Design and Evaluation of HMI Concepts for Cooperative Driving through a Driving Simulator

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Abstract

Most developments for cooperative driving focus on automated systems taking over control from the driver (also known as Cooperative Adaptive Cruise Control), but it may take quite some time for such technology to achieve a sufficient degree of penetration in the market. Therefore, it has been argued that it might be worthwhile to develop aftermarket advisory systems for cooperative driving for the transition phase. In the current paper we summarize several studies focusing on the design and evaluation of an advisory system for cooperative driving. We show how such systems can be developed through studies employing a driving simulator and discuss where we hit the boundaries of what can be studied through a driving simulator.

Introduction

Cooperative Driving refers to vehicles driving in road trains (platoons) with short inter-vehicle time-gaps, where the acceleration and braking behaviour of a lead vehicle is copied to the following vehicles by means of wireless communication. It may be combined with automatic lane-keeping to provide a high level of automation for the following vehicles. Cooperative Driving has been claimed to provide benefits for highway traffic: it is expected to result in a more stable traffic flow, reducing the number of traffic jams following from unstable traffic flow ("phantom" traffic jams). Also, because of the small inter-vehicular distances, the road capacity is expected to increase. Finally, because of a more stable traffic flow and the reduced inter-vehicular distances, fuel consumption is expected to decrease. While first road tests with cooperative driving have shown the technical feasibility of cooperative driving, the technology is not yet mature and it is expected that it may take quite some time before the technology can be rolled out. Also, legislature needs to be modified, which again may take quite some time. Therefore, it has been suggested that advisory systems might provide a means to speed up the market penetration for cooperative driving. In assistance systems, the driver receives advice about the desired speed but needs to perform the required acceleration and braking actions himself. While this means that the inter-vehicular distances cannot be as small as with automated acceleration and braking, still it has been shown that such advisory systems already have a beneficial effect on traffic flow 1,2.

The aim of the research presented in this paper was two-fold: to investigate how to present speed advice to drivers (Interaction design) and to investigate how drivers may be persuaded to use such technology by applying persuasive technology. In the remainder of the paper we summarize three studies, which were conducted with a driving simulator in which platoon driving was implemented. The driving simulator setup is shown in Figure 1. Since cooperative driving is primarily intended for a highway context, all studies involved highway scenarios. At the end of the paper we will discuss methodological issues associated with conducting research on the topics under discussion with a driving simulator.

Ethical issues: Since only behavioural measures were collected and no recordings were made involving personal data, a low ethical risk level applied and no approval of an ethical committee was required. Therefore, only informed consent forms were used.

Proceedings of Measuring Behavior 2014, (Wageningen, The Netherlands, August 27-29, 2014).
Editors: A.J. Spink, L.W.S. Loijens, M. Woloszynowska-Fraser & L.P.J.J. Noldus. www.measuringbehavior.org

Interaction Design

In two studies, requirements and design guidelines for the interface for an advisory system were investigated. Specifically, it was investigated which type of advice should be provided and which modalities such an interface should employ.

In one study, it was investigated whether the advice should provide information about the desired acceleration or the desired speed target. With automated cooperative driving, the control system continuously adjusts the acceleration, complying with the insight that many small adjustments ensure a smoother traffic flow than fewer large adjustments. If we want advisory cooperative driving to mimic this behavior as much as possible, it implies that the system will present frequent advices for small changes in acceleration. However, we believe that the mental model of the driver is cast more in terms of speed targets, and that acceleration is only a low-level control parameter to reach a certain speed target. To investigate whether drivers prefer advice in terms of acceleration or speed targets, in one condition, participants received the acceleration advice calculated by an algorithm for automated cooperative driving, while in the other condition the acceleration advice was mapped onto a speed target advice. The visual displays for the two interfaces are shown in Figure 2. Both subjective and objective measurements (speed response) were collected. The experiment was conducted with 29 participants.

Figure 1. Driving simulator setup. The driving scenario is shown on an array of five LCD screens (of which only the middle three are shown). A sixth screen below the middle screen shows the standard dashboard display with speedometer and RPM display. A small screen (18 cm diagonal), mimicking a display in the mid console, is attached to the right of the sixth screen to present the displays under investigation.

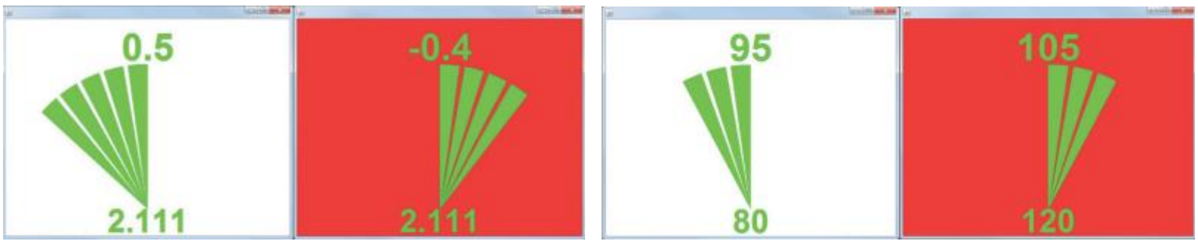

Figure 2. Left: Display for acceleration advice. Right: Display for speed advice.

It was found that eleven participants preferred the acceleration advice and eighteen preferred the speed advice. The ones preferring the speed advice said that the acceleration display allowed more precise control of the vehicle, while the ones preferring the speed advice said that the speed display allowed more freedom in how to implement the advice. The preference was also reflected in the performance: Those preferring the acceleration advice drove with a smaller time gap with the acceleration advice than with the speed advice, while for those preferring the speed advice it was the other way around.

In another study, it was investigated how to map the advice onto the visual and auditory modality. For advisory cooperative driving to provide the expected benefits on throughout, drivers should execute the advice as quickly as possible, turning the advice into an urgent message. Because of the inherent eyes-busy driving context, urgent messages are best communicated through the auditory modality, but at the same time the acceptance of auditory messages is an issue because of their obtrusiveness. In addition, the bandwidth for non-speech audio is limited, meaning that it may be hard to find auditory warning signals for different driver assistance systems that are sufficiently distinctive to be easily recognized. For this study, only speed advice was considered. In an iterative process, different concepts were explored and evaluated with experts. The final concept emerging from this process consisted of a multimodal interface in which a glanceable visual display informed drivers whether they were driving at an appropriate speed or too fast or too slow (Fig. 3), and auditory warning signals informed drivers how much to adjust their speed and when to stop speeding up or slowing down.

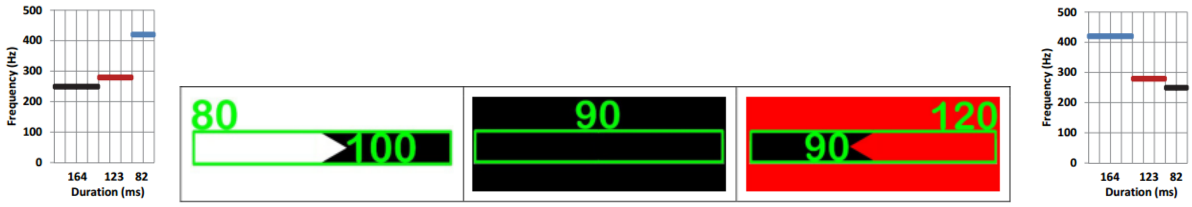

Figure 3. From left to right: Auditory warning signal for Speed up; Visual displays for Too slow, Appropriate, Too fast; Auditory warning signal for Slow down. The durations and inter-signal intervals of the auditory warning signals were adjusted to signal the amount of acceleration/deceleration needed.

To evaluate the concept with target users, several studies were set up with a driving simulator. In a study with 24 participants, the speed advice was presented through the auditory and visual modality, and participants' opinions concerning the usefulness, pleasantness, annoyance and so forth were elicited about different design options. In a study with 12 participants, different design options for the auditory warning signals were evaluated in terms of experience attributes (annoyance, understandability, mental load) and their effects on behaviour. For the latter, a metric was developed call Speed Response, which is the acceleration behaviour in a 5-second interval after the warning signal is presented. Typical graphs showing results are shown in Figure 4.

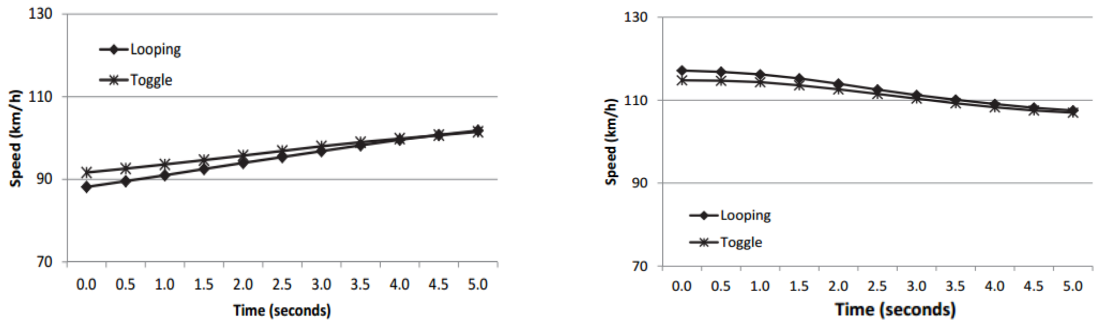

Figure 4. Speed response for two different auditory warning signals. Left: response to "speed up" warning signal. Right: response to "slow down" warning signal.

Enhancing the compliance of drivers with cooperative speed advice

A third study focused on the willingness of drivers to engage in cooperative driving. While cooperative driving has clear societal benefits, the benefits for individual drivers may not be immediately obvious, therewith potentially reducing the willingness of drivers to engage in cooperative driving. It was investigated how drivers could be convinced to engage in cooperative driving by providing them with persuasive messages tuned to their individual persuasion profiles. Persuasion profiles represent the idea that users differ in their sensitivity to (or tendency to comply with) messages representing specific persuasion strategies. The notion of persuasion profiles was already validated in other studies [3]. Six different persuasion strategies were designed for the driving context, drawing the driver's attention to the beneficial effects of cooperative driving in terms of driving safely, in a relaxed or sustainable way, saving time or money (because of avoiding speed fines), or experiencing enjoyment. Participants' profiles were determined through a questionnaire [4] and it was investigated whether their cooperative driving behaviour showed differential effects of messages that were compatible or incompatible with their persuasion profile. An experiment was set up comprising different sessions where 28 participants went through a baseline condition, a condition where they received only speed advice, and a condition where they received speed advice combined with a persuasive message. The speed advice was offered such that the obvious way to comply was by lowering speed and joining a platoon in the right lane, and non-compliance was signaled by maintaining or increasing speed, staying in or moving to the left lane and taking over the platoon. Again, subjective and objective measures were collected. The objective measures consisted of lane choice and speed response. It was found that speed advice itself already resulted in behavioural change and that persuasive messages did not enhance the behavioural change. No evidence was found that messages which were compatible with participants' persuasion profiles led to more compliance with the advice than incompatible messages.

Conclusion and Discussion

Three studies were summarized investigating how to support drivers in cooperative driving, using a driving simulator setup. Two studies focused on the design of the interface, investigating whether to present acceleration or speed advice and how to map the advice onto the visual and auditory modality. The third study focused on the question of how to raise the adoption of cooperative driving . With respect to the latter question, the hypothesis that messages that are compatible with drivers' persuasion profiles increase their willingness to engage in cooperative driving could not be confirmed. Of course, before taking this as refuting evidence for the hypothesis, more studies should be conducted, as the outcomes of the current study may also arise from the specific characteristics of the experiment. In this respect, several elements of simulator studies may cast doubt on their suitability to study behavioural effects of novel technologies other than cognitive aspects such as driver's understanding of the interface and distraction. In the first place, experimental studies involve volunteers, which may give a biased view on the behavioural effects (of course, field studies involving volunteers may suffer from the same bias). Secondly, with respect to behavioural effects of persuasive technology, what should matter in the end is the long-term effect; that is, we are interested to find out whether people adopt certain technology and how this technology affects their behaviour in the long term. In order to address this issue, the current study had people join for three sessions of one hour each, but one may question whether this is sufficient to study long term effects. In addition, in order to motivate the participants to stay involved in the experiment and conceal the purpose of the experiment, a game approach was taken, turning the experiment into a kind of game, which may have induced a different type of behaviour than what we aimed to study. Thirdly, in order to study behavioural effects in an experiment, we need to define both the experimental and control conditions, and the particular conditions may induce situation-specific strategies, turning the outcomes of the experiment into artefacts which are peculiar to the experiment and not indicative of the behaviour that would occur under realistic conditions. In sum, simulator studies may be perfectly suited for studying cognitive aspects such as usability and distraction, but less suited for studying behavioural effects relating to the adoption of the technology. For the latter, insights from simulator studies can only be preliminary and further evidence needs to be obtained through field studies, where people try to pursue their own goals instead of those imposed by the experimenter.

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