IC-DEEP: A serious games based application to assess the ergonomics of In-Vehicle Information Systems

Joel Gonçalves, Rosaldo J. F. Rossetti, *Member*, *IEEE*, Cristina Olaverri-Monreal, *Member*, *IEEE*

***Abstract*— With the number of in-vehicle information systems and the complexity of their tasks growing at a very high rate in near future, we need a clear understanding of their related distraction or mental workload and its impact on driver performance. Thus, in this paper we introduce these concepts already in the development phase of a product that will be used in an in-vehicle environment. We present the IC-DEEP (In-Car Ergonomics Evaluation Platform), which is an implementation approach in form of a Serious Game (SG) to autonomously assess, under low-time and low-cost conditions, the factors that can jeopardize the driving performance when manipulating or receiving information from in-vehicle information systems (IVISs). We evaluate the feasibility of the proposed approach and draw conclusions on its effects on behavioral changes and IVIS assessment.**

I. Introduction

Nowadays, there are a large number of in-vehicle information systems (IVISs), either for enhancing driving performance or for entertainment, which the driver can operate simultaneously to the driving task. Some of those systems may integrate a communication module consisting of telephone or the Internet, an entertainment module with radio, video or music, or a navigation system module, for instance. Additional equipment such as driver assistance systems that support the driver in the driving task (e.g. collision avoidance systems, night vision systems, etc.) or laser projections and head-up displays (HUDs) to provide the driver with relevant information might be included as part of IVISs as well.

The variety of heterogeneous IVISs results from new technological advances and is a logical consequence of up-to-date consumers' expectations. The growing use of IVISs on the market increased in recent years by a factor of ten [1]. The relatively low cost of some IVISs raises expectations that these systems will equip future vehicles even more.

Despite the recognized benefits of such systems, the potential distraction of IVISs has been thoroughly investigated in an ample number of studies. For example, it has been shown that the use of cell phones during driving increases the rate of accidents [2]. Likewise the manipulation of navigation systems, as well as adjusting the radio or CD players constitutes a source of distraction [3, 4]. Since traffic safety is a common goal and driver behavior causes 95% of all accidents [5], driver skill enhancement has been the primary attempt at achieving lower accident rates.

In our study, we rely on the concept of Serious Games (SGs), which are often used to develop skills in educational environments. SGs are video games used in serious context like higher education, health care, military, etc. [7]. They are based on teaching practices and designed in an instructional way. Noticeably, driver training through SGs can significantly improve driver behavior especially when he is highly motivated and provided with constructive feedback. Motivation is indeed induced by joy of use and represents, as well as feedback, a major characteristic of SGs.

Good serious games set players motivation to frequent and lengthy playing sessions, promote memorization abilities [6] and embody many different concepts of learning, such as learning by doing and from mistakes [7, 8] across several topics and ages [9]. A serious driving game may therefore enable a long-term behavior influence towards safer driving. Characteristics of SGs thus represent a perfect framework to train drivers frequently towards a driving performance enhancement and also to evaluate the usability of information systems.

In this work we present a general methodology for assessing IVISs using SGs, which is prototyped in IC-DEEP (In-Car Ergonomics Evaluation Platform). The proposed platform allows for a widely autonomous IVIS usability evaluation that facilitates the product testing during the design phase. Our IC-DEEP system uses serious games to provide the driver with qualitative feedback in order to improve his driving performance. Our system assesses the driving performance when interacting with in-vehicle information systems and thus, their ergonomic design. The novelty of our approach relies on the training effect and driving behavioral change provided through the system. Since the tool is web-based, access to a big number of users is also supported. This flexibility allows reaching test participants worldwide, and thus subjects do not need to travel to the place where experiments are carried out.

The remainder of this paper is organized as follows. In the next section we review background and related literature. Section III presents a detailed description of the proposed software solution, whereas Section IV shows the results regarding the feasibility of the system. Finally, Section V concludes the paper, with remarks on our main contributions and suggestions for further developments.

J. Gonçalves and R.J.F. Rossetti are with the Department of Informatics Engineering and the Artificial Intelligence and Computer Science Lab (LIACC), Faculty of Engineering, University of Porto, e-mail: {ei10121, rossetti}@fe.up.pt (R.J.F. Rossetti is the corresponding author)

C. Olaverri Monreal is with the Institute of Ergonomics, Faculty of Mechanical Engineering, Technische Universität München, Germany, e-mail: olaverri@lfe.mw.tum.de

II. Background and Related Literature

A. The Driving Process and its Metrics

Driving is defined as a targeted process consisting of several control operations, such as speed and stability control, navigation, obstacle detection and collision avoidance [10]. Secondary tasks addressed in this paper are in-vehicle assignments, such as manipulating a driver information system or reading data from a display.

A decrease in driving performance and safety may follow if the driver dedicates too much priority to a secondary task and neglects the primary one, which is driving safely [11]. To handle secondary tasks appropriately, the driver has to compensate the emerging additional workload regarding the expected situation [12].

Both driver performance and driver behavior are directly related to driving safely [13]. Driver performance very much relies on the driver's skills, knowledge, as well as perceptual and cognitive abilities, and represents what he can do [5]. Nevertheless, driver behavior is what the driver actually does and is characterized by attitude and personality, experience and competence, situation awareness and alertness [14]. However, measuring such inherent characteristics is, sometimes, a hard and time consuming task.

Distraction is defined as cognitive and visual workload [15]. Workload represents the demanded resources for processing information during a task performance per time unit [16]. Visual workload is defined as the fatigue caused by the visual attention demanded during execution of a secondary task [15]. Cognitive load represents the stress on the working memory caused by high task difficulty, time pressure or arousal [17]. A proper understanding of usability in general and particularly in the IVIS context is important to investigate how the interaction between the user and IVISs can be measured. Visual appeal and simplicity are crucial factors for the user to understand how to manipulate and interact with a system or product [18]. A key factor to determine the user friendliness is the error rate and its prevention and recovery. The error rate can be reduced using standards and ensuring consistency within software applications and also between versions. User exploration and functionality control, as well as explicit feedback might also be relevant [19].

Interaction with IVISs often takes place while driving and therefore it affects vehicle control. Driver performance is measured by comparing individual performance with standard values. A standard value represents a range viewed as normal from average values gathered from an appropriate number of participants, serving then as reference. There are several metrics that are commonly accepted and used such as the Lateral Control and Speed Control.

According to the definitions in [13], Lateral Control aims to understand how the driver manages the vehicle position within the lane boundaries. Depending on the task, Lateral Control can be measured through Mean Lateral Position or the average position of the front-right wheel relatively to the right side of the lane, and Standard Deviation Lateral Position (SDLP) or variation of the lateral.

Speed Control is commonly divided in Mean Speed, Maximum Speed, and Speed Variation. Mean Speed represents the average velocity and Maximum Speed the highest speed driven during the whole experiment. The Speed Variation represents the variance of velocity over the distance travelled.

B. Platforms to test IVIS usability

Simulators are normally used for evaluating visual and cognitive workload in a driving context. They enable the assessment of vehicle control and event detection when the driver is exposed to additional activities that demand his attention. For example, authors in [20] investigated the values related to the combination of vehicle control and reaction times and their viability to detect safety issues using a driving simulator. Additionally, errors that resulted from user interactions with IVIS applications were studied in [21] after authors had pre-classified the participants in the trials.

A game constantly demands that the player acts and reacts appropriately to the feedback provided by the game. In the context of driver training, the game has to support particularly the development of "visual search skills, techniques for paying attention to driving, speed and space management, driving emergencies, risk recognition, and avoidance and basic vehicle control skills" [5].

It has been shown in several works that training and observer feedback can influence the driving behavior [22]. For example, the authors in [23] investigated in a recent study the relation between motivation, locus of control and driving behavior by training drivers in a simulator. After training, participants increased internal and decreased external locus of control, thus resulting in a safer driving behavior.

The ability of influencing the player is one of the major strengths of the SG concept. This has been already confirmed in the driving context, e.g. to make drivers sensitive to the effects of alcohol [24, 25]. Also, the educational component of driving serious games has been exploited in several projects [26, 27].

In the context of learning, serious games internalize several advantages compared to driving simulators. Two major ones are the usage of low-cost commercial hardware (usually cheaper than simulators) and its continuous availability. A commodity personal computer is sufficient for executing the game.

Low-cost simulators were identified as cost-effective and practical for a first assessment of information systems, especially in an early stage of the design process. Low-cost approaches are already validated by comparing its results with values from field tests or more sophisticated simulators [20, 21].

A lot of research has been dedicated to measuring the factors that might distract the driver from the road. In our approach, we combine the theory behind driving behavior analysis with the serious games concept, and create a widely autonomous IVIS usability evaluation tool that enables obtaining data from multiple players worldwide to assess in-vehicle applications.

III. Methodology

A. Implementation process

The tool implementation process is depicted in Fig. 1. It starts with the selection of an IVIS. This particular device is then defined in the input phase for evaluation. Our approach is divided in the following phases:

- System Setup – phase in which the usability context and test specification for a specific prototype are defined;
- Behavior Elicitation – phase that deals with the collection of data through the user, who is actively playing the game;
- Data Processing – phase where the IVIS is evaluated over the data previously gathered. This last step results in a report including data analysis and the overall classification of the IVIS.

In the following part we describe the specific aspects of the three phases.

1) System Setup

During the setup process we first define the usability factors relevant to evaluate the selected IVIS, as well as the measurement criteria for each factor.

The usability context is specified according to the specific IVIS in question, the environment conditions and the particular user conditions (e.g. previous experience of the user in the game with the studied IVIS). The test specification has clear objectives, is task-oriented and contains an evaluation function. Depending on the assessment, the system architecture entity called *Evaluator* (see Section III, B) may specify boundaries to constrain the test. The boundary constraints shall be used to validate and select relevant data.

The test-bed platform deploys tests to the players. During the deployment, the platform matches the defined test constraints with the registered players.

2) Behavior Elicitation

During the Behavior Elicitation step, the serious game player provides the system with data that will be analyzed later. We aim to obtain driving performance data, interaction data with the prototype and a subjective evaluation from the player.

The three types of data are saved in a single file, which is the Test Data. These data are then uploaded to the server after the test is completed, concluding the elicitation phase.

Data from pilot tests allows reconsidering the original settings of the system, then validating the rules and practicability of the game. For instance, users may report any kind of problems such as IVIS interaction or unclear objective understanding, which can be solved through modifications in the IVIS prototype implementation.

3) Data Processing

In the course of this step the data gathered in the previous phase are evaluated. Information related to the tests performed (e.g. vehicle position over time in the map) is filtered using previously defined boundaries to sort out comparable groups, thus obtaining relevant driving performance and interaction metric values. Moreover, the platform clusters the information creating driver profiles. An individual driver behavior record is guaranteed through this clustering that can be further used to a) provide the user with feedback about his performance, b) change the game evaluation formula to penalize identified infractions, and c) other contexts such as traffic simulators validation.

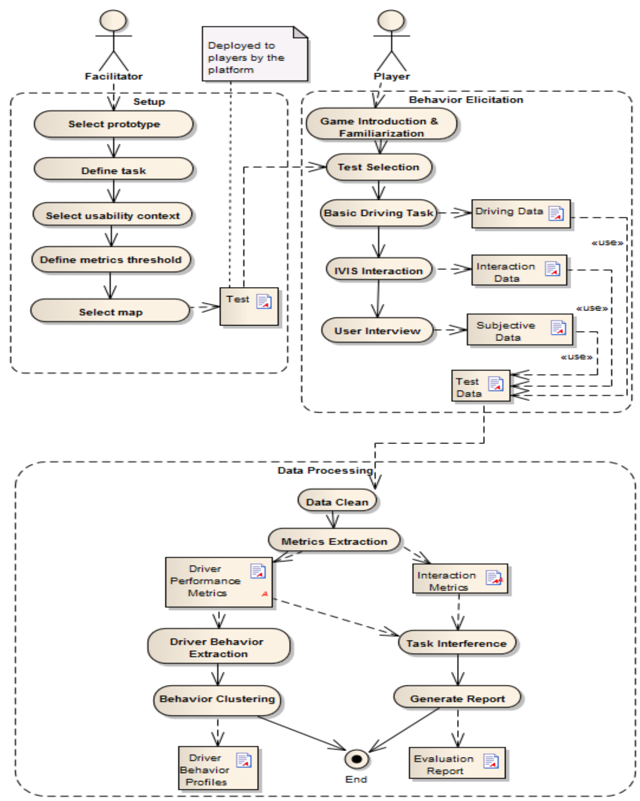

Figure 1. Implementation process for an autonomous IVIS usability evaluation.

The validation step is achieved by pilot experiments to detect data abnormalities or unexpected results, for example, by comparing the obtained data with data from field tests.

B. System Architecture

In this section we capture the functional requirements of the software and show the workflow between the serious game design and its development. Fig. 2 shows a system architecture diagram. There are three distributed entities in this architecture, namely *Platform*, *Evaluator*, and *Player*.

The following layers constitute the stack structure of the platform, namely *Test*, *Metrics Extraction*, *Usability* and *Driver Behavior*.

1) *Test Layer*

At the Test Layer, tests are disseminated by the Test Manager Module while the Data Test Handler module handles data from the client game.

2) *Metrics Extraction Layer*

The data collected within the game are processed in the Metrics Extraction Layer. The Driver Performance Extraction Layer obtains driving metrics while the Interaction Performance Extraction component outputs the interaction metrics. While the Test and Metrics Extraction layers are processing, the Data Validation layer evaluates the data. In these layers, data are classified as valid by checking the Evaluator's constraints that were previously defined to perform the test.

3) *Usability Layer*

The Usability layer uses driver and interaction performance to compute, in the Task Interference Extraction, the IVIS interaction interference on driving. The Usability Report Generator layer outputs the usability assessment results.

4) *Driver Behavior Layer*

The Driver Behavior layer focuses on the driving behavior. The driving performance is interpreted by the Driver Behavior Extraction component, and finally the Driver Behavior Clustering classifies similar driver behaviors.

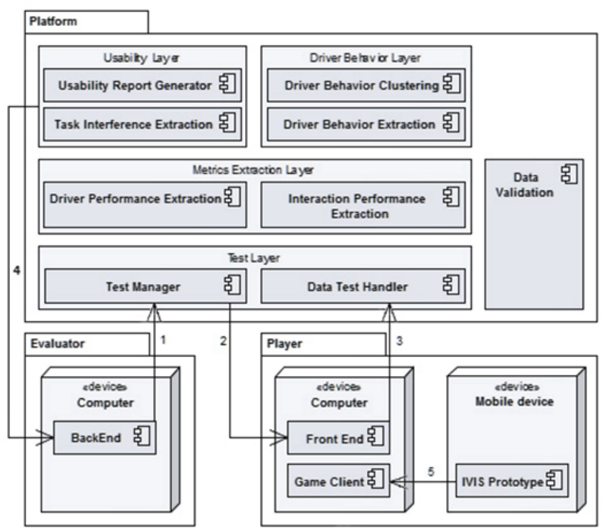

Figure 2. System architecture: (1) Evaluator creates new test, (2) Test Manager disseminates the test, (3) test data are uploaded to the platform, (4) the evaluation conclusion report is sent to the Evaluator, and (5) IVIS interaction data are uploaded to the game client.

Evaluators can remotely interact with the IC-DEEP platform using a backend application. This application is used to create tests, conclude them and see the results in a report format. Players only require a computer to host the game.

On the computer the Front End components search for test updates and upload test data. The Game Client component is the final game as depicted in Fig. 4. The image shows the secondary task to be performed during the experiment, on a display with the information associated with the penalties imputed to the player.

C. *Experimental set up*

To evaluate the feasibility of the proposed IC-DEEP system, we deployed a preliminary test to the players' computers. We defined a rural scenario, with a speed limit of 50 Km/h, and a sample of 5 players. A script describing the driving test was then delivered to the players. During the test execution the driver had to complete three laps through the circuit (Fig. 3), the first without performing secondary tasks. During the first lap no feedback was provided to the player by the game.

The feedback system was first activated in the second lap, warning the player about infractions such as exceeding the speed limit or changing the lane. Warnings were delivered through a Head Up Display showing an icon and through an acoustic alarm.

The system incorporated a microphone to obtain the user input for the reading tasks. The interaction steps, (i.e. keys pressed by the user) during the manually interactive task were also logged by the system.

After finishing the driving test, the participant's subjective impression was elicited by prompting him with a post-task questionnaire. All collected data (i.e. driving, interaction and subjective impression) were then uploaded to the platform for analysis. After the test completion players were rewarded with a score depending on the driving performance. The score was initially set and depending on the number of infractions the number of points was reduced. The same traffic rule infraction committed several times was only recorded after a period of 3 seconds.

The score gives the driver feedback about his performance and motivates him by means of high-score list or incentives. Through feedback we intend to influence driving behavior, providing the driver with training to divide his attention in an appropriately balanced manner that allows him to cope with additional workload.

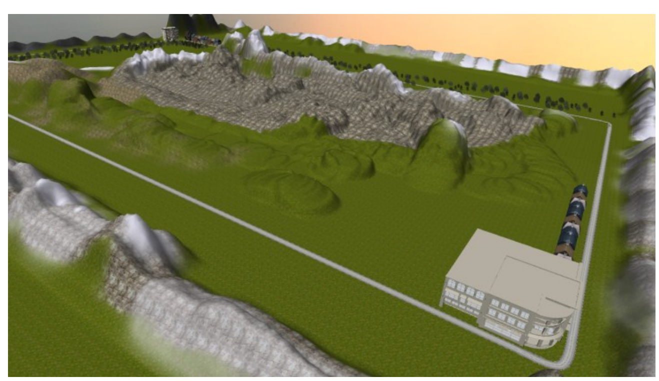

Figure 3. Circuit used to perform the tests within the IC-DEEP platform.

The Data Processing step handles the incoming test data and delivers a report for the Evaluator. The report presents detailed information about the driving performance and subjective satisfaction metrics, during the interaction with the particular IVIS.

Figure 4. IC-DEEP evaluation platform to autonomously assess in-vehicle information systems.

D. Metrics

As previously mentioned, there are several metrics that are commonly accepted and used to measure the driver performance. To evaluate our system we compared the individual performance of the driver without performing secondary tasks and while performing them. We initially focused on the Lateral Control and Speed Control metrics, as well as behavior change. To indicate the Lateral Control performance we used the SDLP, and for the Speed Control the mean velocity. We logged the vehicle position (center of the vehicle) and the velocity vector at each frame. Thus, we could obtain the vehicle mean lateral position, in relation to the lane right border, and the respective SDLP through the root mean square deviation (RMSE).

Behavior change was measured on the basis of the Mean Velocity Correction Time (MVCT), which denoted the time spent to decrease a too high speed to the speed limit allowed.

Measured values were obtained from track segments, where the tasks were performed. The first segment provided the baseline values with no secondary tasks involved, whereas the second provided data related to driving while performing a secondary task.

IV. Preliminary Results

The data resulting from the tests performed showed that the feedback provided by the IC-DEEP platform affected the driver performance, as depicted in Fig. 5. The MVCT decreased when feedback was provided, meaning drivers corrected faster their velocity misbehaviors. MVCT values in the baseline situation, with no feedback, were relatively high with ranging from 2.3s (2 min) to 6.3s (5 min). This pattern results from participants' lack of velocity control. With feedback, participants in the tests improved their MVCT during the game, now going from 1.2s in the first minute to 0.6s after 5 minutes.

The measurement of the standard deviation lateral position (Fig. 6) showed that the deviation was higher during the secondary tasks 1 and 3 (by 28% and 61% respectively, regarding the baseline values), while during task 2 there was a tendency to decrease controlling the lateral position deviation, being the variance improved by 14% regarding the baseline values. Task 2 improvement must be carefully interpreted because low SDLP does not necessarily means better driving; it can also mean the driver is distracted or under high workload. Fig. 7 shows that the mean speed value decreased when the drivers were exposed to a secondary task. Also, it was found that the difficulty of the task affected the speed.

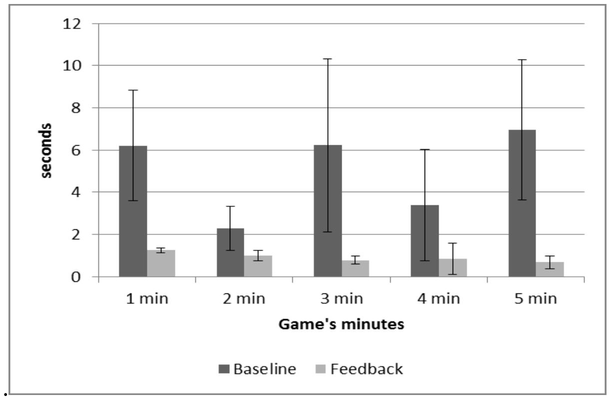

Figure 5. Mean Velocity Correction Time depending on the playing time.

Since Task 3 required a manual device control, the participants decreased the mean speed almost 50% to adjust to the additional workload. Task 2 required reading a medium size text and here the speed was reduced in 42%. Finally, reading a single string from the screen (Task 1) made participants decrease their speed 16%.

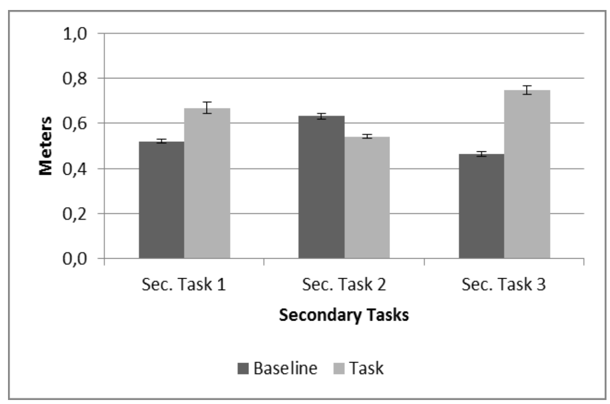

Figure 6. Standard Deviation Lateral Position depending on the secondary task performed.

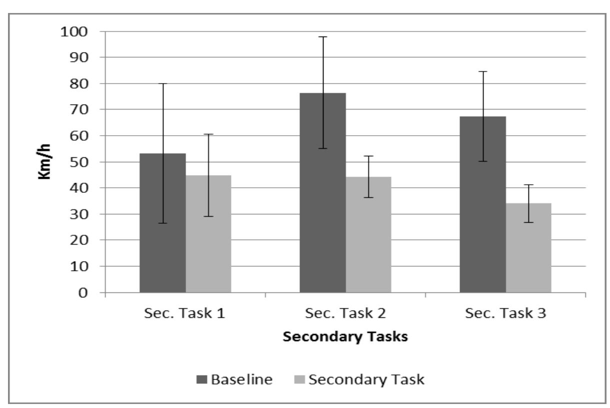

Figure 7. Mean Velocity depending on the secondary task performed.

All participants agreed that the game design was helpful to correct their behavior. Additionally, 80% of the participants classified the information presented by the user interface as clear and intuitive, and they did not find the system distracting or unsafe.

V. Conclusion & Future work

In this paper we presented the In-Car Devices Ergonomics Evaluation Platform, coined IC-DEEP, to autonomously assess, under low-time and low-cost conditions, the factors that can jeopardize the driving performance when manipulating or receiving information from an in-vehicle information system. We showed that the problem was tackled satisfactorily through the technologies chosen, which are suitable to cope with the intended abstraction and flexibility features.

We argue that driver training can significantly improve drivers' behavior. Similarly to the effect conventional video games have on players, motivating them to frequently play and embody many different concepts of learning, a serious game enables a long-term behavior influence regarding driving safety. Our results showed a positive behavior change evolution over time when the game gives feedback to the player. We interpret this evolution as result of an increasing awareness of the infractions related to the allowed speed, and motivation to improve the score of the game. In the information system assessment context, characteristics of driving simulators are close to the intended serious game. This fact arouses expectation of similar applicability and measurements. However, our IC-DEEP platform promotes a more conscious handling of in-vehicle applications in case of decision-making, balanced attention division, and interaction process regarding surrounding driving situations and risks. Thus, serious games represent a framework not only to train drivers towards driving performance enhancement but also to evaluate usability of information systems.

The data gathered from serious driving games have to be compared and harmonized with data of high-fidelity simulators and real-world measurements to prove reliability and validation. This is the very next step we plan to pursue in this research.

References

[1] M. Baumann, A. Keinath, J. F. Krems, and K. Bengler, "Evaluation of in-vehicle HMI using occlusion techniques: experimental results and practical implications.," *Applied ergonomics*, vol. 35, no. 3, pp. 197-205, May 2004.

[2] K. H. Beck, F. Yan, and M. Q. Wang, "Cell phone users, reported crash risk, unsafe driving behaviors and dispositions: a survey of motorists in Maryland.," *Journal of safety research*, vol. 38, no. 6, pp. 683-8, Jan. 2007.

[3] P. Green, "The 15-second rule for driver information systems," *ITS America Ninth Annual Meeting Conference*, no. Cd, pp. 1-9, 1999.

[4] J. C. Stutts, D. W. Reinfurt, and E. a Rodgman, "The role of driver distraction in crashes: an analysis of 1995-1999 Crashworthiness Data System Data.," *Annual proceedings / Association for the Advancement of Automotive Medicine. Association for the Advancement of Automotive Medicine*, vol. 45, no. May, pp. 287-301, Jan. 2001.

[5] Y. F. Liu, Y. M. Wang, W. S. Li, W. Q. Xu, and J. S. Gui, "Improve Driver Performance by Experience of Driver Cognitive Behavior Model's Practice," *Components*, pp. 475-480, 2009.

[6] C. Lampert and C. Schwinge, "Der gespielte Ernst des Lebens : Bestandsaufnahme und Potenziale von Serious Games (for Health)," *Heart*, no. 15, 2009.

[7] A. Stapleton, "Serious games: Serious opportunities," *Australian Game Developers' Conference, Academic Summit, Melbourne, VIC*, 2004.

[8] M. E. Gredler, *Designing and evaluating games and simulations: A process approach. Houston, TX: Gulf Publication Company*. Houston: Gulf Publication Company, 1994.

[9] R. V. Eck, "Digital Game-Based Learning: It's Not Just the Digital Natives Who Are Restless," *Technology*, pp. 0-7, 2006.

[10] D. M. Jim Hedlund, Herb Simpson, "International Conference on Distracted Driving: Summary of proceedings and recomendations," *Injury*. Canadian Automobile Association/Traffic Injury Research Foundation, p. 32, 2006.

[11] B. Metz, N. Schömig, and H.-P. Krüger, "Attention during visual secondary tasks in driving: Adaptation to the demands of the driving task," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 14, no. 5, pp. 369-380, Apr. 2011.

[12] N. Schömig, B. Metz, and H.-P. Krüger, "Anticipatory and control processes in the interaction with secondary tasks while driving," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 14, pp. 525-538, Jul. 2011.

[13] J. Engström et al., "INFORMATION SOCIETY TECHNOLOGIES (IST) Driving performance assessment," *Contract*, no. 2004, pp. 1-149, 2005.

[14] P. C. Cacciabue, *Modelling Driver Behaviour in Automotive Environments: Critical Issues in Driver Interactions with Intelligent Transport Systems*. Springer, 2007, p. 428.

[15] F. Tango, L. Minin, F. Tesauri, and R. Montanari, "Field tests and machine learning approaches for refining algorithms and correlations of driver's model parameters.," *Applied ergonomics*, vol. 41, no. 2, pp. 211-24, Mar. 2010.

[16] C. D. Wickens and J. G. Hollands, *Engineering Psychology and Human Performance*, 3rd ed. Prentice Hall, 1999, p. 573.

[17] C. J. D. Patten, A. Kircher, J. Ostlund, L. Nilsson, and O. Svenson, "Driver experience and cognitive workload in different traffic environments.," *Accident; analysis and prevention*, vol. 38, no. 5, pp. 887-94, Sep. 2006.

[18] N. Bevan, "International standards for HCI and usability," *International Journal of Human-Computer Studies*, vol. 55, no. 4, pp. 533-552, Oct. 2001.

[19] Patrick W. Jordan, *An Introduction To Usability*. CRC Press; 1 edition, 1998, p. 136.

[20] M. Reed and P. Green, "Validation of a low-cost driving simulator using a telephone dialing task. Final report," *Orlando, FL: Link Foundation for Simulation and Training*, no. June, 1995.

[21] S. L. Jamson and a. H. Jamson, "The validity of a low-cost simulator for the assessment of the effects of in-vehicle information systems," *Safety Science*, vol. 48, no. 10, pp. 1477-1483, Dec. 2010.

[22] L. E. Decina, K. W. Gish, L. Staplin, and A. H. Kirchner, "Feasibility of new simulation technology to train novice drivers.," 1996.

[23] J. L. Huang and J. K. Ford, "Driving locus of control and driving behaviors: Inducing change through driver training," *Transportation Research Part F: Traffic Psychology and Behaviour*, Oct. 2011.

[24] Dutch public ministry, "Verkeerstalent Online." [Online]. Available: http://www.verkeerstalent-online.nl/. [Accessed: 10-Feb-2012].

[25] J. R. Parker et al., "The Booze Cruise: Impaired Driving in Virtual Spaces," *IEEE Computer Graphics and Applications*, vol. 29, no. 2, pp. 6-10, Mar. 2009.

[26] BESIER, "3D-Fahrschule." [Online]. Available: http://www.3dfahrschule.de/. [Accessed: 10-Feb-2012].

[27] H. G. Research, "Road Ready Streetwise." [Online]. Available: http://www.healthgamesresearch.org/games/road-ready-streetwise. [Accessed: 10-Feb-2012].