AUTOMATED DRIVING FUNCTIONS GIVING CONTROL BACK TO THE DRIVER: A SIMULATOR STUDY ON DRIVER STATE DEPENDENT STRATEGIES

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ABSTRACT

Many car companies and other organisations are working hard to get automated driving on the road. Where some prefer driverless cars, most foresee a future where control of the vehicle will be shared between the driver and automated functions in the coming years. Sharing tasks and responsibilities creates the interesting challenge of transition of control of the vehicle between driver and automation. This paper presents research into this transition. By taking into account the attentiveness of the driver, different strategies were evaluated in a simulator study to create an optimal transition given the situation at hand. The study concentrates on an automated platoon system ‘Virtual Tow Bar’. The results show that the differences among the tested conditions are small and no large trends are visible in either the subjective or the objective results. Hence it is concluded that the experiment should be repeated with a larger group naïve participants and probably more extreme parameter settings.

INTRODUCTION

Many car companies and other organisations are working hard to get automated driving on the road (see e.g. Hoeger et al. 2008; Jootel 2013; Kameda 2013). Where some prefer driverless cars, most foresee a future where control of the vehicle will be shared between the driver and automated driving functions in the coming years.

Sharing control of the vehicle means that the driver must be able to hand over the control to the automated driving function and either actively regain control from the automation function or get handed over control by the system. These transitions must be designed well as they take place while driving. TNO has taken up research to gain insight in the process of transition of control and the related research questions (‘how should the system take over’, ‘how can the driver take back control’, ‘can the driver be regarded as a backup if the system fails’, etc.). By designing and evaluating the different transitions of control, it is the long-term goal of the research to come to architectures and model-based designs for the transition of control and techniques and guidelines on how to evaluated these transitions.

As a case study, TNO’s automated system Virtual Tow Bar (VTB) is taken. The VTB is an automated system that allows a vehicle to follow its predecessor at a relatively short following distance, controlling both the longitudinal and lateral motion. The VTB system is designed to operate on public motorways (i.e. without using dedicated lanes), initially limited to platoons of two vehicles. The first vehicle is driven by a human operator and (once engaged) the second vehicle is controlled by the VTB. The VTB is designed with the goals to reduce fuel consumption (especially for trucks) and improve traffic throughput. To achieve these goals, the system must maintain relatively short headways, in the order of magnitude of 0.2-0.3 s (see e.g. Jootel, 2013), i.e., much smaller than headways normally adopted by drivers.

This paper reports on an explorative driving simulator study conducted to evaluate different strategies to come to an optimal transition from automated driving to manual driving, where the state of the driver is taken into account. The transition was initiated by the automated system when approaching the highway exit to be taken by the driver to continue his journey on the desired route. The upcoming automatic disconnect was preceded by a warning. The warning process asked for a confirmation from the driver that he/she was ready to regain the driving task. The timing of the warning and the confirmation process was made dependent on the driver state. (Note that the situation where the driver is not capable to regain control must ultimately be dealt with, but is beyond the scope of out current work).
For the driver state we concentrated on the topic of attentiveness of the driver. It was the goal of the project to investigate different strategies to re-involve the driver and not to measure his/her level of attentiveness. In the simulator study the level of attentiveness was manipulated by instructing the participants either to be attentive, or to engage in a secondary task that was designed to be highly distracting. For next steps in the research eye tracking may be used as a basis to measure driver attentiveness (Ahlstrom, 2013).

Previously research was conducted on finding the most important parameters that influence the transition of control when the driver switches the VTB system on and off, and on driver behaviour after he/she switched the VTB system off (Willemsen et al. 2014a; Willemsen et al. 2014b). Results of this research were taken into account in the reported study in the settings of several parameters of the VTB system and in the driver interface.

VIRTUAL TOW BAR SYSTEM

As explained in the Introduction the VTB system uses short following distances, which means the driver cannot be regarded as a backup to take over in case of system failure or any other emergency. To create a safe transition towards the small following distance, a scheme was designed to let the driver switch the system on from a safe following distance. Once activated, the automated system decreased the following distance to the desired (small) following distance. When switching off, either by the driver or by the automated system itself, the system first increases the following distance to a safe length before giving back control to the driver.

System Model

The VTB was modelled as a combination of a Cooperative Adaptive Cruise Control (CACC) controller (Ploeg et al., 2014) and a Lane Keep Assist (LKA) system. The Cooperate part of the system consisted of short-range communication between the two vehicles in the platoon. Via this channel, the longitudinal following controller had access to the current acceleration command of the lead vehicle, which provides additional damping with respect to an autonomous ACC that only has distance and relative speed as control inputs. The LKA algorithm was used to provide lateral control of the vehicle with respect to the middle of the lane. The controllers were combined and logic was added to create different system modes to switch the system on and off (Willemsen et al. 2014a; Willemsen et al. 2014b).

System Interface

A dedicated user interface was developed for the earlier experiments and improved based on the feedback from these experiments (Figure 1). A touchscreen visual display was mounted in the mid console (see Figure 2) of the mock-up of the driving simulator, as high as possible without blocking the view on the road. On this display the current system status was shown together with a graphical indication of the current time headway and guidance to help the user engage the system. Moreover, this display was used to also notify the driver of an upcoming automated switch off (Figure 2) and request confirmation of this notification of the driver. Lower in the mid-console, within easy reach for the participants, a pushbutton was placed which they could press to engage or disengage the system. Pressing the brake pedal would also initiate a disengagement of the system.
The goal of the study was to develop strategies for the automation to notify the driver of a switch off by the automation, not to develop a specific HMI. We therefore wanted the user experience with the system to be as good as possible, i.e. without flaws in the interface that might disturb the experience. We therefore needed an interface of which we could assume it would be understood and accepted by the user. Experiences in previous studies were taken into account in the design of the basic interface. Using an iterative process we designed, developed and tested the additional warning towards the driver for an automated switch off in a low-fidelity simulator. Besides the visual display, acoustic warnings were provided to the driver at the moment information or warnings were presented to alert the driver to the new visual information.

METHOD

Because of the safety implications of automated driving and the wish to have a natural driving environment (i.e. no test track environment) the experiment was conducted in a moving base driving simulator.

Driving Simulator and Scenario

The experiment was carried out in a high fidelity moving base driving simulator (Van den Horst and Hogema, 2011). It consisted of a BMW mock-up mounted on a 6DOF moving base. The road and traffic environment was projected on cylindrical screens around the vehicle. The projection system for the front view had a horizontal viewing angle of 180 degrees, realized by three projectors. The vertical viewing angle was 41 degrees (22 degrees above and 19 degrees below the neutral viewing direction). The driver could use the existing BMW external rear view mirrors to look at two screens placed behind the vehicle displaying the environment behind. Similar, the internal rearview mirror could be used to look at a 32 inch LCD screen placed in the back of the car. Feedback of steering forces was given to the driver by means of a high-fidelity electrical torque engine.
Participants drove on the right-hand lane (the slower lane) of a two-lane motorway behind a lead vehicle that was driving with an average speed of 120 km/h. The participants were instructed to follow this lead vehicle and switch the automated function on when possible. There were no entries or exits on the route until the very end of the run. The participants were instructed to take this exit after the automated function had switched itself off. Slight curves, surrounding traffic, and two signs indicating the upcoming of the exit made the experience more realistic.

**Parameters and Experimental Setup**

Goal of the study was to investigate different strategies for the automated function to switch itself off in case of an attentive or an inattentive driver. Hence the participants drove one run where they were asked to stay attentive and two runs where they were asked to perform a demanding secondary task. This secondary task consisted of the HASTE task (Engström, Johansson, & Östlund, 2005): participants were presented with matrices of arrows on an additional LCD touch screen. An example can be seen in Figure 2, in which also the position of the touch screen in the simulator mock-up shown can be seen. The task was to determine whether an arrow pointing upwards was present. Participants gave their answers by pressing ‘‘yes’’ or ‘‘no’’ on the touch screen. A new matrix was presented every 10 seconds. Each matrix remained on the display for 2 s before a new matrix was presented. Participants were instructed perform as good as possible on the HASTE task by getting as much answers right as they could during their whole trip.

The time gap of the VTB system was 0.3 s. Hooking on and off phases took 15 s and the transition just before hooking on and after hooking off were instant (no additional countdown from 5 s as presented in Willemsen et al. (2014b).

At a certain distance upstream from the exit, the participant was warned and requested to provide a confirmation by pushing a button on the touch screen of the interface (Figure 2). If the driver did not confirm within a certain time the warning and confirmation request was repeated. Closer to the exit, irrespective of the driver reacting to the confirmation request, a warning was displayed that provided the amount of meters till the exit (Figure 1 without the confirmation request and button). The timings of the warnings and feedback requests were different between the attentive and inattentive driver states (see Table 1). The unadapted transition strategy was to warn the participant and ask for confirmation the first time at 1000 m before the exit. From 500 m before the exit the participant was continously informed on the distance (‘count down’) till the VTB system would switch off. In the adapted strategy,
the participant was warned and asked for confirmation earlier, at 2000 m before the exit and the ‘count down’ was shown from 1000 m before the exit. In both strategies, if the participant did not react to the first confirmation request, a second one was issued at 750 m before the exit.

Table 1. Parameter combinations in the simulator experiment.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Driver distraction</th>
<th>Transition strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-</td>
<td>Familiarization run</td>
</tr>
<tr>
<td>1</td>
<td>attentive</td>
<td>Unadapted</td>
</tr>
<tr>
<td>2</td>
<td>inattentive</td>
<td>Unadapted</td>
</tr>
<tr>
<td>3</td>
<td>inattentive</td>
<td>Adapted</td>
</tr>
</tbody>
</table>

The order of presentation of the second and third condition were balanced over the participants.

Participants

A total of 16 participants attended the experiment. It shoud be noted that all participants were research colleagues with a background outside the automotive domain to prevent they had too much information about automated driving and the transition of control before the experiment. First the subjective results, acquired through questionnaires is discussed followed by analyses of the logged signals.

RESULTS AND DISCUSSION

Subjective Results

Drivers judged the amount of information or understanding they had about the environment when they had to take over control to be in the middle between more than enough and not enough. They rated the unadapted strategy slightly lower than the adapted strategy when they were distracted by the secondary task (see Figure 3, on the left). This suggests that the adapted strategy helped the participants to take over control with more information about the traffic situation.
Figure 3. Left: Situational awareness (1 = not enough, 7 = more than enough), right: Experienced time headway (1 = too close, 7 = too far).

Figure 3 on the right shows that the participants experienced the car in front of them too close when they were paying attention. Note that the car was driving at 0.3 s behind the lead vehicle, which is much closer than these drivers would normally drive. Since they always received the attentive condition before both inattentive conditions, this might be an order effect, meaning that drivers got used to driving (being driven) so close to a preceding vehicle. It could also mean that when engaged in a secondary task reliance on the system is higher and a closer gap becomes acceptable. This should be investigated in follow-up research.

When asked about their feelings of safety when taking over control, participants on average answered only slightly above the mid value (4) and with very small differences among conditions, as can be seen in Figure 4 (left). Some participants felt much safer than others, values ranging from 2 to 6. The average not being higher than 4 does suggest there is concern with the drivers about their safety when taking over. Apparently these concerns were there both with and without the adapted strategy.

Figure 4. Left: Experienced safety (1 = not safe at all, 7 = very safe), right: Automated driving creates a dangerous situation, (1 = strongly disagree, 7 = strongly agree).

The results for the question about whether taking over control after being driven autonomously created a dangerous situation again suggests the drivers had concerns about safety and dangerous situations. In Figure 4 (right) it can be
seen that they felt a dangerous situation was more likely to arise when they had been inattentive. In contrast to the result from Figure 3 (left), there is no evident difference between the condition with and without the adapted strategy.

It seems that participants found the amount of warnings neither too few nor too many for any of the conditions (Figure 5). This could mean that the extreme values of number of warnings was not reached and that drivers accepted both the maximum as well as the minimum amount of warnings. This would mean that the difference between conditions as presented in this experiment was not large and minimal warnings were enough to alert the driver again. This could be different when either the automation switches off more often, making the warning more annoying, or when the time of distraction becomes longer or more intense, which means that the minimum amount of warnings is not sufficient anymore.

How would you judge the amount of wanings you recieved before taking over control?

![Bar chart showing the amount of warnings](image)

**Figure 5. Amount of warnings (1 = too few, 7 = too many).**

**Objective Results**

The effect of the additional task is evaluated through the reaction time of the drivers on the confirmation request, and the steering behaviour after regaining control and taking the exit. This is shown in Figure 6.

![Graphs showing reaction times, steering wheel usage, and steering wheel reversals](image)

**Figure 6. Left: Reaction times, Middle: Steering Wheel usage, right: Steering Wheel Reversals (cond1: attentive, cond2: inattentive with unadapted strategy, cond 3: inattentive with adapted strategy).**

The reaction time was calculated as the time between the first confirmation request and the driver pushing the confirmation button. In some cases the driver did not react to the confirmation request: one in each tested condition. These data were not taken into account.
In the inattentive case the reaction time is lower than in the attentive case for the unadapted warning strategy, for the adapted warning strategy (earlier warning) the reaction times are larger. This could mean that the drivers were anticipating the warning, however, in the adapted warning strategy the warning may have come earlier than expected by the drivers, as they drove at least the attentive run before the other inattentive runs. Furthermore a large reaction time is not critical as the situation is not urgent. Moreover in the adapted strategy the warning was even 1000 m earlier than in the other two cases, so even with an increase of the reaction time of about 3 s, the reaction is in fact still further upstream from the merging point.

For the calculations of the steering wheel usage, data of three participants were excluded as they switched off the VTB bar system too early. In that case they were not at the highway exit they should steer onto and the required steering was less than for the other cases.

The amount for steering used after switch off (middle chart in Figure 6) shows differences: the inattentive participant with the unadapted warning strategy uses largest steering angle range and the inattentive paricipant with the adapted strategy the smallest. This may suggest that earlier warnings prepare the driver better to take over the steering of the vehicle. This needs further detailed research.

Regarding the steering wheel reversals the results are quite the same for the different conditions. Although it was expected that the first run would show more reversals as the participants would learn to take over control after more practice and this seems not to be the case.

CONCLUSIONS

Results of a small driving simulator (16 participants, runs of nearly 5 minutes) experiment are shown, in which an automated driving system hands back the control to the driver on initiative of the automated driving system. Immediately after getting back the control the drivers had to take an exit. Different timings of take over warnings were tested with attentive and inattentive participants.

Overall it can be concluded that the differences between the tested conditions are small and no large trends are visible in either the subjective or the objective results. Probably the participants were able to rebuild their situation awareness in a short time. Further, only distraction was differed over the tests (fatigue, drowsiness, absence were not investigated). In general the participants were moderately positive about the system, though there were concerns about the safety with the short following distances. Hence it is concluded that the experiment should be repeated with a larger group naïve participants and probably more extreme parameters (longer distraction times, larger difference between conditions).

REFERENCES


