ASSESSING HUMAN FACTORS OF NEW ROAD DESIGNS IN A DRIVING SIMULATOR

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SUMMARY

The TNO Human Factors Research Institute conducts several behavioural studies in a driving simulator focussing on assessing human factor issues of new road designs. Following a brief description of the TNO driving simulator, two examples of such studies are presented. One example includes the evaluation of two Variable Message Sign (VMS) Schemes for tunnel evacuation in terms of driving behaviour. The second example deals with studies on human factor aspects of dedicated Automated Vehicle Guidance (AVG) lanes along freeways. The behavioural consequences of several design options have been assessed in the TNO driving simulator.

INTRODUCTION

The success of new driver support systems, traffic management systems, or road designs depends ultimately on the way road users are able and prepared to use them. Precisely because of the unpredictable human factor, new solutions should preferably be tested in a realistic but safe environment. Current developments in simulation techniques enable the visualisation of complex systems and allow designers at an early stage to study design alternatives flexibly, dynamically, and interactively. Moreover, dynamic simulation makes it possible to investigate how road users will behave in a given road environment dependent on certain design parameters (Hoekstra, van der Horst & Kaptein, 1997). The TNO Human Factors Research Institute recently has conducted several behavioural studies in a driving simulator that focussed on assessing human factor issues of new road designs.

Following a brief description of the TNO driving simulator, two examples of such behavioural studies in the driving simulator are presented. One example includes the evaluation of two Variable Message Sign (VMS) schemes for tunnel evacuation in terms of driving behaviour. The second example deals with studies on human factor aspects of dedicated Automated Vehicle Guidance (AVG) lanes along freeways. The behavioural consequences of several design options have been assessed in the TNO driving simulator.

THE TNO DRIVING SIMULATOR

The TNO-driving driving simulator consists of a mock-up on 6 DOF moving-base platform in front of a cylindrical screen. The core of the system is a high performance graphics system surrounded with inexpensive Intel-based sub-systems (Hogema & Hoekstra, 1998). The basic elements of the driving simulator are:

- A Vehicle Model PC : calculating the vehicle model (360 Hz) and controlling the motion system (60 Hz),
- A Supervisor PC: Interacting with experimenter, storing data and controlling other traffic (30 Hz),
- A Sound PC: generating 3D-audio,
- An ESIG-2000: a four-channel Computer Generating Imaging (CGI) system generating the synthetic environment at a 30 Hz update rate,
- A MOOG 6DOF2000E motion-base.

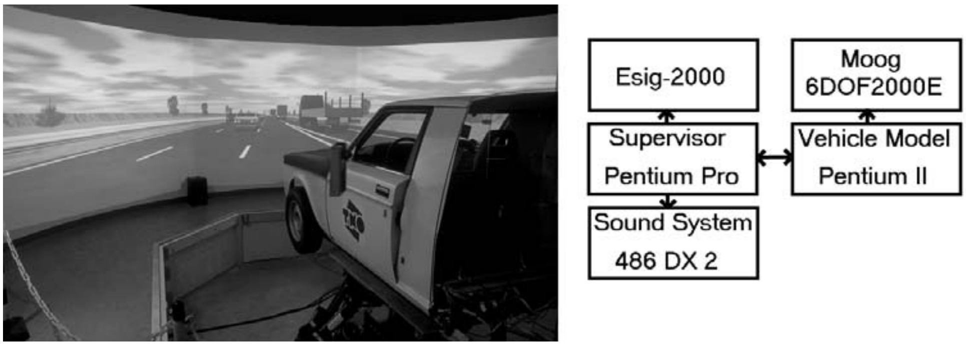

Fig 1. The TNO-driving simulator.

To these basic elements, dedicated subsystems can be added. Typical subsystems are intelligent in-car systems such as Adaptive Cruise Control and driver support systems. The flexible set-up allows subsystems to attach to a local network, which provides the necessary data exchange.

The graphics can be tuned according to the experiment (120° or 160° FOV, with or without rear and/or side view mirrors). The choice for a set-up with PC-based sub-systems gives a lot of flexibility in adding other subsystems and allows increasing performance every year at reasonable cost.

The simulator’s flexibility also extends to generating other traffic. The simulator has three different methods for generating other traffic:

- A longitudinal model: This means that a car only looks at the car in front for calculating its new speed. An exception is lane changing. Based on several parameters the car will look for an acceptable gap in the other lane and will adjust its speed to make a smooth lane-change. This model is very efficient for highway driving tasks, in which the other traffic has to be controlled for performing special events such as traffic-jams, very dense traffic, special overtaking manoeuvres, etc. This model is capable of handling about 120 cars at a 30 Hz update rate and runs on the Supervisor PC.

- An expert system with autonomous behaviour of every individual participant. A scripting language is used to describe the behaviour of the autonomous agents. This system is originally designed for being used in city-environments and rural roads. The expert system runs on a separate PC that is attached to the network.
- The MIXIC model: MIXIC is a microscopic traffic simulation model, which can use real-life data for simulating traffic streams on motorways. This implementation is currently under development in the STREAM project which aims at the development of a generic traffic simulation model which can be used to study the effects of new Intelligent Traffic Systems on-line as well as in off-line simulations (van Arem, de Vos & Vanderschuren, 1997). The U.S.A. Department of Defense (1998) standard for coupling real-time simulators High Level Architecture (HLA) will be used to connect the MIXIC-model to the driving simulator.

APPLICATIONS

VMS Schemes for tunnel evacuation

The future Westerscheldetunnel will consist of two separate tunnel tubes (one for each direction) of 6.6 km in length. Due to financial constraints a separate evacuation tube for pedestrians will not be built. Since the diameter of each tube is just large enough to contain two 3.5 m traffic lanes, no room is left for an emergency lane or a pedestrian lane along the side of the road. In order to enable evacuation of road users from one tube to the other, transverse links will be built between the tubes every 250 m. In case of an emergency in one of the tubes the doors of these transverse links are opened and road users can escape by foot to the other tube. However, they enter this safe tube directly at the left lane and measures have to be taken to create a safe situation for these pedestrians. In a driving simulator study two different Variable Message Sign schemes were evaluated. One scheme was designed to move all traffic to the right lane to make the left lane free for escaping people ('*change lane*' condition) and the other to let all traffic come to a complete stop across both lanes ('*stop*' condition). Within each condition, two strategies were tested, a *gradual* and an *abrupt* one, see Fig. 2. In addition, argumentation signs were used to explain as much as possible to the driver what was going on.

In total, 64 subjects participated in the experiment. Each subject drove seven times through the tunnel, of which five were control runs. In two runs (run 3 and 7) the subject was confronted with one of the signalling schemes.

The results of the lane changing behaviour for the two Change lane conditions reveal that all subjects had changed lanes within 30 s, see Fig. 3 (first confrontation in run 3). The abrupt strategy without the white arrow results in a somewhat faster lane changing to the right lane. During the second confrontation with the signalling scheme (run 7), all subjects had changed lanes within 25 s.

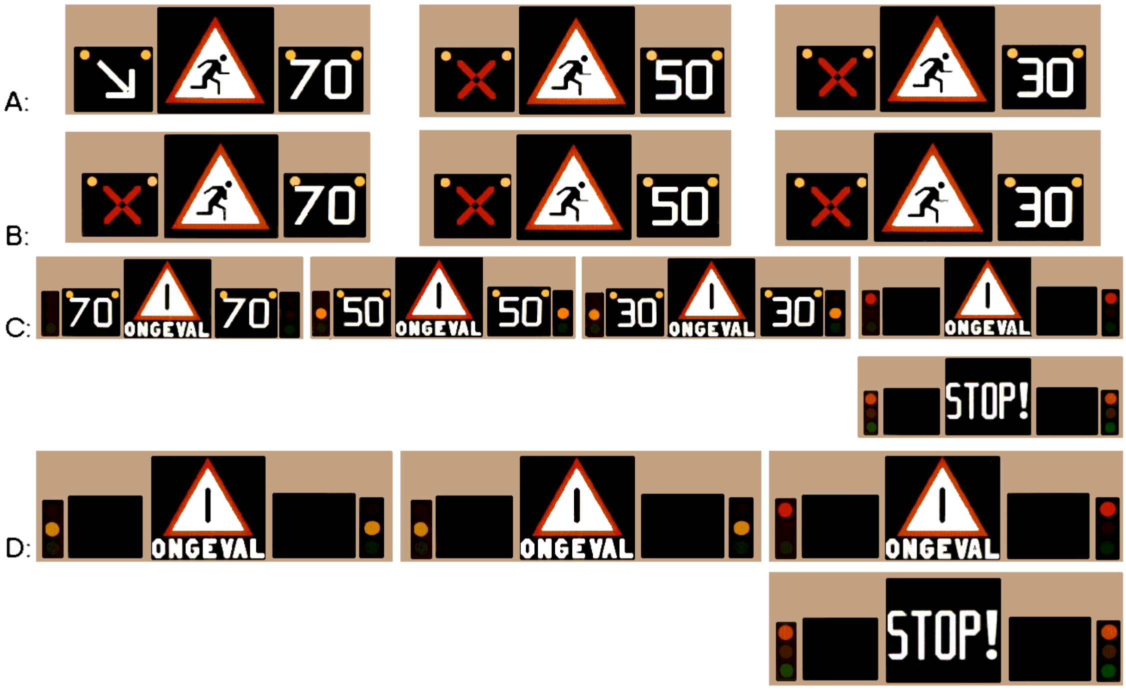

Fig. 2 VMS schemes used in the different strategies. Sequence A: *Change lane/gradual*, during the first 10 s the left signalling is shown, after 10 s it is changed to the middle one, and after 20 s the right signalling is given. Sequence B: *Change lane/abrupt*, idem. Sequence C: *Stop/gradual*, with (from left to right) during the first 10 s the left signalling ('ongeval' means 'accident') with green, then blinking yellow for 10 s, followed by steady yellow for 10 s, and finally the red traffic signal with alternating the 'ongeval' and 'stop' sign. Sequence D: *Stop/abrupt*, with 10 s blinking yellow, 10 s steady yellow, followed by red and the alternating additional signs.

The VMS scheme that was designed to let all traffic come to a complete stop resulted in the driving behaviour as displayed in Fig. 4. Less than 20% of the drivers in the left lane had stopped within 60 s. About 50% stopped after they were confronted with a pedestrian on the left lane, whereas 9% then changed lanes, and 21% actually hit the pedestrian. With the abrupt strategy the latter occurs more frequently.

In run 7 the Stop scheme was presented for the second time, but now without actually a pedestrian entering the left lane, 50% of the subjects did not stop at all.

The comparison of both schemes (Change lane or Stop) indicates that moving the traffic to the right lane in a tunnel is an effective measure that results in an empty left lane within 30 s. In contrast with to these results, stopping all traffic in a tunnel does not seem to be a feasible measure. Even in a driving simulator people do not seem to be willing to stop in a tunnel, especially when no apparent reason for doing so is obvious to the driver. For more detailed information about this study the reader is referred to IJsselstijn and Martens (1998) and to Martens, M.H., Koster, E.R. and Lourens, P.F. (1998).

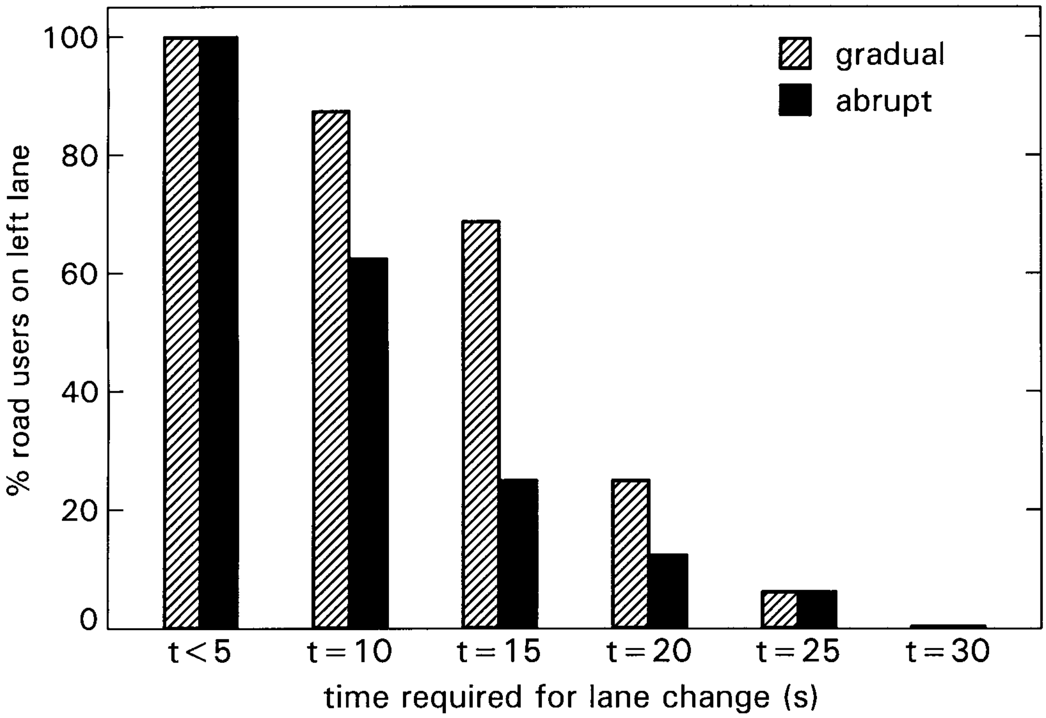

Fig. 3: Percentage of drivers in the left lane after the onset of the signalling scheme (first confrontation) for the Change lane conditions (*gradual* with white arrow, *abrupt* with directly the red cross).

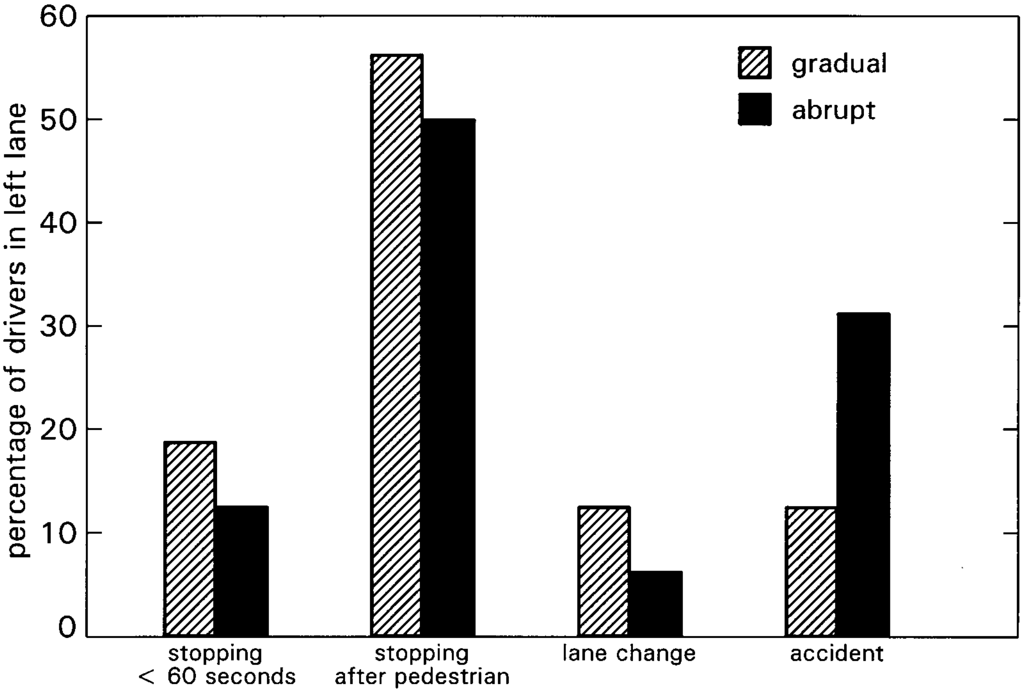

Fig. 4: Driving behaviour in the left lane for the first confrontation with the Stop VMS scheme (run 3), (*gradual*: with speed reduction (70-50-30 km/h); *abrupt*: without any speed reduction signs).

Human Factors Aspects of dedicated Automated Vehicle Guidance lanes

The application of new technologies in road traffic (Advanced Transport Telematics, ATT) may contribute to a more efficient use of the existing infrastructure for traffic and transportation, to improve traffic safety and reduce the environmental impact. Increasingly advanced systems within cars and along the road, may change the driving task considerably. Systems that inform and support the driver or even take over parts of the driving task are emerging (e.g. navigation, route guidance, Adaptive Cruise Control, Collision Avoidance, and Heading control systems) with perhaps a fully automated vehicle guidance concept for the further future (Coëmet et al., 1998). With an automated vehicle guidance (AVG) system, short headways and tight steering would allow high traffic densities and narrow lanes. People will have to be prepared to make use of such high performance transportation systems. Moreover in case automated driving is possible on part of the road network, at some stage a manual control will have to be resumed. An automated system will have to provide a condition in which a driver is capable to safely and comfortably take over control. A series of driving simulator studies was performed to investigate what impact the main characteristics of an automated vehicle guidance system have on user acceptance. In a first study drivers were asked to give ratings on comfort in different headway conditions, while being driven on a highway with the left lane dedicated to automated travel (De Vos, Theeuwes, Hoekstra & Coëmet, 1997). A second study compared different levels of support during the transfer of control to the driver and looked at the impact of traffic conditions on the ease and safety of leaving an automated lane (De Vos, Hoekstra, Hogema & Soeteman, 1997). Another study focussed on the acceptance of tight margins in lateral direction (De Vos, Hoekstra & Pieterse, 1998; De Vos, Godthelp & Käppler, 1999). In one part of this study subjects drove in an automated mode with AVG speeds of 80, 105, and 130 km/h on an automated lane with varying width (2.0, 2.75, 3.5 m), partly physically separated from the manual traffic lanes by means of a barrier and partly directly adjacent to the normal manual traffic lanes. In the other part of the study, subjects drove the same route while steering the car themselves. By means of a button board, subjects gave a subjective rating about the driving situation on a seven-point scale ranging from very uncomfortable to very comfortable. In total 8 subjects participated in this simulator experiment.

In the automated trials, only the factor lane width showed a main effect [$F(2,14)=21.0$, $p<0.001$] on the comfort ratings. In the manual trials an effect of both physical separation [$F(1,7)=11.1$, $p<0.05$] and lane width [$F(2,14)=27.4$, $p<0.001$] was found (see Fig. 5). Comfort decreases with decreasing lane width. Moreover, while driving manually, the presence of a barrier reduces comfort considerably.

During manual control, subjects reduced their speed both in narrow lanes [$F(2,14)=25.8$, $p<0.001$] and in the presence of a barrier [$F(1,7)=25.7$, $p<0.01$], see Fig. 6. For the largest lane width/without barrier condition, the average speed was 116 km/h, whereas in the most narrow lane/with barrier condition, the average speed dropped to 78 km/h.

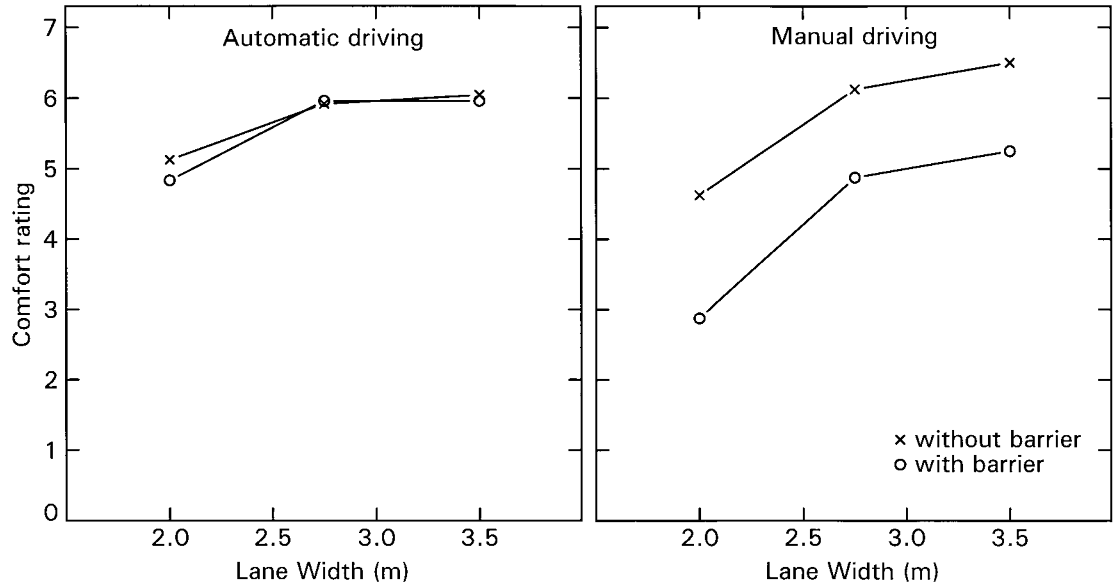

Fig. 5 Comfort rating as a function of lane width and physical separation (with/without barrier) in the automated (left figure) and the manual trials (right figure).

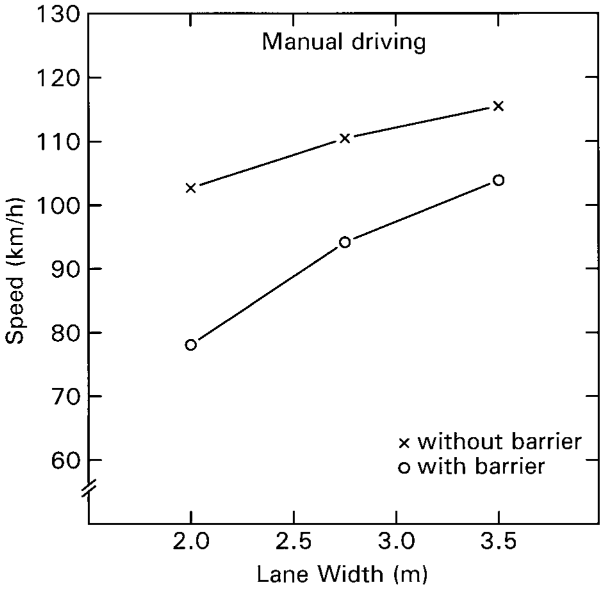

Fig. 6 Driving speed in the manual trials as a function of lane width and lane separation (without and with barrier).

In this experiment no significant effect of lane width on average lateral position was found [F(2,14)=0.04, n.s.]. The presence of a barrier caused a shift of the average lateral position [F(1,7)=1.47, p<0.01] from 0.08 m to the left of the centre of the lane without barrier to

0.43 m left of the centre of the lane with barrier. Standard deviation of the lateral position showed no main effect of physical separation [F(1,7)=0.84, n.s.]. There was a trend of decreasing standard deviation with decreasing lane width [F(2,14)=3.18, p<0.1]. Standard deviations ranged from 0.07 m. in the wide lane condition to 0.016 m in the narrow lane condition with barrier, showing that subjects steered very accurately to stay within the narrow lane. In coherence with this result it was found that the proportion of high frequency steering increased with decreasing lane width [F(2,14)=6.56, p<0.01], whereas this measure was not affected by physical separation [F(1,7)=0.32, n.s.].

In order to cope with the narrow lane condition subjects reduced their speed and shifted their course away from the barrier. Steering effort was increased in the tight lane conditions, but not to a large extent, indicating that in a self-paced situation adaptation is achieved through speed reduction. Given the design parameters of an automated lane, the present results provide a guideline for the maximum speed that should be respected before control of the vehicle is transferred from the auto-pilot to the driver. The presence of a barrier and driving speed are not a factor in the comfort of an AVG system. Therefore, a barrier between the automated lane and the manual lanes, installed for safety reasons, e.g. to prevent drivers in the manual lane from unintentionally entering the AVG lane, does not affect the acceptance of being driven in an AVG system. However a barrier is a discomfort factor in case of manual driving.

CONCLUSIONS

The added value of 3D visualisation of complex road designs was obvious for the road designers involved in the two projects presented. These examples of behavioural studies demonstrate that a systematic comparison of different design alternatives by conducting a controlled experiment in a driving simulator provide a solid base for assessing dynamic driving behaviour before actual implementation. A try-out in a driving simulator can be very cost-effective. An important issue of this approach is that the validity of a driving simulator to address a specific research question (does the simulator evoke the same behaviour as would be shown in reality under similar circumstances?) is sufficiently proven in advance (Kaptein, Theeuwes & van der Horst, 1996).

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