.*

Each of the bands can give us certain information about that driver's actual mental state. Unfortunately those markers are very individual ones and they are hard to be generalized. The topics to investigate are mainly correlations between them and/or ratios among them. Very interesting view gives us anon-linear analysis of EEG signals [6].

One of the possible direct measurements of driver's workload is a classification of his EEG signals. The driver was during the experiment forced to push a functional button in placed in three possible positions. The proband had to react on audio-visual stimuli. To do the task more complex, the driver should decide depending on visual instruction, which way to handle the appropriate button. Thanks to that fact the difference could be more apparent. Figure (Fig. 9) shows the ALPHA/DELTA ration from O2-electrode during a simulated drive.

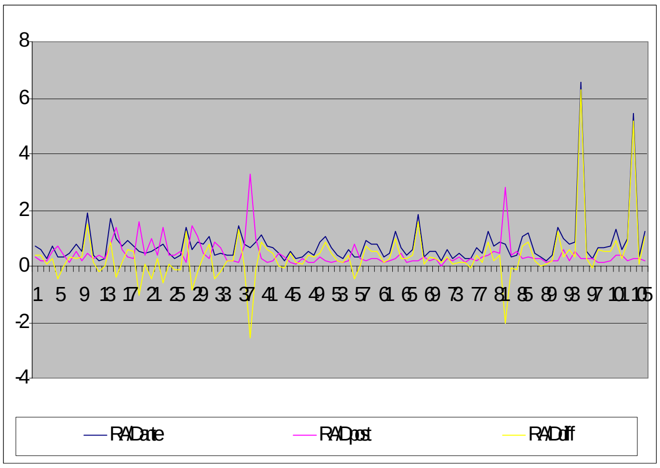

Fig. 9 Alpha Delta Ratio

From the graph it is possible to see difference (yellow curve) between the situation before (blue) stimulus and 3 sec. after the stimulus (purple). It is possible to derive that the position of the functional button really matters (with respect to the driver's workload).

4. Conclusion

Usage of car driving simulators in connection with a complex set of measurements can give us a good view on the driver's behavior. None of the contemporary methods is reliable enough so that it can give satisfactory results for general population of drivers. We brought a set of analytical methods (approved by our experiments) which combination can give a very complex evaluation. It is recommendable to weight each of those factors for each particular driver type. Consequently the measurements of tasks of HMI become more objective and reliable.

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