Czech Technical University In Prague

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DIPLOMA THESIS

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In-vehicle traffic-signal system

Prague 2014

Acknowledgments

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Title: In-vehicle traffic-signal system

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Key words: Virtual traffic signs, Human-machine interaction, Graphical user interface, GUI, Traffic sign recognition, ADAS, Driving simulator

Abstract:

This paper studies in-vehicle driver assistance system that displays traffic signs and influence of such a system on driver performance. During the experiments on a simulator driver behavior was observed with the help of eye-tracking device and video camera. A study of driver performance, namely reaction to road situations and following directions of traffic signs during controlling vehicle with and without assistance device is provided. Statistical data about drivers following traffic sign instructions, the reasons in case of not following those in real road situations as well as driver acceptance of the system collected during surveys is analyzed.

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Abbreviation Table:

ACC – Adaptive Cruise Control

TSN – Traffic Sign Notification

TSR – Traffic Sign Recognition

V2I –Vehicle-to-Infrastructure

ADAS – Advanced Driver Assistance Systems

VTL – Virtual Traffic Lights

GUI – Graphical User Interface

V2V – Vehicle-to-Vehicle

VTS – Virtual Traffic Signs

HUD –Head-Up display

PDV – Personal Driver Values

DVI – Driver Vehicle Interface

POI – Point of Interest

1 INTRODUCTION:

Traffic signs on the road are one of important means of traffic control and management. The problem of drivers not following signs instructions is one of the issues of congestions and accidents. Among the reasons of drivers not following traffic signs instructions are limited visibility of signs because of landscape and weather conditions, materials the signs are made of, ageing of image, incorrect expectations, driver inattentiveness, personal and other reasons.

Advanced driver assistance systems have a wide appliance in modern vehicles. The purposes of such systems are mainly driver comfort, safety and traffic control and management as well as providing driver with travel related information. The traffic sign information system is the one delivering driver the images of traffic signs according to driver location in virtual form on an in-vehicle display.

When introducing such a system into a vehicle it is important to assess its influence to a driver and his/her performance while exploiting it. To evaluate the system usability it is necessary to observe if driver refers to the information it provides and whether it helps during driving. Any additional device in a vehicle may tend to distract of driver attention from the road. Movements of eyes during performing driver task help to explore the object or zone of driver visual attention and to observe to which sources of information he/she refers to while driving and, thus, explore if they exploit the system. To assess the effectiveness of the system it is necessary to observe if the information about virtual traffic signs impacts driver reaction to instructions of traffic signs. Observing the zones of visual attention of driver together with actions at the same point of interest on the road helps to analyze if the information driver collected was effective in making decisions in road situations. In addition, to analyze system subjective acceptance by user it is necessary to collect driver attitude about driving with the system tested.

1.1 Aim of the experiment:

It is necessary to observe the driver reaction to instructions of traffic signs in two phases: driving with only physical traffic signs on the road and driving with the help of application that duplicates physical traffic signs at in-vehicle display. Driver track following and ocular behavior shall be recorded during the experiment. Analysis of performance to compare driver reactions in two phases of experiment is to be done. It is important to estimate the effect of the system to driver performance by studying if the system helps driver to avoid neglecting traffic signs compared to driving without application during simulation.

1.2 Structure of the Thesis work:

The following paper is organized into three nominal parts.

A. At the beginning of this work there is a research of work in the area of in vehicle information systems, traffic signs in particular. In addition, there is a description of available methods of assessment of in-vehicle information systems and their graphical user interfaces.
B. The next part specifies technical equipment used in the experiment. Simulator system, eye-tracking device and in-vehicle information system application are described, available schemes and pictures are provided.
C. Data collection stage includes detailed description of experiment organization, experiment scenario, specification of points for observing driver behavior, proband groups and demographic distribution within them
D. Next stage analyses the results of data obtained during the experiment. Analysis of observed situations and data obtained from questionnaires is provided.
E. The thesis is concluded with conclusions of in-vehicle information system evaluation, its efficiency and improvement recommendations.

2 Background.

2.1 In-vehicle information systems.

Per involvement into the primary driving task, in-vehicle information systems can be subdivided into the following groups.

The *first group* systems are those that are a part of, or somehow are associated with the major driver task (i.e. vehicle controlling and maneuvering), such as adaptive cruise control (ACC), lane departure warning, pedestrian protection, automatic parking, blind spot detection, driver drowsiness detection, hill descent control and many others. In other words, the technologies of those systems are designed in such a way that they either provided driver with information that may affect driver's action while controlling the vehicle, like giving a signal to driver in drowsiness detection and anti-collision systems, or performed certain functions of controlling the vehicle instead of driver, like automatic breaking in anti-collision systems and pedestrian detection. Nowadays these systems are widely implemented by most world's car manufacturers in contemporary vehicles.

The *second group* lists the systems that provide additional information to driver while one is performing the primary task. The information provided is often taken from some source database or environment. To those belong the traffic sign notification systems, route planning and navigation systems, weather and traffic information and others. These systems have a wide implementation in modern vehicles and can be a part of vehicle design as well as are suggested in optional packages by car retailers or in aftersales market.

It is necessary to mention that the classification suggested above is rather conditional. For the example, navigation systems are starting to be implemented for vehicle control in off-road environment for application in different spheres like agriculture and industrial sector. In a review made by Mousazadeh (1) navigation is used for vehicle autonomous driving along the crop rows and guided by an operator. Another research by MaKkelaK and Numers (2) describes outdoor navigation for autonomous guided vehicle to perform transportation at a steel plant along a predefined route. These kind of systems aim to decrease the load to human operator in controlling vehicle.

The traffic sign notification systems (TSN) were initially intended to provide driver with on-road sign information in a convenient way. Those systems obtain information about road traffic signs and display it to driver on a device placed in cabin of a vehicle. Either a particular group or all traffic signs can be displayed to the driver. The systems vary in techniques of obtaining the information and in types of display. Being employed together with ACC system, for example which is explored in (3), traffic sign recognition can be not only the information system, but also the one associated with major driver task. The given example does the research of the system with speed imitation traffic sign recognition for the purpose of controlling the vehicle speed. Together with readings of the traffic sign, the front detectors data about the front obstacle (vehicle) was used for cruising speed control. The simulation was run in a closed racetrack area with two vehicles – one controlled by a human, and another by a robot.

2.2 Traffic sign notification systems overview and classification.

By the source of information, TSN systems can be conditionally subdivided into the following subcategories:

- **a.** Video-based (of vision-based) systems ;
- **b.** Hybrid (or fusion) systems[2];
- **c.** Interactive systems.

For *video-based* TSN systems a very important issue of traffic sign notification is reading the sign. As observed by Møgelmose, Liu and Trivedi (4), the basic issues of traffic sign recognition process are the detection of sign itself and the tracking of the sign for its proper display in the zone of its action. In such systems the sign is read by frontal view camera installed in the vehicle, or in a display device (usually installed in the area behind or under rear-view mirror) and the sign is recognized via image classification algorithms (hence the name). A selective traffic sign[1] vision-based recognition is represented in the paper by Aliane, Fernández, Bemposta and Mata (5). The system is designed to provide the alerts about violation of particular Speed Limit, Stop Sign and Forbidden entry traffic sign. The notification is an audio signal sent to driver via in-vehicle loud-speakers. The system can be employed for traffic management and analysis, the data of violations is recorded and stored according to GPS coordinates of position of vehicle at the instance of violation.

The *hybrid, or fusion*, TSN systems usually use the combination of two (or more) technologies to detect and identify the traffic sign. In the papers, (6) and (7), vision-based TSR system is supplied with an additional module for better accuracy of notification. Thus, Bahlmann, Pellkofer, Giebel and Baratoff (6) suggest adding the GPS maps module for helping in the conditions when the vision systems performance is compromised, i.e. limited vision at night, in bad weather conditions or at adhesive light during the day. On the other side, the GPS maps data does not usually take into account the construction road works that are accompanied by temporary traffic signs and limitations, the variable traffic signs notifications with variable speed limits and some rural roads data from which is not registered in maps. Here the vision module of the system contributes to the whole system performance. In addition, the expert knowledge of traffic regulation rules is used in the system and according to the authors, can be modified in respect to country of application use. The experiment result showed that the fusion system showed better time of detection traffic sign than the when the data is obtained only from the camera.

Another hybrid TSR, described by Garc´ıa-Garrido, Ocana, Llorca, Sotelo, Arroyo and Llamazares (7) in addition to video recognition, uses V2I communication for cancelling notification of traffic signs that do not belong to the location and GPS data of vehicle location. The two of three modules' (stereo vision and GPS) data are used to determine the vehicle distance to the detected traffic sign. As in the system described previously, here the detection of traffic sign is done with the help of vision system. In this case it is a stereo vision system which provides better possibilities for calculation of distance from vehicle to traffic sign. For simulation of V2I infrastructure part proposed in the given system the authors have installed RF wireless sensor motes for transmission to each traffic sign in the zone of simulation plus a receiver into the tested vehicle. Better accuracy of the vehicle position at GPS bad signal or delay is gained with the help of its determining via two motes on different traffic signs and trajectory of vehicle movement. The experiment run in this paper describes offline data evaluation, but states that real time detection would be possible. The results showed the detection rate of 89 to 98 %.

It may be concluded that the main objective of the hybrid systems described is to tolerate disadvantages in performance of their separate components. Thus accuracy of read data from the traffic sign images in limited visibility conditions is enhanced with the help of GPS maps data as well as with the help of special distance detectors. On the other hand, the changing data from variable or temporary traffic signs, or the missing data can be compensated by identification of traffic signs by image processing techniques applied in real time video recording.

Interactive systems assume vehicle communication to infrastructure (V2I) or to other vehicles (V2V). It means that information displayed on an in-vehicle device is obtained from (or sent to) the some object or database outside the vehicle. One of the motivations of exchanging the information between in-vehicle ADAS is a possibility of traffic control and management as well as traffic data collection. One of the examples of V2I communication has been already described above in (7), where receiving the transmitter signal is used for accurate display of traffic sign. Here the infrastructure part is presented by the transmitter units placed at each traffic sign. Calculation of vehicle location by evaluation of its distance to two traffic signs in the infrastructure makes it possible to ascertain the position of vehicle with not only the purpose of sending the more accurate traffic sign information, but also opens the possibility to collect data of traffic in the evaluated area. Such kind of system implementation makes it possible to display all kinds of traffic signs regardless of its visual readability by only making a virtual representation of not only traffic sign, but also other traffic marking on the road. In the next sub-chapter, several examples of virtual traffic sign systems will be explored.

2.3 Virtual traffic signaling systems. Overview of related work

Virtual traffic lights.

The purpose of implementation of VTL system described by Rua do Campo Alegre (8) is traffic regulation of separate intersections. In the mentioned article, the author suggests replacement of physical traffic lights by the virtual ones to be displayed by in-vehicle device. The system suggests traffic management on the intersection based on intersection area traffic flow via regulation of traffic light signaling regime depending on the situation on intersections. This should be realized via V2V communication and the necessary traffic light should be switched on according to the demand. The paper concentrates attention on the development of graphical user interface (GUI) of the tested in-vehicle information system represented by a monitor device placed in cabin. The basic requirements to the VTL system are that they are designed with maximal possible accordance and similarity to those of physical traffic lights and the transition from physical to virtual system is to be of maximal comfort for a driver. As for the physical traffic lights, those should agree with the following uniform rules: information displayed is to be clear and easy to understand; the notifications are to be displayed within an adequate visibility range to ensure the good driver response time; the displaying device is to be uniform format-wise to read the transmitted data without additional information delay time; the colors of traffic lights should be uniformly understandable, i.e. green –

for go, orange for temporary traffic control, yellow – for warning and red – for stop; the light units are to be mounted within driver visibility (above the road, on the street corners), signal timing is to be set according to the intersection parameters such as geometry and traffic volumes as well as speed of passing cars.

The following *parameters* describe *the suggested VTL system*:

- the HUD (head-up display) with image projection to the windshield. This version of HUD was selected because minimal information needs to be displayed – signs of warning of upcoming traffic sign with text information of distance to it, arrows of traffic direction and traffic light itself;
- the distance of virtual information projection to driver eyes was between 2.5 to 4 meters in lateral field of view so that the image did not interfere with driver sight zone to the main road (central field of view);
- it is stated in the paper that the luminance parameters of projected image were selected so that the displayed information would be visible in all weather conditions as well as it did not interfere with the road traffic environment. Unfortunately, the author does not specify if those parameters were assessed before the experiment.
- the distance of warning about the upcoming traffic sign (with specifying the value of distance) is selected as 200 meters. The authors selected it according to norms of placements of actual traffic sign warning in the area (150 to 300 m – in Portugal); the warning sign displayed before the intersection with traffic light is supposed to increase the car stopping distance and driver preparedness.

The simulation scenario.

The measurements have been taken in urban scenario, which was selected as the most common area for installation of traffic lights, with track length of 2874, 6 m, one intersection and two- or three-lane road. The traffic density level was a medium to high and no critical events were present. All proband drivers followed the same traffic scenario with identical set of events. Before the experiment drivers were given to test the simulation tool on a separate scenario with the traffic lights. Each participant drove two scenarios that looked different but were schematically the same – one with physical traffic lights and another – without. The simulator was represented by a real car cabin and projected visualization of the scenario. 10 participants took part in the experiment, each provided data for passing 8 intersections in general. There was equal amount of men and women, the average age of participants was 35 with driver experience from 6 to 10 years.

The results.

In the course of experiment the GUI of the application has been improved based on the feedback from the participants on the early stages. The initially proposed design was reflected on by participants as not intuitive – visualization of traffic light was rather schematic and then was replaced by the image repeating the view of classical traffic sign.

The participants provided feedback on the subjective safety level of the application and 55% of probands considered it as safe as physical traffic lights.

There was observed higher tendency in deceleration change rates while driving with VTL system.

Virtual traffic signs (VTS).

Maihöfer and Eberhardt in (9) describe the system of virtual notification of a particular group of traffic signs – warning traffic signs. The goal of the suggested system realization is to increase the safety on the road by increasing driver's area of sight with the help of providing the warning at in-vehicle device earlier than the driver sees the dangerous situation in reality. The possible situations of which driver is to be notified in advance are accident that happened on upcoming section on the road but is not visible yet because of road curvature or ascending path. As mentioned in the paper the zone of action of each traffic sign is specified by connection of it to a particular area with possibility of narrowing the zone of action along a certain lane. The sign is to be displayed to driver when the vehicle is within this area and it (the sign) should stop displaying as soon as vehicle leaves it. As the paper concentrates on the communication infrastructure of system realization part, the graphical interface and HMI interface are not described. The important notice from this paper is that warning notification is that it encourages drivers decelerate before limited visibility road sections. Such a system can contribute to decrease risk of accidents and hazardous situations especially in unknown areas and possibly notification of icy road and other information from infrastructure to benefit the driver.

2.4 Types of information display

To draw driver's attention to the information visual and/or auditory displays of information, or their combination, can be used. Visual displays are classified by their location in relation to viewer – head-up display (HUD) and head-down display (HDD). In-vehicle head-up display's sense is to place information in or near to the zone of driver gaze while he or she is performing major driving task. The most common representation of HUD is projecting transparent image on a windshield preferably in the lateral zone of view – not to interfere with the central zone of view. Another variation is placing an added monitor behind the steering wheel. However if an added HUD is not transparent, it can affect the visibility of the road. The head-down display (HDD) is usually represented by a portable or built-in device attached to the dashboard zone and requires driver's head rotation or change of gaze down off from the road. Visual information on a display may be accompanied by a warning sound of appearance of a particular traffic sign.

Unlike navigation systems, for example, where driver needs to provide input to the system by setting destination, changing route etc., traffic sign information system, once it is started, will not require driver input. So one of the basic assets of developing the in-vehicle device of such a system will development of an user interface that would provide minimum distraction to a driver from major task.

2.5 Graphical user interface.

Some of the requirements of in-vehicle information systems GUI are described in the articles mentioned above. From what has been mentioned it can be followed that the interface of virtual traffic lights of traffic signs notification systems displays are to have as many conventional traits as possible to repeat graphical, color, shape and other properties of physical signs. In addition, the display technology must have good contrast and luminance, the weather and lightning conditions should be taken into account as well, and the best solution for device placement in the cabin shall be approached. It is important to note that the notification method selected shall not be irritating for the driver, so, for example, if special alerts are meant to be employed by the system design requirements, they need not be of unusual color or noise.

Shneiderman and Plaisant [10] state general requirements that are to be met by display of any graphical user interface. The following list outlines those applicable to GUI of an in-vehicle system:

- Displayed data shall agree with accepted legislative rules. Which means that all symbols, terminology, graphical representation are to agree with legislation and norms.
- Information displayed shall be recognized and easily comprehensible by the user. This stays for using familiar graphical and space representation of figures, sections, as well as correct making of accents on important things.
- The information shall be of possible minimal load to the user. If new terms or symbols are introduces those are to be delivered to the user according to the procedure. It is preferable to use familiar notations and graphical representation.
- Input data shall be compatible with format of the displayed data
- Representation of the information shall be manageable. Which means that user is to be able to adjust the system for his/her best convenience by rearranging the information according to importance or priority.
- Only the data that is usable (functional) shall be displayed. Unnecessary information will only provide undesirable distraction.

It is also preferable to represent the data graphically rather than in text and to use high-quality displays for better image read. It is desirable to involve potential users of application in the process of its development – organize focus groups, testing, brainstorming etc. Here are also some techniques of attracting user attention to important, according to system purposes, issues:

- Using of maximum two levels of graphics (color) intensity.
- Use marking to emphasize important – underlining, enclosing to boxes, pointing, bulleting etc.
- Use of maximum three fonts and up to four font sizes.
- Use blinking and color change carefully.
- Up to four color shall be employed.
- Use of sharp tones only in the situations of extreme emergency. Soft tones shall be normally used for regular system notifications.

2.6 Overview of methods for data evaluation.

Tested systems of virtual traffic lights [8] suggest a wide range of data collection and evaluation methods. Some of them are provided bellow. A set of papers on observation of driver performance and assessment of graphical user interfaces has been reviewed to explore available methods of data evaluation.

Measuring of driver workload by NASA-TLX test

NASA-TLX stands for Task Load Index of subjective evaluation of physical and mental demand evaluation of task by the operator after using the human-machine interaction systems. In the test the evaluation occurs on the 6 scales: mental demand, physical demand, temporal demand, performance, effort, frustration. Each participant is suggested to take the test after performing the experiment task. As a result statistical weights of workload for each participant are obtained.

Lane-change test for evaluation of ergonomics of in-vehicle systems.

The authoritative description of the test is provided by the ISO standard (26022) [13]. According to the standard mentioned, the ergonomics of an in-vehicle device is assessed by performing the lane-change test. The meaning of the test is evaluation of driver performance by comparison of track following. The following driver tasks are identified during this test:

- Calibration task, which is a kind of a reference task being used for comparison of the results in different conditions that vary in sites or time. It can be also referred to as a model task.
- Primary task, or task performed by the experiment participants. In a given test it is a task of following the course track and performing vehicle control by driver.
- Reference task is referred to selected model of comparison of performing secondary task, i.e. task of driver interaction with in-vehicle system.
- Secondary task is usually performed with a primary task.
- Dual task comprises performance of primary task adding the task of interaction with an assessed system – secondary task.

For every experiment a physical environment is to be provided while the task is performed.

Evaluation of subjective data obtained from questionnaires

The pre- and post-experiment interviews can be conducted with the proband drivers after the simulation designed for testing of a certain application. The questionnaires collect demographic data provided by the driver, driver's acceptance of a tested device or application, drivers subjective feeling during the simulation and perception of the situations during driving. This information can be used in assessing systems tested. When evaluating the particular application usually feedbacks of the probands that drive with application are compared to those that drive without application in the same simulation environment.

While developing the interview questions an interviewer should follow a previously formulated hypothesis on the expectations of experiment results. Shahab, Terken, and Eggen from Eindhoven University of Technology [11] have described the procedure of selecting questions for the interviews of identifying driver's speed behavior – from the subjective view of personal driver values (PDV). Having conducted brainstorm they have identified the basic values from the opinion of drivers: safety, time, comfort, fun, money, being a good driver, sustainability and identified 52 questions in those vale categories. The resulting questions were identifying the reasons of drivers driving faster, slower, regularity of driving faster etc. The approach of identification of driving behavior reasons in questionnaire can be used in assessment of traffic sign notification system. The supposed question to answer is if the driver is able to change driving habits if such a system is present in vehicle.

Measuring driving dynamics

It is possible to measure exact driver response by getting the following data from driving simulators: time of pressing pedals (breaks and gas), steering wheel angle, deviation of driving trajectory etc.

Deceleration and breaking. The speed reducing and velocity parameters before the intersection as the result of notification of upcoming traffic light seen by driver in application are measured in [8]. The deceleration of speed is evaluated through measuring of start of breaking (start of reducing speed after the in-vehicle system notification of a red signal of traffic light). The speed variation in the same simulated situation was compared between the drivers.

Statistical tests.

Kruskal-Wallis test. Researchers from Virginia Tech [12] performed the experimental comparison of two kinds of in-vehicle information displays – integrated HUD (placed at a head-up field of view) and convenient DVI (located on a front panel). One of the proposed methods assessment of these two technologies was analysis participants' subjective preference rating by Kruskal-Wallis test with non-parametric method, which is used to determine if samples belong to the same distribution; it can be used in comparison of more than two groups. The results of the test provided by given example state that the participants ranked the HUD higher than the DVI.

T-test. Campo Alegre [8] uses the test for comparison of means of deceleration rates obtained from driving the simulation with application to driving without.

Student's t-test is used for distribution of two mean values, used to compare two different sets of data obtained, relatively, from experimental and control groups.

One-sample t-test is used in experiments when a mean (reference sample) value is known and being taken as reference sample is used as a constant for comparison of data obtained from experiment.

Two-sample t-test is used for testing of two sets of data obtained from two experimental groups.

Statistical hypothesis testing. Data from scientific study, assumed as hypothesis, is used as a reference. The task of the test is find out which data obtained from experimental study lead to rejection of the reference (hypothesis). If those data are found, its set is to be used for creation of an alternative hypothesis. When the reference hypothesis is unknown, the testing is called confirmatory data analysis.

Tracking ocular movements

Defining the direction of eye glance is a vivid method of evaluation of concentration of human visual attention.

The following driver eye glancing patterns can be observed with the help of eye-tracking devices: number of glances to objects of interest, duration of glances to objects of interest, location of glance.

A phenomenon of possibility of noticing object without looking at it has been studied by the researchers from Federal Highway Administration, Virginia, USA [15]. Defining the angle at which an object, traffic sign in particular, is noticed, shall help to collect more accurate data by eye-tracking devices. On the other hand, the effect needs to be taken into account when analyzing data from the eye-tracking devices.

Another kind of eye behavior is called “saccades”. It is defined as fast movements of eye while scanning the scene and can be observed at unfamiliar scenes containing a lot of object with information of interest.

3 Technological platforms.

3.1 Simulator system

The experiment is held at a realistic simulator *3D light simulator Octavia II* that is based on a cockpit of liter version Skoda Octavia II is cut behind driver seat. The equipment of the cabin is very close to the real car environment with roof, passenger seat, transmission gear etc.

The simulator consists of four functional layers. The first is represented by physical (represented by car cabin and PCs that are connected the same network) and software sections (Virtual reality engine providing 3D graphics and sound of vehicle plus mathematical model of car and environment). The second layer is responsible for storage of simulated scenarios including simulation of traffic of vehicles in the testing tracks. The third and the fourth layers deal with the modelling and storage of visual scenario objects, their shapes, textures and physical properties.

Three monitors are used for graphical display of the simulated scenario: one – is in frontal cabin area and provides front view, and two – on the sides and provide side vision to driver. The images are displayed in a real-time as a response to the driver manipulations with vehicle controls – steering wheel and pedals. The image is projected to the monitors with the help of three projectors and six mirrors. The rear-view mirror is implemented as a part of scenario graphics on the front-view monitor. For experiment purposes, the simulator is equipped with additional devices: in-cabin camera used for supervision during testing and main driving stages in both phases of experiment, and with in-vehicle device (head-down information display) used in the 2nd phase of experiment. The camera is placed behind and in-between the driver and passenger seat. It captures the image on the front monitor and part of a front panel with the head-down application display and in this experiment is used for simulation supervision purpose. If needed, the camera can be used for recording of the experiment. However, the core data in this test is being recorded from the eye-tracker camera. The following scheme describes simulator engines that are responsible for simulation of visual and audio environment displayed to a person when driving in it.

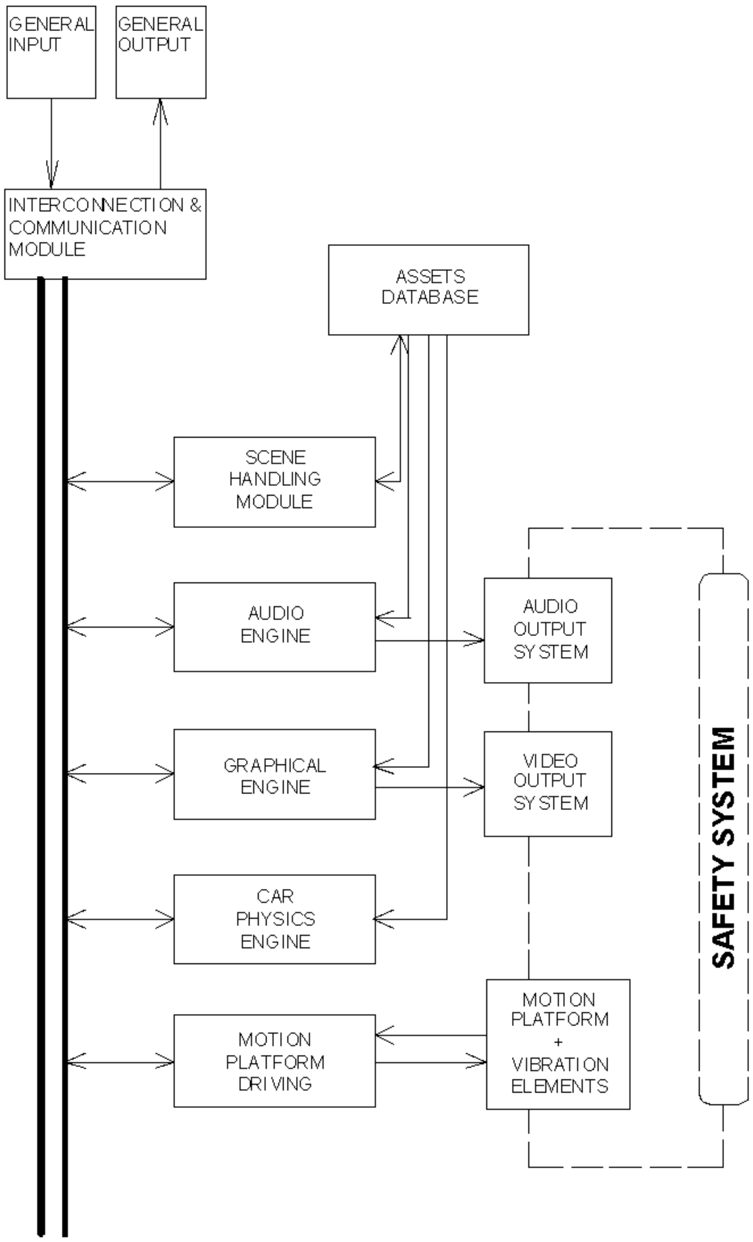


Figure 1. Schematic representation of simulator modules. Image courtesy of Petr Bouchner

3.2 Eye-tracking system

The eye-tracker used is iView X™ HED, produced by S.M.I.. It consists of two cameras mounted on a helmet. Camera 1 – one to track the gaze of human eye and another – for display of the view from the position of driver.

It collects data of absolute measure of eye movement, which is noted as an orbital eye tracking. The system employs so called Dark Pupil System in which the pupil is represented as a dark contrasted ellipse. This type of system requires comparatively less setup time and is working rather robust regardless of eye color. The system is calibrated to provide video output with indicator of eye movement. The basic structural elements of a device are: adjustable helmet, IR video camera unit for tracking of direction of sight, a camera to cover the frontal view area (scene camera), a cable with two USB ports (one per each camera) and a PC called work station. The two cameras are mounted in frontal part of a helmet by means of a special bracket. Cable connects two cameras to computer to which the video output if each recording session is saved. The video data represents recording of visual from the view of proband and contains an indicator (red cross) of gaze direction. Each camera is calibrated according to individual peculiarities of facial geometry to provide optimal scene view and adjust focused eye image.

Figure 2: Eye-tracking device

3.3 In-vehicle information system.

The system is represented by a tablet (Acer Iconia Tab with display of 10’’). The information if traffic signs is displayed on the screen by the scheme described bellow.

The system reads geographical location of the traffic signs from the local database, namely coordinates, radius of visibility and direction of action of traffic sign (according to direction of simulated driving movement). The system obtains information about vehicle location and calculates the active traffic sign to be displayed.

The graphical interface of a system is represented by 5 columns. Signs are divided into the columns by the following intuitive distribution.

The 1^{st} *column* contains signs related to speed limitation. In a given scenario those are: “Maximum speed of 50”, “Maximum speed of 80”, “Zone with traffic limitation” (IP 25a), “City/town/village in local language” (č. IS 12c), “End of city/town/village in local language” sign (č. IS 12d), “End of zone with traffic imitation” sign (IP 25b). There is a yellow box always present in the top of the column. It displays current maximum available speed according to the traffic sign currently in action. If no traffic sign that is a condition of speed limitation is in action, maximum allowed speed according to the traffic rules in a particular area is displayed (i.e. – 50 km/h in the city, 90 km/h at the rural road).

The 2^{nd} *column* contains signs associated with priority rules: “Intersection” (č A3), “Give right of way” (č P4), “Stop, give right of way” (č P 6), “Main road traffic sign” (č P 3), “Roundabout” (č. C 1), “Crossroads” (č. P 1).

The 3^{rd} *column* contains the signs providing information of the direction of movement, information and warning about the pedestrian crossing, parking, about traffic light regulated intersection, wild animals. The traffic signs displayed here are: “Pedestrian crossing” (č. IP 6), “Zebra crossing”(č. A 11), “One-way traffic” (IP 4b), “Turn right”(č. C 4a), “Wild animals” (č. A 14), “Traffic signals ahead” (č. A 10).

The 4^{th} *column* contains prohibition traffic signs: “No waiting” (č. B 28), “No stopping” (č. B 28).

The 5^{th} *column* contains navigation signs with cultural or tourist destination (č. IS 24b).

The following images illustrate the system graphical interface. Figure 3 illustrates the initial state of the system when simulation starts. Driver is displayed maximal allowed speed in the current position, though no traffic sign is provided. Figure 4

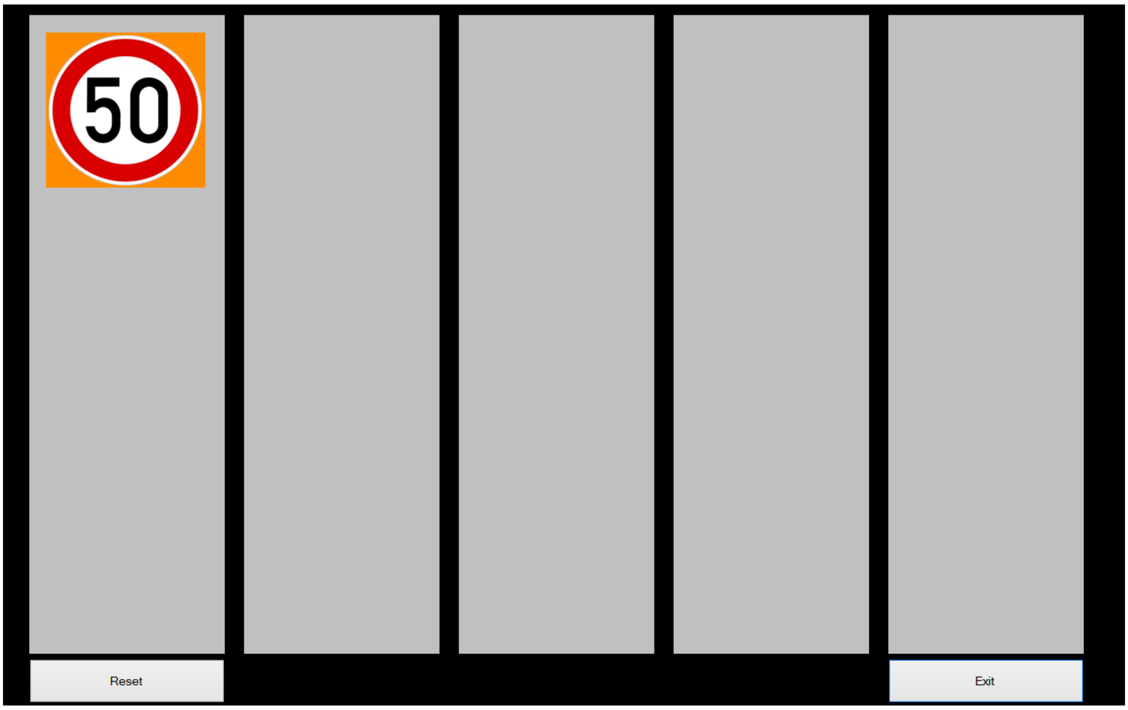


Figure 3: In-vehicle system display. Initial view (POI Start)

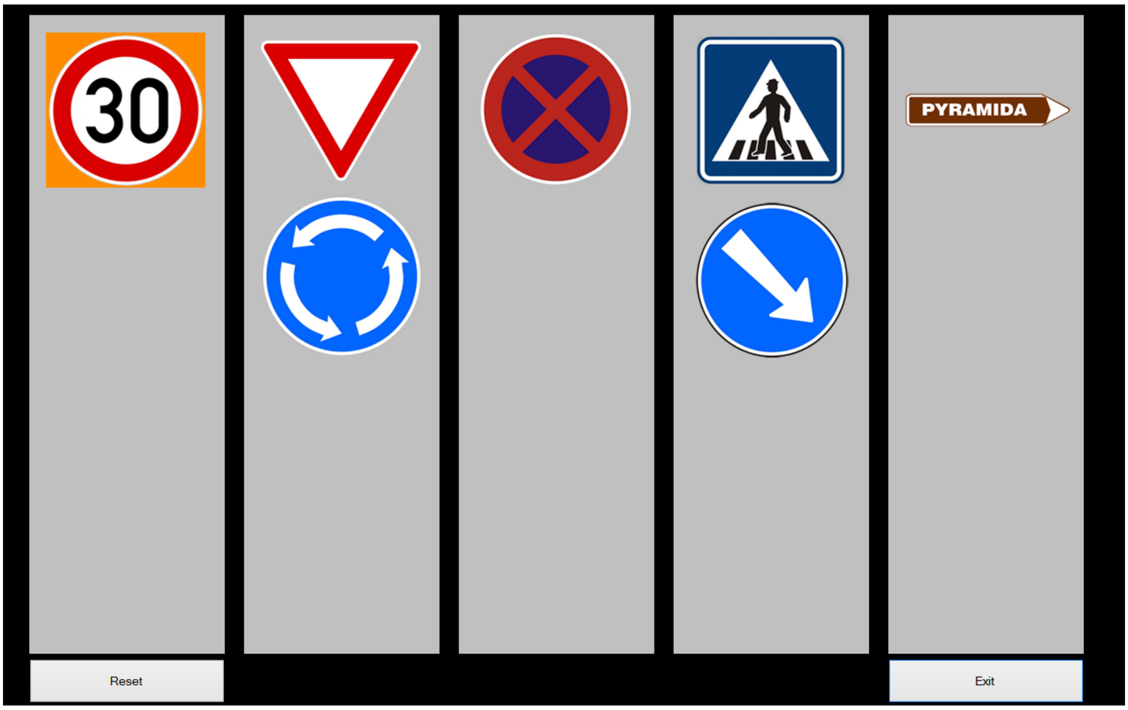


Figure 4: Roundabout display (POI H)

4 Data collection.

Hypothesis of the experiment. It is presupposed that the proposed information system will improve driver awareness of the road situation as compared to driving without application. Driver awareness is to be evaluated on the subject of following direction traffic signs, reaction in hazardous situations and following instructions of traffic signs.

Measurements. Given the available technical equipment, the experiment has been set up on the driving simulator described in section 3.1, an eye-tracker (section 3.2) and information display (section 3.3) that is synchronized with experiment scenario to provide actual display of traffic signs. To assess driver awareness there has been assumed a model behavior, namely following the correct direction according to the information signs that indicate cultural or tourist destination (č. IS 24b). This particular traffic sign was also selected as a reference point to assess number of glances of traffic signs. The motivation of such a choice is reducing probability of error due to driver ability to read known traffic signs without looking at it – the effect also known as conspicuity angle [15]. Another goal is to observe saccades and compare if the virtual traffic signs decrease or eliminate this step in pursuing the information of the traffic situation. Also two hazardous situations were designed in the scenario to observe and compare the percentage of mistakes done by probands from two groups – one driving with only physical signs and another to be provided duplicated signs on in-vehicle display.

4.1 Stages of experiment.

Experiment is divided into two phases with different drivers participating in each phase. The group participating in the *1st phase* is given no assistance device while probands of the *2nd phase* are driving with the application displaying the traffic signs according to the simulation scenario i.e. all traffic signs used in the designed scenario are duplicated at the monitor display in the cabin.

There are five basic stages identified in each measuring procedure of the experiment:

A. Preceding questionnaire;
B. Calibration of an eye tracking device (or eye-tracker);
C. Test-driving
D. Main driving;

E. Closing questionnaire.

Stage 1. Preceding questionnaire.

Every proband is interviewed upon arrival to the experiment prior to other experiment stages and before being seated into the simulator. The questionnaire contains general questions to identify the driver profile i.e. age, driving experience, character of driving, gender; background enquiry about driver's following or not following traffic signs and issues, such as reasons and circumstances connected with the problem. The question list is provided in Annexure A.

Stage 2. Calibration of an eye-tracker.

It is performed in accordance to physical parameters of driver. An eye camera is set for proper tracking of driver's pupil and front-view camera is set to embrace the windshield and front panel visibility. Calibration is performed while proband being seated in the simulator. Before eye-tracker calibration proband is suggested to adjust driver seat, steering wheel to his/her convenience and comfort as well as a correct view of the road (test-drive scenario is initiated for necessary adjustment in a simulated driving environment).

Stage 3. Test-driving.

It is a free drive in a separate scenario different from the experiment scenario and is proposed to each driver to experience the driving simulator physical properties such as break and gas pedals, steering wheel; as well as to test the lane keeping and also to detect the simulator sickness phenomena before the main driving. During and after testing driving the eye-tracker calibration is checked and adjusted, repeated calibration is performed if needed.

Stage 4. Main driving.

During this stage a proband is watched via in-cabin camera for following the correct goal path. In case of driver's failure to follow the path, one is guided to return to the point of mistake after which he/she continues independently. Failure to follow the correct path is recorded into the experiment Protocol and is used for further data evaluation. Experiment protocol is recorded during each simulation and notes about the experiment and technical details of simulator and eye-tracker are recorded there. The main driving procedure in the condition of precise following of traffic sign instructions takes approximately 10 minutes. The figure below illustrates a proband driver taking part in the experiment.

Figure 5: Proband driver participating in experiment

Stage 5. Closing questionnaire.

Every proband is asked questions related to his/her perception of the driving experience during simulation, such as confidence of road situation, feelings about identifying hazardous situations as well as questions related to experience and attitude to traffic sign displaying in-cabin devices etc. Closing interview list is provided in Annexure A)

Driver task specification.

Task 1 was given to the 1st group of drivers participating in the Phase 1 of the experiment. Those probands were assigned to navigate to the point of destination and were performing this task with only following instructions of traffic signs they meet on their way (in the scenes of roadmap of the scenario).

In *Task 2,* drivers were following the same goal with following the instructions of the in-scene placed traffic signs but were provided with an assistance device represented by the display placed in the cabin in the middle of the front panel. All traffic signs depicted in the scenario were duplicated on the display.

4.2 Calibration of experiment.

Task 1. All probands participating in the experiment were given a single instruction in a verbal form to reach the goal that he/she sees at the beginning of the tour following the directions provided by navigation signs with cultural or tourist destination (č. IS 24b). The goal is implemented in experiment scenario as a bill-board with a goal image. All instructions are provided to probands before the start of main driving and after test-driving and eye-tracking system calibration so that all the subordinate tasks related to technical setting of experiment were closed while performing the two basic tasks given to probands. To minimize the factor of national and cultural background of probands, the last are informed of the meaning of sign "Cultural and tourist destination" as identifying of it is not the among the list of driver actions of this experiment, while recognition and following it is. The navigation task is supposed to be the decision making trigger for the driver at each intersection.

Task 2. Along with all the instructions provided to probands in before task 1, brief verbal description of the in-vehicle device and its function are given stating that one will be assisted by an in vehicle display application showing the traffic signs met while driving.

Proband groups.

The requirements to the invited probands was to be an active driver with minimal experience of 1 year and during the experiment to be not under the action alcohol, drugs or any other toxic substances. The total number of 26 drivers participated in the experiment – 13 in each phase, with approximate equal gender, age and driver experience. Overall, 28 drivers were invited to the experiment, but measurements from two could not be taken because of simulator sickness phenomenon. The following charts depict demographic groups of probands who participated in all five stages of the experiment. Elder participants are not present in the experiment mainly because most of them wear glasses and eye-movement is hardly possible to be tracked with most of the optical lenses. However future measurements could be performed with application of more sophisticated eye-tracking devices. All probands were active drivers of persona cars.

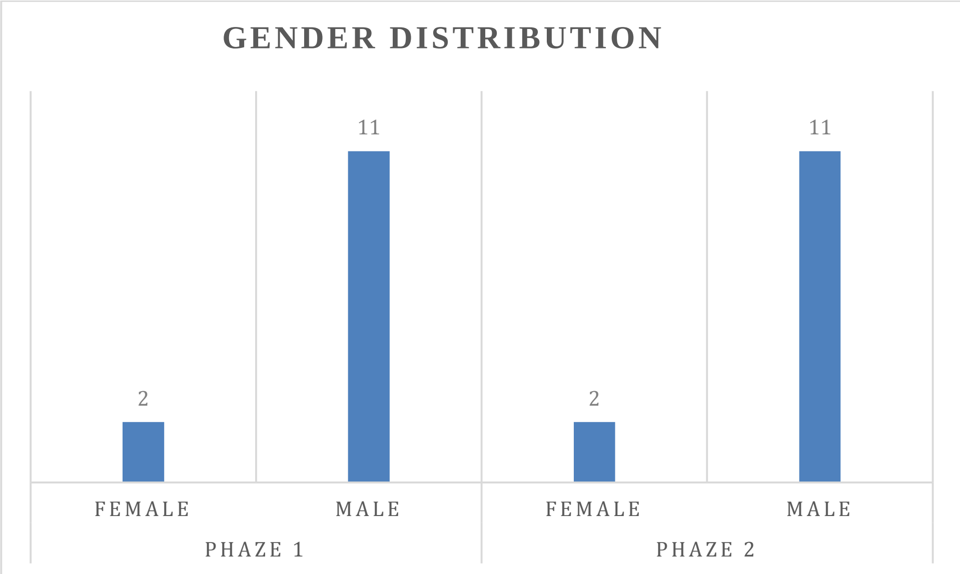


Chart 1. Gender groups

Chart 2. Driving experience of probands

Following traffic sign instructions is one of the important aspects of studying behavior of aggressive drivers. In addition, it is rather valuable to explore the traffic sign display application effect on aggressive drivers. All probands were asked if they considered themselves offensive or defensive drivers. By their own estimation, there was equal amount of offensive (aggressive) drivers in each phase of experiment. Of course, this is only a subjective estimate.

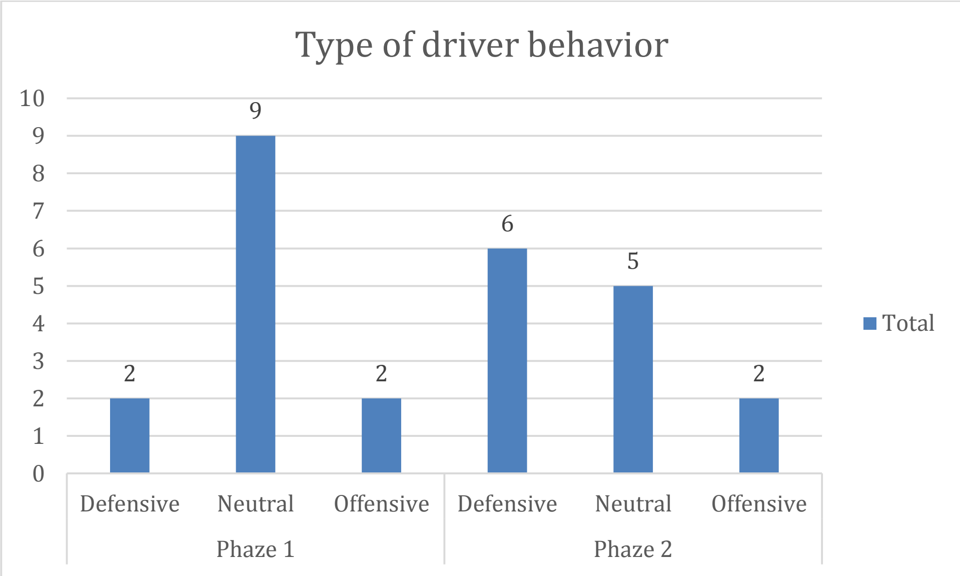


Chart 3: Type of driver behavior

Road map and traffic management.

In the scenario used there can be identified two main classes of the road – city and rural road with lane width of 3.5 m. The total track length is about 8 km (3 km of rural road and 5 km in both cities together). The traffic signs are located in the scenario according to the rules of legislative documents [14].

Driver starts the trip at point marked as "Start" and finishes at point marked as "Finish". An ideal driving path repeats the basic model (path trajectory) meaning one does not make any detours from the ideal route, is schematically indicated with direction blue arrows.(for illustration see Figure 2 or Annexure C). All drivers were told to follow the instructions of traffic signs.

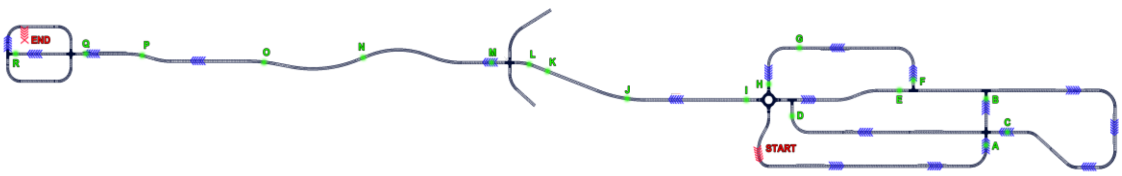


Figure 6. Roadmap

The traffic in the scenario is designed to create special situations that are a part of driving primary and dual tasks. Those situations of interest are used as points of evaluation in the data analysis process.

Points of interest (POI) in the simulation scenario.

All points of interest are positioned from the view of the driver participating in the experiment. The traffic signs described below are not the only traffic signs present in the scenario. List of all traffic signs is provided in Annexure B. The reference pictures for each POI is provided in Annexure D. Each of POIs is described below, listed in order of appearance along the track path of the simulation scenario:

a. Start of driving (POI Start). A proband driver is supposed to identify the locality by landscape around (city) and follow the corresponding speed limitation.

b. The intersection (POI A) is marked with a traffic sign “Intersection” (č A3) that belongs to the group of Warning signs, which means that the right of way is not regulated by vertical road signs. According to instruction of this traffic sign, a driver is supposed to give way to the vehicle approaching from the right.

c. The intersection (POI B) is marked with “Give right of way” (č P4) traffic sign that belongs to Priority group. According to the instruction of this sign driver following the subordinate road is supposed to give way to the vehicle moving along the main road, which is in the simulation scenario is approaching from the left.

d. Second intersection (POI C) with a traffic sign “Intersection” (č A 3) (see POI A).

e. Intersection (POI D) marked with “Give right of way” (č P4) and sign “Stop, give right of way” (č P 6) from Priority group. (According to scenario idea, the last traffic sign is put there because of road works being held on the main road and there is a possible traffic of service vehicles). The diver is supposed to stop before continuing traffic. After the intersection driver is following the road with on-way traffic “One-way traffic” (IP 4b).

f. Intersection (POI E) is marked with “Main road traffic sign” (č P 3) from the Priority group. The point of interest is peculiar because of several traffic signs placed close to each other before the intersection. The expected challenge for driver is reading the historical goal navigation sign and making correct decision of turning to the left. The sign-reading task is complicated by sign's visibility in the particular landscape.

g. Zone (POI F-H) of acting speed limitation of 30 km/h is marked with a "Zone with traffic limitation" (IP 25a) traffic sign. There is no repeater of the speed limitation during the zone of the sign action. The driver is supposed to fulfill the speed limitation of 30km/h before sign action is over. During the section of action of this traffic sign, the skateboarder is crossing the road (POI G) on the second of two pedestrian crossings (marked by corresponding signs (č. A 11) "Pedestrian crossing" (č. IP 6). Driver will succeed to hit the break safely only if following the assigned speed limitation. There is the "End of zone with traffic imitation" sign (IP 25b) at the end of the zone.

h. Roundabout (POI H) marked with sign of "Roundabout" (č. C 1) from the Regulatory group preceded with "Roundabout" from group of warning signs (č. A 4).

i. Place (POI I) marked with "End of city/town/village in local language" sign (č. IS 12d) is identifying the boundary of a municipal area. The sign belongs to the Informative sign group. The driver may exceed the speed limitation for the municipal area and is supposed to follow speed limit for the rural road.

j. "Maximum speed of 50" (POI J) (č. A 14) traffic sign from the group of Warning signs.

k. "Wild animals" (POI K) (č. A 14) traffic sign from the group of Warning signs.

l. Intersection (POI L) marked with sign "Crossroads" (č. P 1) from the Priority group.

m. "Wild animals" (POI M) (č. A 14) traffic sign from the group of Warning signs.

n. "Maximum speed of 80" (POI N) (č. B 20a) from the Prohibition traffic signs group.

o. Appearance of a deer (POI O). A driver is supposed to fulfil the breaking task in case of following the speed limitation instruction by the sign in 1.4.1.15.

p. Boundary of a city (POI P) is marked with sign “City/town/village in local language” (č. IS 12c) from the Informative signs group. The driver is supposed to limit his speed by 50 km/h.

q. Intersection (POI Q) with a traffic light preceded by the warning sign “Traffic signals ahead” (č. A 10).

r. Intersection (POI R) with a “Stop, give right of way” (č P 6) sign.

s. The destination (POI End) is marked with a “Parking” (č. IP 11a) and “Residential zone” (č. IP 26a) traffic sign. Driver is supposed to drive to the parking slot.

The two predefined hazardous situations are specified above as Points of interest G and O.

5 Data analysis

To find out possible reasons of drivers not following traffic signs instructions the questionnaire forms have been competed with each of the participants. Proband testimonials from their driver experience were collected at the beginning of each experiment. Twenty six questionnaire forms have been filled in.

Pursuing the goal to find out why some of traffic signs may not cause the desired effect a question has been raised. The Chart 4 shows that more that more than half of participants are committed to disregarding traffic signs.

Chart 4: Intended disregarding of traffic signs

The most popular reason for that was the circumstances caused by other participants of traffic. Among all questioned probands, the majority declared they cared about following traffic. For reference, please see Chart 5.

Chart 5: Following traffic signs

Fewer drivers have been fined for speed violation.

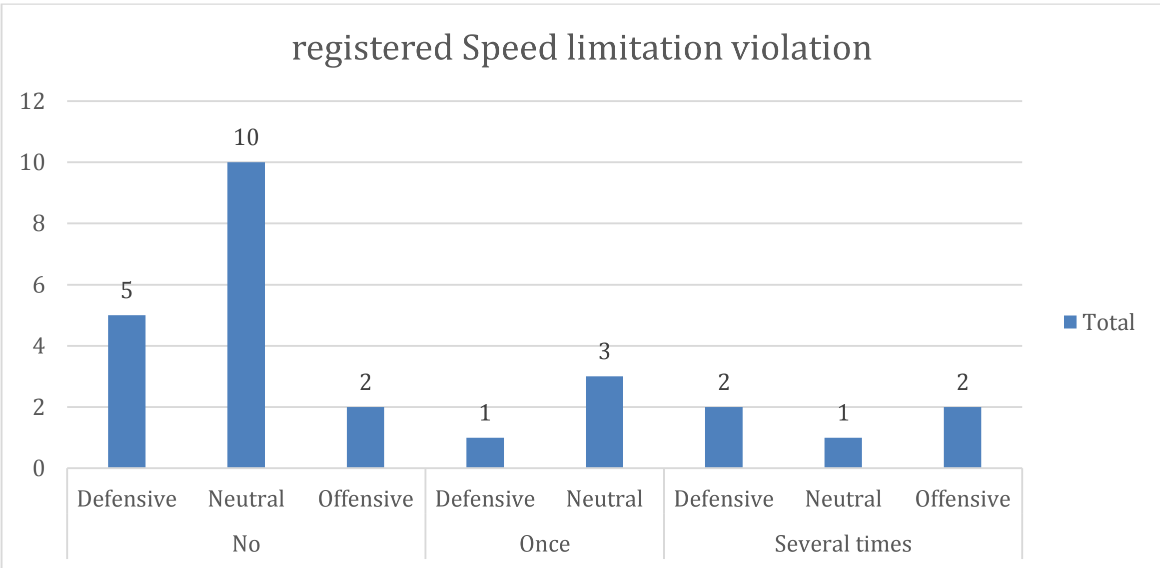
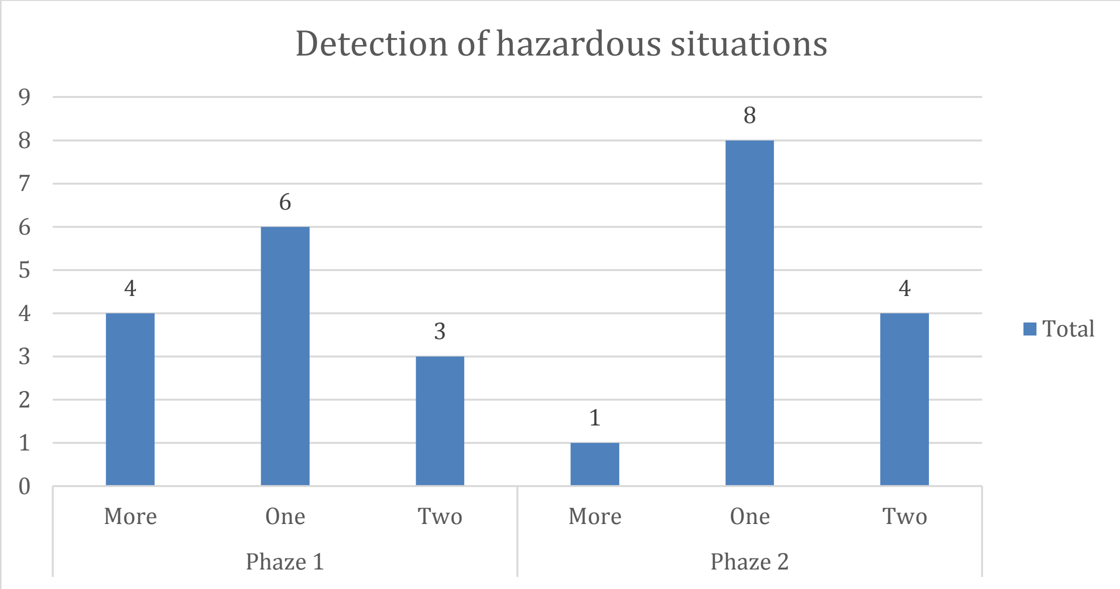


Chart 6: Speed violation

In post-experiment survey, probands participating in both phases were asked to reflect about the experiment. The goal was to determine the subjective load of drivers during simulation. As intended by the experiment design, there were two hazardous situations (POI G and POI O). The goal is to compare drivers of two phases ability to deal with those situations. In addition, relative questions were asked during post-experiment interviews. Here is how drivers percept situations.



More probands taking the simulation without application considered more than two situations to be hazardous. From reflections collected beyond the questionnaire, those were the POI 1 and POI 2. Indeed, more Phase 1 participants failed to follow the warning "Intersection" traffic sign in both POIs. In addition, a lot of drivers from the 1st Phase did not notice either skateboard rider, or the animal (in some cases – both). The Table 1 provides count of missed events in Phase 1.

Analysis of eye-tracker data.

Almost half of drivers failed to follow the instructions of "Intersection" traffic sign in each case. The data from eye-tracking device show that most of drivers did look at traffic signs in those intersections (Table 2). Total miss of correct direction in the 1st phase of the experiment is six. In contrary, during Phase 2 almost no one failed the navigation task. Analysis of video data obtained from eye-tracker was performed to observe to what extent probands were referring to in-vehicle system. Table 3 illustrates particular points of interest for demonstration. (All tables count probands' fact of glances)

There have been 6 mistakes in Phase 2 in POI F-H. The situation was designed in such a way that driver fails to give way to the pedestrian(skate-board rider) if he/she does not follow the speed limitation provided by "Zone with limited traffic" sign. There has been no such error indicated in Phase 2.

Table 1: Errors in Phase 1

Error type	POI A	POI C	POI E	POI F-H	POI O	POI P	POI End
Fail to follow traffic sign instruction	6	7		6	3	4	1
Fail to follow correct direction	1		3				2

Table 2: Eye-tracker data (POI A and POI C)

Usage of application	POI A	POI C
Glance at traffic sign	10	9
Glance at direction sign	9	10

Table 3: Eye-tracker data (Phase 2)

Location in simulation scenario	**Probands looked at display**
POI Start	9
POI A	7
POI B	9
POI C	6
POI D	5
POI E	11
POI F-H	12
POI G	2
POI H	12
POI I	8
POI J	2
POI L	8
POI N	2
POI P	9
POI Q	9
POI R	11
POI End	5

By glance reference of a proband either to application, or to traffic sign the indicator (red cross/plus) of eye-tracker position is understood. The pictures below (Figure 7 and Figure 8) illustrate the glance fixation at the object.

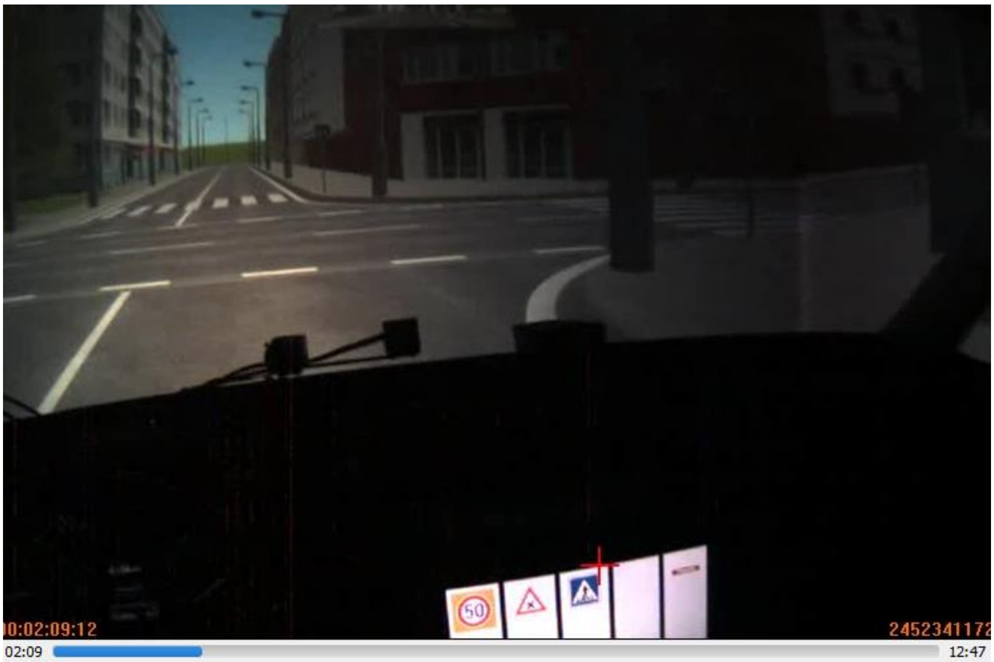


Figure 7: Gaze fixation at in-vehicle display (POI A)

Figure 8: Gaze fixation at traffic sign (POI H)

Besides the glance fixation the effect of saccades has been observed. It has been established from eye-tracker videos that this effect was rather obvious during the Phase 1 of the experiment. The saccades have been detected in the following locations of the scenario (Table 4).

Table 4: Saccades

Location in simulation scenario	Probands looked at display
POI A	1
POI C	1
POI D	5
POI E	4
POI F-H	2
POI G	5
POI H	6
POI L	1
POI Q	1
POI R	2
POI End	6

Of a particular interest are the saccades in POI D, POI E, POI H and POI End. Those are all the intersections with multiple traffic signs, some of them are of limited visibility, or located close to each other. Driver is scanning the scene for traffic sign and for direction to the goal indication.

For example in POI H, total number of signs is five and the direction sign is not available before the roundabout, but only after it. (Figures 9, 10). At the same point in Phase 2, instead of chaotic movements of eyes, the drivers tended to look to application to find out if the searched information is available there. It could be assumed that when having been shown the speed limitation at the beginning of the scenario, the one that was not indicated at any other traffic sign, probands have established some trust in the application device. This trust can be tracked during growing number of reference for information from the application during the experiment.

Figure 9: POI H

Figure 10: POI H (after roundabout)

The application was designed in such a way that it constantly depicted maximum allowed speed in the location, the initial location on the simulation was selected as reference for validation of the application. In nine out of thirteen cases driver referred to application during the first thirty seconds of the simulation.

At average, half of the drivers either looked at application at some moment before, or during (at least once) while crossing the given intersections.

Supposedly, drivers referred to the sign providing the direction to historical goal. As it was mentioned before, during Phase 2 no error of following the correct path was made.

The proband opinion on awareness of traffic signs on their way does not provide much information for comparison (Chart 7). It is necessary to conduct experiment within more vast gender, age and experience groups.

Chart 7: Traffic sign situation awareness. Phase 1

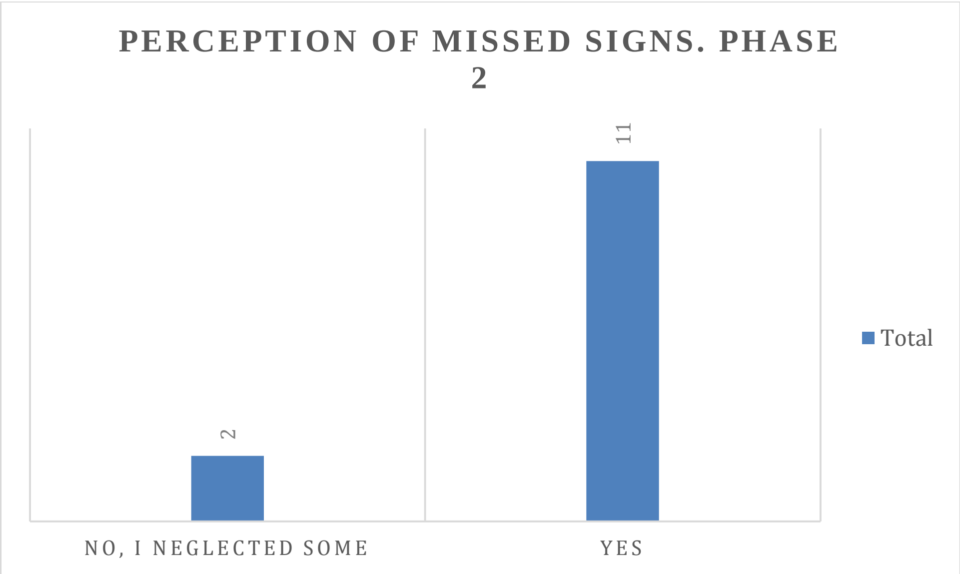


Chart 8: Traffic signs situation awareness. Phase 2

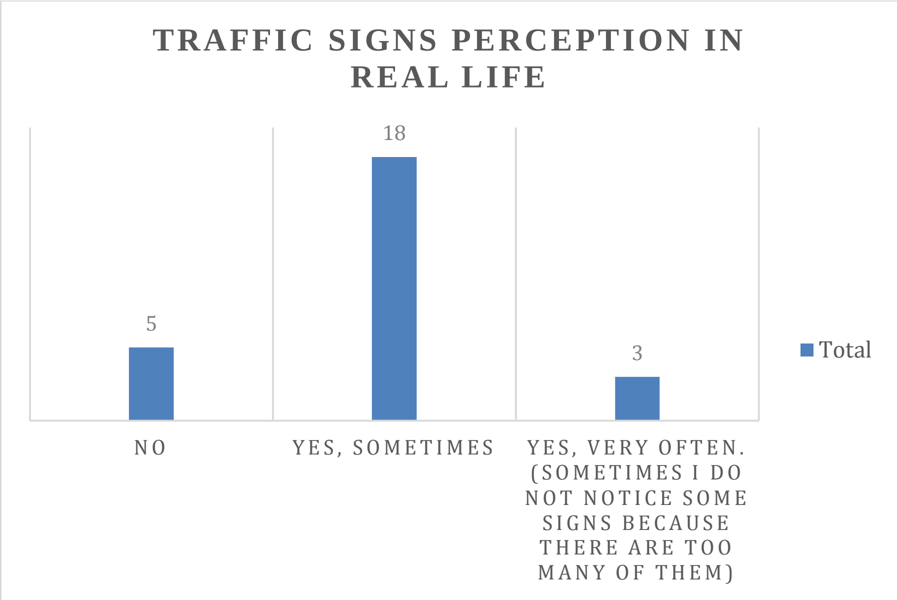


Chart 9: Traffic signs awareness in real life

Most of drivers provided positive feedback about the application. Those who sis not use it in the experiment expressed opinion if the application would be helpful, while those who used the application answered from experience.

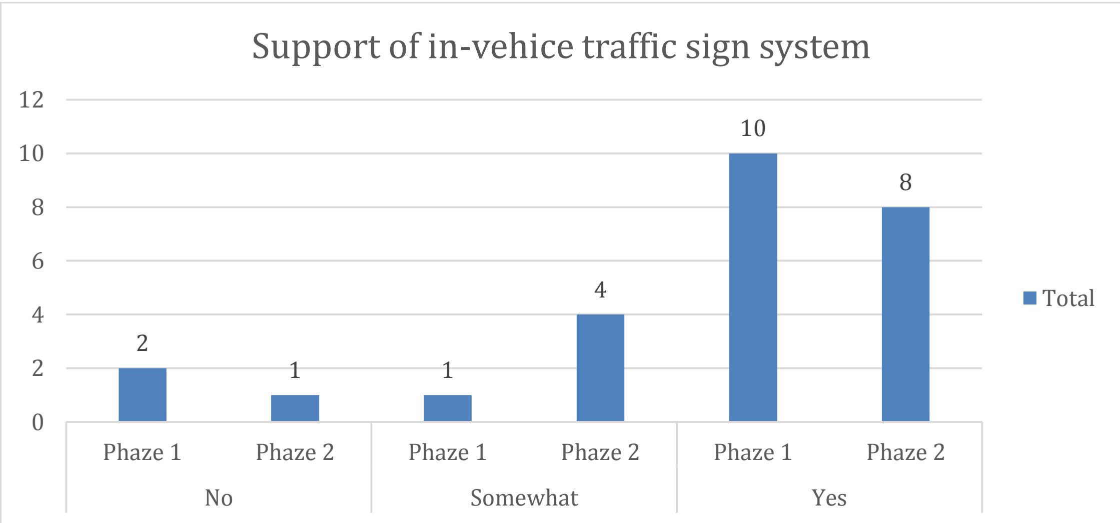


Chart 10

More participants expressed desire to have an application in their personal vehicles. From the feedback provided by probands (optionally) it was estimated that many of participants have had the experience of any kind of in-vehicle information system, traffic sign display system in particular.

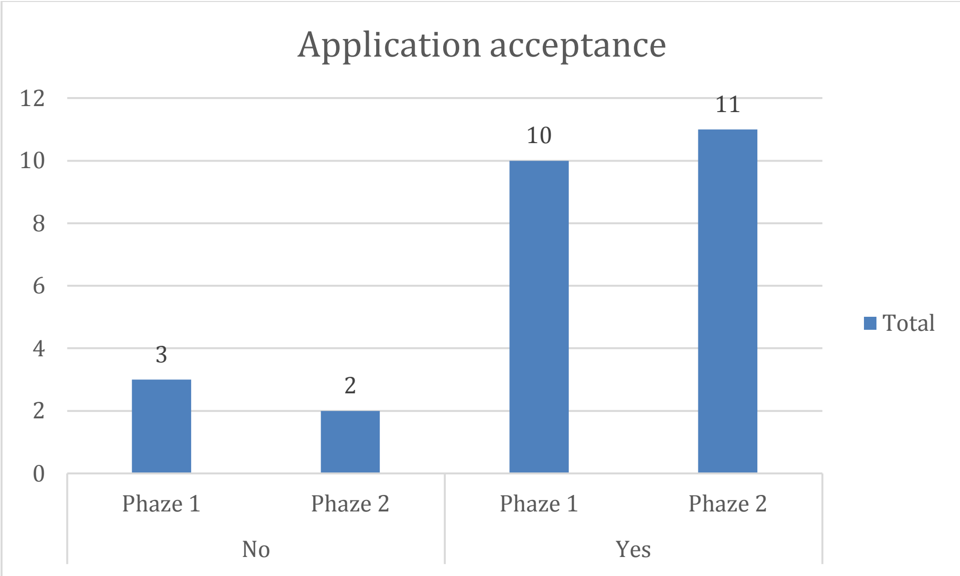


Chart 11

Majority shared knowledge of the applications that depict only speed limitation traffic signs, some provide audio display, some inform driver if one fails to support necessary speed limit.

6 CONCLUSION:

In a given work an in-vehicle traffic sign information system that displays virtual version of physical traffic signs has been introduced. A system with visual notification head-down display was assessed during the experiment on a personal car simulator. By measuring the eye-tracking movements of probands participating in testing and validating number of mistakes the comparative analysis of driver performance with and without such an information system has been provided. During the simulations it has been established, that driver reaction to traffic signs and aimed behavior on the road is more effective when one is assisted by such a system. More probands have followed the right way to destination being helped by the virtual display of the ADAS studied here. Eye-movements have been analyzed and it has been found that driver starts to be aware of the situation in particular points, intersections, faster than with searching for directions and instructions from physical traffic signs. It can be assumed that the system would be especially beneficial in locations with multiple traffic signs and at places where appropriate placement of the signs is not possible, since it is easier to do the search within a smaller range of view provided by display rather than at physical intersection points crowded by other traffic participants. For further assessment of the system it is recommended to perform the research among the wider proband groups. More detailed research and testing of different graphical user interfaces should be done.

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ZÁKON o provozu na pozemních komunikacích a o změnách některých zákonů ze dne 14. září 2000

Annexures

Annexure A – Questionnaires

Annexure B – Traffic signs used in experiment scenario

Annexure C – Roadmap

Annexure D – Points of interest