EX-ANTE EVALUATION OF TRAFFIC SIGNS USING A TRAFFIC SIGN SIMULATOR

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ABSTRACT

Traffic signs and pavement markings are a crucial aspect of road design since they are essential sources of information for road users to calibrate their driving behavior, evaluate route possibilities and cope with unexpected events. A pro-active evaluation of (the quality of) these road design elements will help to improve the safety performance of the roadway.

The Traffic Sign Simulator is an innovative research tool to study road users' comprehension of traffic signs, digital information panels and pavement markings, to investigate their influence on routing decisions (including lane choice) and to collect participants' suggestions for improvements.

Using a driving simulator mock-up, participants navigate through a full HD video from the route(s) in which the planned traffic signs have been digitally implemented using specialized software for camera-tracking and 3D video-integration. Participants' route and lane choice and their visual behavior (using eye-tracking) are monitored while driving through the different scenarios. Laptop pre- and post-tests are applied to collect more in-depth information concerning the participants' processing, comprehension and general evaluation of the traffic signs and suggestions for improvement.

The paper also presents a case study that examines the temporary traffic signs, digital information panels and pavement markings during the reconstruction works on the Vilvoorde fly-over (near Brussels), one of the busiest interchanges in the Belgian highway network. The traffic sign plan in the work zone of Vilvoorde has been evaluated ex-ante because highway work zones are often a major cause of serious accidents due to the temporarily changed road situation.

Keywords: Ex-ante evaluation, traffic signs and pavement markings, Traffic Sign Simulator, work zones, detour

INTRODUCTION

Road crashes and casualties lead to high physical, psychological, material and economic costs. Measures to improve road safety have mainly focused on reducing the number of serious accidents at existing locations. However, a shift towards a more pro-active approach is needed in order to further improve road safety, and meet the European objective to half the number of road casualties by 2020 (European Commission, 2011). This pro-active approach is the core element of the "Sustainable Safety" principle which aims to prevent (serious) crashes and injuries by applying intrinsic safe road design which takes human's limited capabilities into account (Wegman, Aarts, & Bax, 2008). This so-called ergonomic design and the pro-active evaluation of infrastructural projects forms the basis for Europe's road infrastructure safety management (European Parliament & Council of the European Union, 2008; RiPCORD-iSEREST, n.d.).

Traffic signs and pavement markings are a crucial aspect of road design since they are one of the main information sources for the road user to calibrate driving behavior, to evaluate route possibilities and to cope with unexpected events (Castro & Horberry, 2004; Federal Highway Administration, 2012; Martens, 2000; Zhang & Ge, 2012). A pro-active evaluation of (the quality of) these road design elements will help to improve the safety performance of the implemented road design. The Traffic Sign Simulator presented in this paper is a tool that has been developed for this specific purpose.

BACKGROUND

Before describing the effectiveness of traffic signs and providing an overview of already existing research methods to investigate traffic sign perception, we want to clearly define what we understand in this paper by the term 'traffic sign'.

According to the Manual of Uniform Traffic Control Devices (MUTCD) (Federal Highway Administration, 2012), "traffic control devices notify road users of regulations and provide warning and guidance needed for the uniform and efficient operation of all elements of the traffic stream in a manner intended to minimize the occurrences of crashes". The manual describes guidelines for signs, markings and traffic signals, which are thus included in the concept 'traffic control device'. Catro and Horberry (2004, p. 2) on the other hand use a wider definition of 'traffic signs' that was proposed by the International Commission of Illumination (1988) and U.K. Department of Transport (1991) and define 'traffic signs' as "an integral part of the road environment that can include not only upright signs giving warnings and instructions to traffic, speed limits, directions and other information, but also road markings, traffic light signals, motorway matrix signals, zebra and pedestrian crossings, cones and cylinders used at road works and variable message signs. In this paper, the term 'traffic sign' is used in the wider sense to describe all traffic control devices listed above.

The effectiveness of traffic sign perception according to Castro and Horberry (2004) comprises four stages: (a) sign detection (b) sign readability, (c) sign comprehension and (d) sign-induced action. The road user should be able to successfully pass through these four stages if the traffic sign is correctly designed and positioned. The design standards for signs contain a variety of requirements and are indicated on the picture below (FIGURE 1). This list of requirements is not exhaustive. For instance Gartner et al. (1992) add the signal value (i.e. the value of the sign for a road user), the coding system and the information processing capabilities and education of the road users to the information processing of traffic signs.

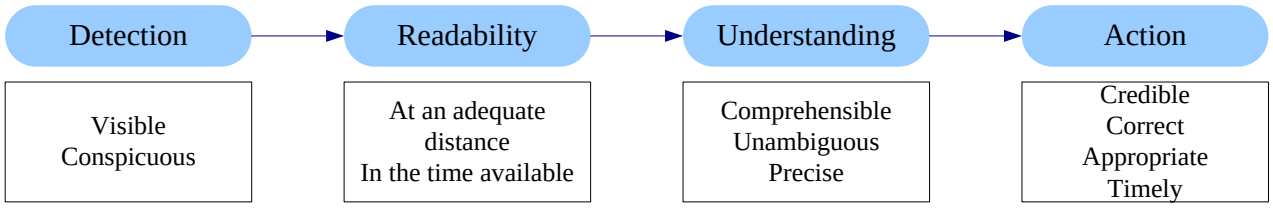


FIGURE 1 Four stages of traffic sign perception with their requirements (Castro & Horberry, 2004).

Since the development of uniform standards for traffic signs around the thirties of the 20th century, various studies have been carried out to investigate ways to design traffic signs more effectively and better tuned to road users' information processing capabilities. A number of existing research tools or techniques can be distinguished. We briefly discuss them below.

Paper-and-Pencil Method

The most basic technique is the paper-and-pencil method. This is a tool that is rather used for applied research than for fundamental scientific research. For the evaluation of planned traffic signs in practice, this method implies that a hard copy of for instance a temporary traffic control plan is shown to a number of people who were not involved in the development of the plan. They are asked to note their considerations and recommendations for improvement. These people can be either professionals or laymen. Ideally, both are questioned, since they can provide interesting feedback from a different point of view. The most important disadvantage of the technique is that it requires a lot of imagination to mentally picture the real-life layout of the plan. These mental images will differ between respondents, they may contain errors and some information might be lacking, resulting in biased and/or incomplete input. Sign detection, readability and understanding can only be evaluated indirectly this way, and behavioral responses cannot be assessed.

Laptop Tests

In studies using laptop tests, participants are exposed to pictures and/or videos about road environments containing traffic signs, or to general questions about traffic sign position, understandability, readability, etc. Laptop testing is a flexible and low-cost tool to execute a wide range of traffic sign assessments, going from very practical questions about particular situations to more fundamental research questions relating to visibility, conspicuity, understandability and (stated) behavior. For example, Borrowsky et al. (2008a; 2008b) use a series of pictures of road scenes in laptop tests to link traffic sign location to driver expectancy (2008a) and driver experience (2008b). Crundall and Underwood (2001) use comparable techniques to analyze the priming function of road signs. An important limitation is the limited dynamics and realism of the situations, which can lead to some biases introduced by the information provided by the researcher to the participant and to incomplete input.

Eye Movement Studies

Eye movement studies make use of an eye-tracker to analyze drivers' visual (search) behavior in order to answer questions like what signs drivers look at, for how long, and in which order. The main advantage of eye tracking is that it is a direct and objective measure for sign detection and reception since eye movements are relatively involuntarily and free from bias due to instructions (Martens, 2000). A disadvantage is that eye fixations do not guarantee that the object is internally processed (the common "look but feel to see" error), and, vice versa, that even without a fixation an object can still be perceived and/or interpreted. This also appears from the model by Castro and Horberry (2004), where it is indicated that detection is only the first step. Eye movement studies

are mostly used in combination with other research tools, such as driving simulators or instrumented vehicles.

Field Experiments

In field experiments, the researcher can either make use of the existing road environment to do an on-field data collection, or a real life test layout can be implemented.

Field experiments – public road

Field experiments can either use the existing road environment, or implement a test design on the public road to investigate the impact of traffic signs on driver detection, readability, understanding and/or resulting behavior. On-road testing is of course highly realistic, but has some important drawbacks as well. Methodologically, the experimenter has only limited control, and ethically, the safety of study participants and other road users might be compromised, especially when being exposed to complex test situations.

The data can be collected in three ways, i.e., on-site observation, in-vehicle observation with trained observers on board, and so-called naturalistic driving by means of an instrumented vehicle.

On-site observations about the impact of traffic signs collect generic observable characteristics of the vehicles passing a certain location. For instance, Erke et al. (2007) examine the effects of different messages for route guidance on Variable Message Signs (VMS) using route choice, driving speed and braking behavior. Gates et al. (2004) study the impact of various sign conspicuity enhancements using traffic operations data, such as vehicle speeds, edge line encroachments and stopping compliance. Important advantages of on-site observations are the non-intrusive nature of the data collection (road users are generally unaware of being monitored) and the large sample size (i.e. all vehicles passing the study location). The main shortcoming is that only parameters describing the revealed behavior can be collected, while factors inducing the behavior cannot be identified.

In studies that apply in-vehicle observations participants drive a normal car while accompanied by one or more trained observers. The participants' understanding and detection of traffic signs and the resulting behavior can be assessed by a number of observable qualitative or quantitative indicators. An advantage is that more detailed driver behavior data can be collected than in on-site observations. An important drawback is that the presence of the observer(s) can lead to some test biases, for instance showing more socially desirable behavior. Inter- and intracoder reliability issues may also reduce the reliability of the data collection. These techniques generally also provide little insight in factors leading to the performed behavior. Alternatively (or additionally), participants can be asked to verbally report on certain aspects of traffic signs they pass. Verbal reports have the advantage that they may provide some information about the internal processes of participants that play a role, although participants are likely to omit some information they implicitly use, especially under high mental load (Martens, 2000). In an alternative but related approach by Garvey et al. (2004), participants are positioned in the passenger's seat and are asked to read a traffic sign aloud as soon as the sign is readable.

Finally, we have the instrumented vehicle, i.e., a car equipped with technology that automatically records a number of driving parameters and captures driver behavior on video. This allows a less intrusive data collection because the researcher is not physically present in the vehicle, which can reduce some test biases (Dingus et al., 2006). The collected data from an instrumented vehicle are also much richer and the videos can be reviewed multiple times or by multiple researchers to ensure reliability and to increase the number of parameters that can be collected. To the best of our knowledge, no studies have used instrumented vehicles with the specific purpose to assess traffic signs, but data collected from running projects such as SHRP2 are

expected to be used for this purpose in the future. A major challenge will be to identify and analyze the data of interest from the huge data warehouses. Limited control over the experiment can be an important drawback.

Field experiments – test track

It is also possible to implement a real-life test setting on a closed test track (e.g. Carlson & Hawkins, 2003). An advantage compared to experiments on the public road is that safety can be ensured by the controlled environment. An important disadvantage of the technique is however that the cost of implementing a realistic test track can be very high. There will also be a lack of interaction with other vehicles, and the driving experience will be more artificial than on the public road.

Driving Simulator Studies

In driving simulator studies, participants sit in a mock-up and navigate through a virtual road environment projected on a screen. Low-level simulators have a fixed mock-up and use one or more computer screens for scenario visualization. High-level simulators on the other hand are more advanced and use a mock-up mounted on a moving base platform and virtual projection on large screens (e.g. 180° to 360°) (Fisher, Rizzo, Caird, & Lee, 2011). For evaluating traffic signs, two types of driving simulator studies can be distinguished. Either a virtually simulated road environment is created, or real-life video footage is being used.

Driving simulator – virtual simulation

In these studies, a fully simulated *virtual* road environment is created, containing particular scenes of interest with particular traffic signs. The driving simulator logs detailed information about a large number of driving behavior parameters, including speed, acceleration, gear use, lane position, etc., and can be combined with an eye tracker to synchronically log visual behavior. This set up was used by for instance Dutta et al. (2004), who explored possibilities to maximize road users' understanding of variable message signs.

Besides the fact that very detailed data can be logged, other important advantages are the experimenter being fully in control over the road infrastructure and environment, thereby included the interaction with other (virtual) road users, and the guaranteed safety for road users (Godley, Triggs, & Fildes, 2002). Some drawbacks are the risk of participant drop-out due to simulator sickness, and the sometimes limited fidelity of the simulator. A major issue is the extent to which behavior in the simulated environment corresponds to participants actual driving behavior in a real-life environment (Fisher et al., 2011). It must be said however, that there is enough research showing that driving simulators generally reach high relative validity (i.e. mutually comparing different scenarios in the driving simulator) (Godley et al., 2002; Yan, Abdel-Aty, Radwan, Wang, & Chilakapati, 2008).

Driving simulator – video footage based

Video footage based driving simulations try to create a more realistic driving scene than traditional driving simulator studies using a simulated road environment. Charlton (2006) used such a tool to study conspicuity, memorability, comprehension and priming of a number of different road hazard warning signs. Lai (2010, 2012) used a video footage based driving simulator to analyze the effects of different color schemes and message lines of VMS on driver performance, and to analyze drivers' comprehension of traffic information on graphical route information panels (GRIP).

These driving simulator studies are well-suited to study detection, readability and understanding of signage because the real-life road environment is presented in a more realistic setting than for instance in a laptop setting. Yet, this technique generally does not provide many possibilities to directly study behavioral aspects since there are little possibilities to interact with the video. Put differently, participants are not really controlling their driving through the road scene; the driving simulator is mainly used as a more realistic setting to show the video. Another disadvantage is that the researchers have a more limited control over the experiment because they are to some extent limited to the existing road environment, although recent improvements in digital image processing allow to integrate virtual objects in a video-taped road environment. Notwithstanding, until so far, research (Lai, 2010, 2012) using these more advanced techniques has only been focused on minor changes, such as the adding of a particular traffic sign or the replacement of an existing traffic sign by a different one.

TRAFFIC SIGN SIMULATOR – DESIGN AND CASE STUDY

Since all methods have their advantages and drawbacks, it is recommended to combine several research methods when experimentally investigating traffic sign perception (Martens, 2000). The Traffic Sign Simulator described in this paper is an innovative research tool that combines a number of techniques to analyze road users' detection, readability, understanding and behavior in an integrated way. The core of the research tool is that participants really have active control over their driving when being exposed to a real-life full HD video recorded road environment in which a variety of 3D virtual traffic signs (i.e. ranging from signs, pavement markings and variable message signs to signs used in work zones and advertisement panels) have been digitally integrated using specialised software for camera-tracking and 3D video-integration. Participants' accelerations and decelerations (e.g., gas and brake pedal), as well as their route and lane choices (e.g., indicator and steering wheel) and their visual behavior (e.g. eye-tracker) are monitored while driving through the different scenarios. In addition to the simulator driving test, laptop pre- and post-tests are used to collect additional information concerning the participants' understanding and general evaluation of the traffic signs and their suggestions for improvement. As such, this approach ensures that the strengths of the different research techniques are fully utilized and combined.

The case study we will use to illustrate the application of the Traffic Sign Simulator relates to the reconstruction works on the Vilvoorde fly-over, one of the busiest interchanges in the Belgian highway network (140,000 vehicles per day). More in detail, we evaluated the traffic sign plan before it was to be implemented in the work zone of Vilvoorde in order to reduce as much as possible the risk for serious accidents due to the temporarily changed road situation (Khattak, Khattak, & Council, 2002). In situations such as these, the quality and accuracy of information offered to the road users is of crucial importance to ensure road safety, to improve traffic flow and to minimize economic loss. The work zone in Vilvoorde is a challenging case since it involves a complex traffic detour that only applies in a limited time frame (2 PM to 9 PM). 23 Participants drove through two video-taped scenarios, i.e., the detour route (assuming it was 4 PM) and the normal route (assuming it was 10 AM), and completed a laptop pre- and posttest. Based on the outcome of the experiment a number of practical recommendations could be formulated, which are indicated in the final subsection of this chapter.

Scenario Production

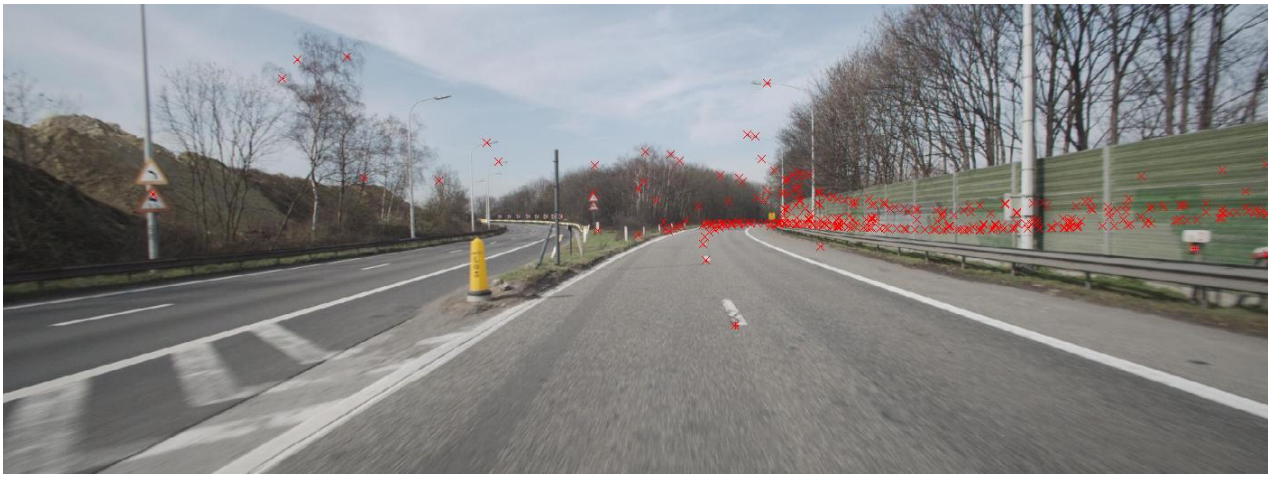
First, the route(s) of interest are filmed using a high-resoluation RED-cam camera with a wide-angle lens that allows to collect video footage in full-HD resolution (4096x2304 pixels in 16:9 aspect ratio). The camera is mounted on the hood of a minivan, so that the footage is filmed from the viewpoint of a normal car driver. The minivan should drive as much as possible at a constant

driving speed. In case the driving speed during recording is lower than the customary driving speed on the route, the number of "frames per distance" can be improved; the camera films at a rate of 25 frames per second, but the distance that is traveled per frame by the camera is reduced by recording at a lower speed, which improves the quality of the final scenario film. For safety reasons, it can be recommended to guide the camera van with police cars, for instance when recording at lower speeds on a highway.

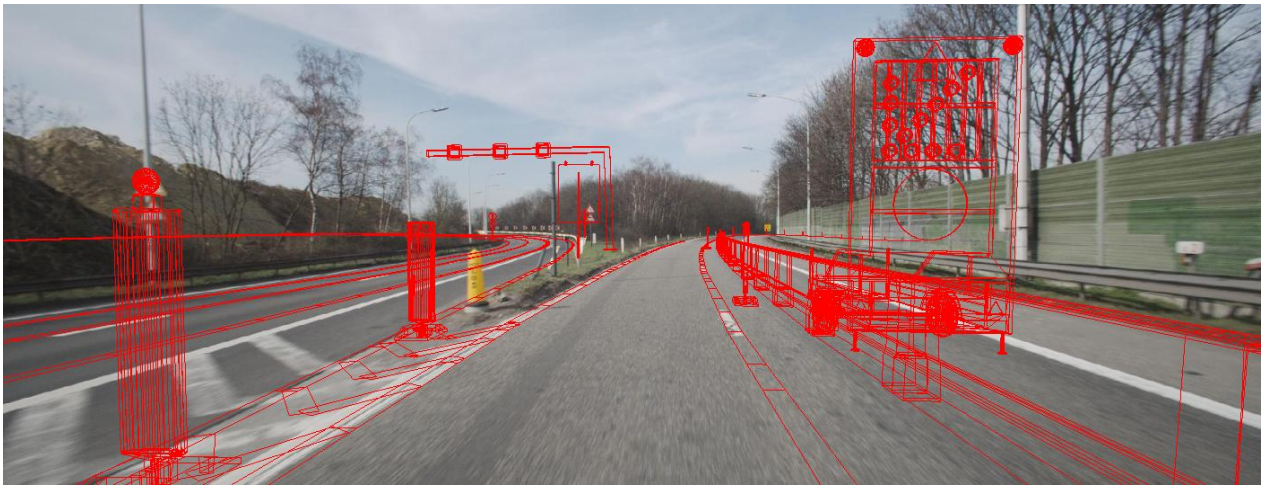
Next, the traffic signs of interest are digitally integrated in the real-life video footage by means of an innovative technique using specialized software for camera-tracking and video-integration. In the Vilvoorde case, it means that all planned traffic signs for the project are digitally inserted into the video. These adjustments go through four stages (see figure 1):

- In the first step, the original HD footage is optimized by adjusting brightness, color contrast and balance.
- In the second step, existing reference points in the image are identified using specialized 3D software. This step is called camera-tracking.
- In the third step, 3D object models of traffic signs are positioned in the virtual 3D-environment.
- The final step includes rendering and masking of the object models. Rendering means that a realistic digital image from the 3D object model is generated to display in the video. Masking means that the simulated objects are hidden behind real-world objects in the video when these objects are in reality more proximate. This process is not straightforward and is much more complicated than the reverse, i.e. covering a real-world object behind a simulated object. Integrating simulated digital objects realistically in a real world video requires both techniques. Using these techniques, 25 photorealistic frames per second are created.

a) Step 1: optimizing image quality



b) Step 2: camera-tracking of 3D reference points



c) Step 3: video-integration of 3D object models

d) Step 4: Rendering and masking: generating 25 photorealistic frames/second.

FIGURE 2 Four-step process to insert signage of interest in video.

Driving mockup and eye-tracker

During the driving simulator experiment, the participant sits in a fixed-based mock-up in front of a large seamless curved screen on which the HD-video (25 photorealistic frames per second) is projected. Participants can speed up and slow down the scenario video by means of the accelerator and the brake pedal. Because both the constant speed of the minivan during the filming of the route and the proportion of the participant's acceleration/deceleration compared to this driving speed is known, an indication of the participant's driving speed can be derived afterwards. Participants can indicate their route choices and lane changes by means of the indicator and steering wheel. Based on this data, the number of lane changes and the route choice are evaluated.

Eye movements are recorded by faceLAB 5.0 (Seeing Machines, Canberra, Australia), a video-based, dash-mounted eye tracking system. FaceLAB system can track eye movements via the relationship between the pupil and the reflection of the infrared light on the cornea. The system runs at a sampling rate of 60Hz and an accuracy of approximately 0.5° of visual angle (~1° at the periphery). With the current configuration, the system can accommodate head rotations of +/-45° and gaze rotations of +/-22° around horizontal-axis, allowing participants to have large freedom of movement. Additionally, the faceLAB system can make (somewhat less precise) estimates outside the viewing angle (e.g., glances to a side mirror), based on head movement and tracking of facial features. An overlay between the scenario video and the logged eye tracking is used afterwards to derive parameters which are related to the detection of the traffic signs, such as the number of glances at a certain traffic sign per participant or the number of participants with or without detection moment for a certain traffic sign.

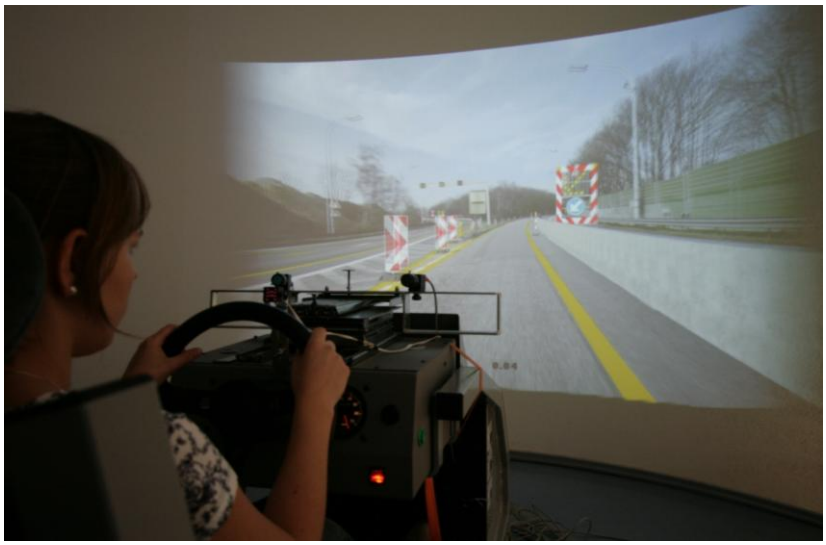


FIGURE 3 Traffic Sign Simulator mock-up with eye-tracking system.

Laptop Pre- and Post-Tests

Laptop pre- and post-tests are applied to further complement the Traffic Sign Simulator. The purpose of these tests is mainly to improve the insight in participants' understanding and processing of particular traffic signs or situations. Participants' understanding can to some extent be derived from their decisions in the simulated drives, but only superficially.

In this case study the pre-test is used to collect general socio-demographic information about the participant, and to test the participants' understanding of the traffic sign that is used to indicate the time-dependent detour. The sign is briefly shown to the participants first. Next they are asked to draw the sign they just saw. The researcher notes the order in which the different

elements of the sign are drawn, and which elements are remembered (in)correctly or missed. Finally, the participant is asked to formulate the meaning of the sign in his/her own words.

In the post-test, the participant evaluates the complexity of the sign. The participant is also asked about his/her real-life familiarity with the study area. In this case study, the researcher also went through both scenario videos again together with the participant to ask for his/her detailed feedback and suggestions for improvement throughout the study area.

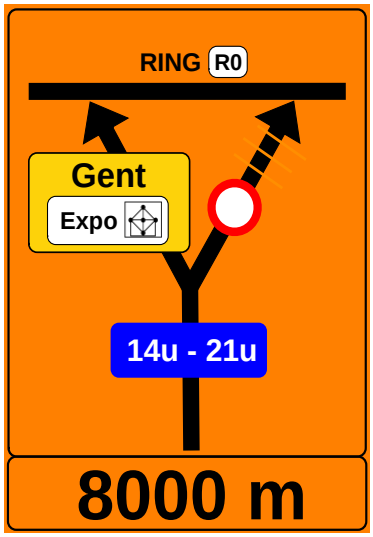
As such, the pre- and post-test allow a wide range of other interesting supplementary analyses.

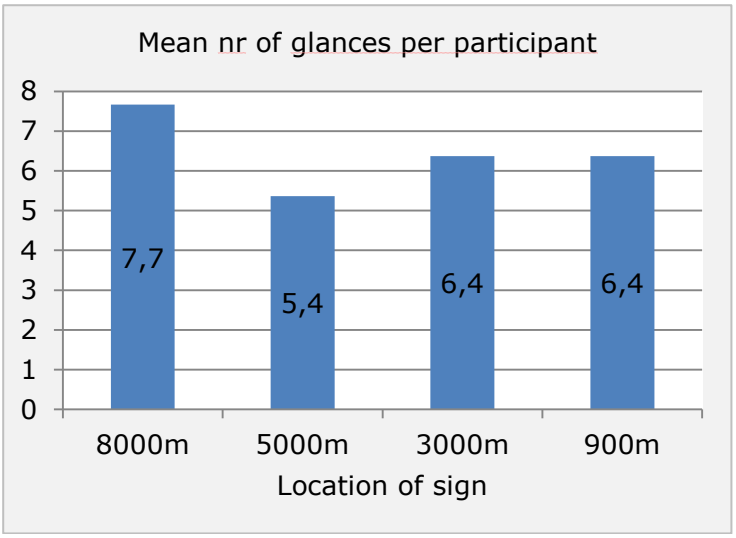
Application and Illustration

Besides the ex-ante evaluation of the traffic sign plan for the road works on the Vilvoorde fly-over, the Traffic Sign Simulator has also been used in other practical applications, such as the testing of parking routes in cities, the evaluation of route guidance systems to industrial zones or detour routes from the motorway network to the secondary road network in case of an incident on the motorway.

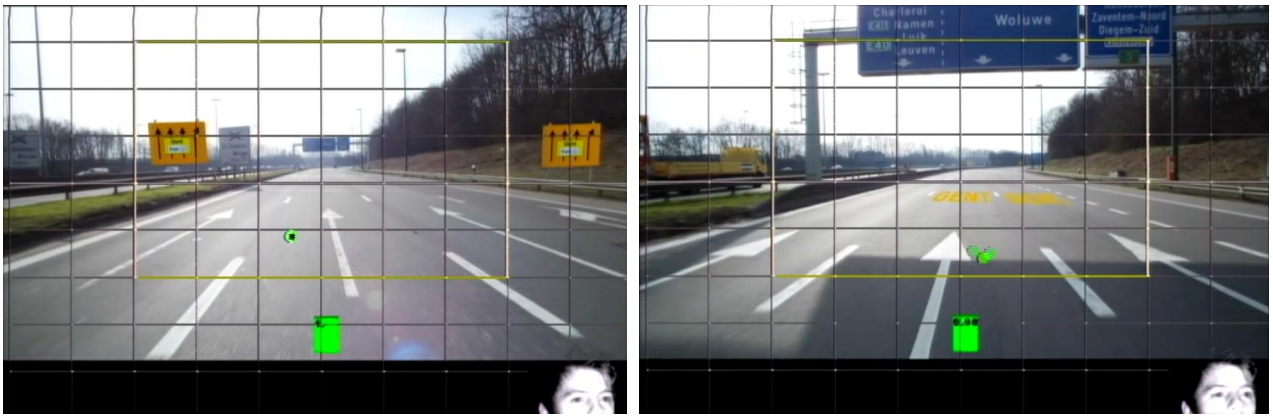
In this paper, we provide a brief overview of the most important practical conclusions and recommendations from the ex-ante evaluation of the traffic sign plan for the road works on the Vilvoorde fly-over to illustrate the results that can be expected from a Traffic Sign Simulator study (Brijs et al., 2011):

- Repeated exposure to the main announcement sign is required (both over distance and by positioning the sign systematically at both road sides). This can be derived from the participants' high number of glances to the repeated panels in the scenarios (on average 5-6 glances per person per sign for the repeated signs, see figure 4.a), as well as from participants' feedback, and the relatively high amount of incorrect route choices (7 out of 21) in the scenario between 9PM and 2PM, taking the detour route while the regular connection is opened as well.
- Interference between temporary traffic signs (orange sign panels) or markings and regular traffic signs (blue sign panels) or digital information panels is to be avoided, even though traffic regulations clearly indicate that the regular traffic signs are to be ignored when temporary traffic signs are present (see figure 4.b).
- Temporary pavement markings with destination names ("GENT") are shown to require only few and short glances, and they are considered very useful by participants (see figure 4.b).
- Context-dependent design of the traffic signs (e.g. by adding location-specific additional road elements such as median position and other lanes) improves understanding of the traffic sign (see figure 4.c).
- Most participants chose the middle lane in the scenario where the detour applies (2PM till 9PM); only two participants chose the right-most lane. Both choices are correct, but it indicates that a number of participants may be in doubt about the status of the right-most lane. This implies that the right lane capacity will not be optimally used, especially at the start of the road works.

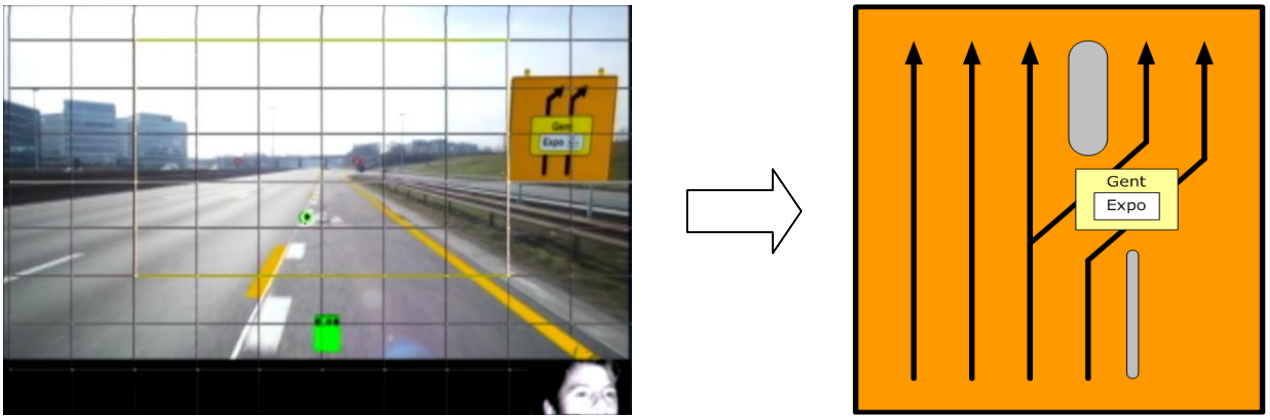




a) Number of glances at announcement sign



b) Interference with other traffic signs



c) Context-dependent traffic sign design

FIGURE 4 Illustration of case study results

DISCUSSION

Benefits of the Traffic Sign Simulator

The pro-active evaluation and optimization of traffic signs in a realistic virtual environment can lead to major benefits to society. Effective traffic signs can avoid dangerous situations or interactions between road users by reducing driver errors and unexpected behavior because of confusion or late decision making. It can also lead to improvements in traffic flow, reducing congestion and time-loss for road users.

Research using a video-based driving simulator has to date not applied major adjustments to the videos, limiting the possibilities for studying non-existing signage in a real-life setting. The Traffic Sign Simulator is unique in combining a video-based driving simulator with sophisticated 3D-engineering and visualization techniques to study complex non-existing traffic signs in a highly realistic virtual setting. Therefore, the combination of a high realism and a high control over the experiment in a safe (virtual) environment is the major strength of the research tool. By combining the research tool with laptop pre- and post-tests and with eye-tracking, it allows to study all components of traffic sign effectiveness.

Furthermore, differences between different socio-demographic groups can be explored, and feedback from different groups can be included, which will help to "design for all". This is a strategy indicating that design standards need to recognize the variability in performance between different road users, and that therefore the least fitted users of the system should form the basis for design requirements (Hakamies-Blomqvist & Peters, 2000; Hunter-Zaworski & Stewart, 1999).

Research Opportunities

The Traffic Sign Simulator can both be used for fundamental scientific research, as well as for very practical problems. The combination of different research methods allows to do research on many traffic sign related topics that are of scientific and/or public interest, such as research concerning sight distance (e.g. Discetti & Lamberti, 2011), the effect of different messages displayed on VMS (e.g. Lai, 2010), dynamic route choice behavior (e.g. Iida, Akiyama, & Uchida, 1992) or the impact of advertisement panels on driving behavior and visual attention (e.g. Beijer, Smiley, & Eizenman, 2004; Crundall, Van Loon, & Underwood, 2006). Furthermore, a number of practical applications can be the testing of parking routes in cities, the evaluation of route guidance systems to industrial zones or other areas of interest and detour routes.

Challenges

The inclusion of participants' actual driving speed could be an important improvement to the tool. At this point, the accelerator and braking pedal are used to determine the pace of the video, but no indication of actual driving speed is shown to participants.

The inclusion of interactions with other road users would be another possibility to reduce the gap between the virtual scenario and the real-life situation. In the Vilvoorde study, the video was free of other vehicles since approaching traffic was blocked by escorting police cars for safety reasons because of the slow driving speed of the camera van. But also in other applications, the possibilities for interaction are limited by what happened during the recording of the video.

Improving the flexibility of the camera track is another possibility for improvement in further research. At this point, the camera track is fixed, and some behavior of the participant will not be visually supported (e.g. incorrect route choices).

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REFERENCES

Bai, Y., Finger, K., & Li, Y. (2010). Analyzing motorists' responses to temporary signage in highway work zones. *Safety Science*, *48*(2), 215–221. doi:10.1016/j.ssci.2009.08.005

Beijer, D., Smiley, A., & Eizenman, M. (2004). Observed Driver Glance Behavior at Roadside Advertising Signs. *Transportation Research Record*, *1899*(1), 96–103. doi:10.3141/1899-13

Borowsky, A., Shinar, D., & Parmet, Y. (2008). Sign location, sign recognition, and driver experience. *Transportation Research Part F*, *11*, 459–465.

Borowsky, Avinoam, Shinar, D., & Parmet, Y. (2008). The Relation Between Driving Experience and Recognition of Road Signs Relative to Their Locations. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *50*(2), 173–182.

Brijs, K., Ariën, C., Brijs, T., Van Vlierden, K., Kuppens, J., & Van Der Linden, M. (2011). Ex-ante evaluation of traffic signs at A7 Vilvoorde Fly-over using the Traffic Sign Simulator. On the autority of the Flemish Agency for Roads and Traffic.

Carlson, P. J., & Hawkins, G. (2003). Legibility of overhead guide signs with encapsulated versus microprismatic retroflective sheeting. *Transportation Research Record, 03-2465*, 59–66.

Castro, C., & Horberry, T. (2004). *The human factors of transport signs*. CRC Press - Taylor & Francis Group.

Charlton, S. G. (2006). Conspicuity, memorability, comprehension, and priming in road hazard warning signs. *Accident Analysis & Prevention*, *38*(3), 496–506. doi:10.1016/j.aap.2005.11.007

Crundall, D., & Underwood, G. (2001). The priming function of road signs. *Transportation Research Part F*, *4*, 187–200.

Crundall, D., Van Loon, E., & Underwood, G. (2006). Attraction and distraction of attention with roadside advertisements. *Accident Analysis & Prevention*, *38*(4), 671–677. doi:10.1016/j.aap.2005.12.012

Cruzado, I., & Donnell, E. (2009). Evaluating Effectiveness of Dynamic Speed Display Signs in Transition Zones of Two-Lane, Rural Highways in Pennsylvania. *Transportation Research Record: Journal of the Transportation Research Board*, *2122*(-1), 1–8. doi:10.3141/2122-01

Department of Transport (DoT). (1991). *Specifications for drawings and markings: warning signs* (No. (P)530). London: DoT.

Dingus, T. A., Klauer, S. G., Neale, V. L., Petersen, A., Lee, S. E., Sudweeks, J. D., … Knipling, R. R. (2006). The 100-Car Naturalistic Driving Study, Phase II - Results of the 100-Car Field Experiment. Retrieved from http://trid.trb.org/view.aspx?id=783477

Discetti, P., & Lamberti, R. (2011). Traffic Sign Sight Distance for Low-Volume Roads. *Transportation Research Record*, *2203*(1), 64–70.

Dutta, A., Fisher, D. L., & Noyce, D. A. (2004). Use of a driving simulator to evaluate and optimize factors affecting understandability of variable message signs. *Transportation Research Part F: Traffic Psychology and Behaviour*, *7*(4-5), 209–227.

Erke, A., Sagberg, F., & Hagman, R. (2007). Effects of route guidance variable message signs (VMS) on driver behavior. *Transportation Research Part F*, *10*, 447–457.

European Commission. (2011). *White paper - Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system* (p. 31). Brussels: European Commission.

European Parliament, & Council of the European Union. (2008). Directive 2008/96/EC of the European Parliament and of the Council of 19 November 2008 on road infrastructure safety management. *Official Journal of the European Union*, *L 319/59*, 9.

Federal Highway Administration. (2012). Manual on uniform traffic control devices for streets and highways. FHWA Federal Highway Administration.

Fisher, D. L., Rizzo, M., Caird, J. K., & Lee, J. D. (2011). *Handbook of Driving Simulation for Engineering, Medicine, and Psychology*. CRC Press - Taylor & Francis Group.

Gartner, N. H., Messer, C. J., & Rathi, A. (1992). Traffic flow theory. *Tuner_Fairbank Highway Research Centre*. Retrieved from http://www.tfhrc.gov/its/tft/tft.htm

Garvey, P. M., Chriwa, K. N., Meeker, D. T., Pietrucha, M. T., Zineddin, A. Z., Ghebrial, R. S., & Montalbano, J. (2004). New font and arrow for national park service guide signs. *Transportation Research Record: Journal of the Transportation Research Board*, *1862*, 1–9.

Gates, T. J., Carlson, P. J., & Hawkins, G. (2004). Field evaluation of warning and regulatory signs with enhanced conspicuity properties. *Transportation Research Record: Journal of the Transportation Research Board*, *1862*, 64–76.

Godley, S. T., Triggs, T. J., & Fildes, B. N. (2002). Driving simulator validation for speed research. *Accident Analysis & Prevention*, *34*(5), 589–600. doi:10.1016/S0001-4575(01)00056-2

Hakamies-Blomqvist, L., & Peters, B. (2000). Recent European research on older drivers. *Accident Analysis & Prevention*, *32*(4), 601–607. doi:10.1016/S0001-4575(99)00073-1

Hunter-Zaworski, K., & Stewart, R. (1999). Next Frontier in Accessible Traveler Information Systems: World Wide Web-Based Information Systems. *Transportation Research Record*, *1671*(1), 1–4.

Hustad, M., & Dudek, C. (1999). Driver Understanding of Abbreviations on Changeable Message Signs in New Jersey. *Transportation Research Record: Journal of the Transportation Research Board*, *1689*(-1), 46–52. doi:10.3141/1689-07

Iida, Y., Akiyama, T., & Uchida, T. (1992). EXPERIMENTAL ANALYSIS OF DYNAMIC ROUTE CHOICE BEHAVIOR. *Transportation Research Part B: Methodological*, *26B*(1). Retrieved from http://trid.trb.org/view.aspx?id=365194

International Commission of Illumination. (1988). *Roadsigns* (No. CIE 074-1988). Vienna, Austria: CIE Cental Bureau.

Khattak, A., Khattak, A., & Council, F. (2002). Effects of work zone presence on injury and non-injury crashes. *Accident Analysis and Prevention*, *34*, 19–29.

Koyuncu, M., & Amado, S. (2008). Effects of stimulus type, duration and location on priming of road signs: Implications for driving. *Transportation Research Part F: Traffic Psychology and Behaviour*, *11*, 108–125.

Lai, C.-J. (2010). Effects of color scheme and message lines of variable message signs on driver performance. *Accident Analysis & Prevention*, *42*(4), 1003–1008. doi:10.1016/j.aap.2009.12.002

Lai, C.-J. (2012). Drivers' comprehension of traffic information on graphical route information panels. *Accident Analysis and Prevention*, *45*, 565–571.

Martens, M. H. (2000). Assessing Road Sign Perception: A Methodological Review. *Transportation Human Factors*, *2*(4), 347. doi:10.1207/STHF2-4_4

RiPCORD-iSEREST. (n.d.). Road infrastructure safety management: Results from the RiPCORD-iSEREST Project.

Wegman, F., Aarts, L., & Bax, C. (2008). Advancing sustainable safety: National road safety outlook for The Netherlands for 2005–2020. *Safety Science*, *46*(2), 323–343. doi:10.1016/j.ssci.2007.06.013

Yan, X., Abdel-Aty, M., Radwan, E., Wang, X., & Chilakapati, P. (2008). Validating a driving simulator using surrogate safety measures. *Accident Analysis and Prevention*, *40*, 274–288.

Zhang, Y., & Ge, H. (2012). Assessment of Presence Conditions of Pavement Markings with Image Processing. *Transportation Research Record: Journal of the Transportation Research Board*, *2272*(-1), 94–102. doi:10.3141/2272-11