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The transition of control from "Pilot Assist" to Driver – preliminary research

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Abstract

More and more cars nowadays are provided with a "Pilot-Assist". The Dutch-Police-Academy and the Netherlands-Forensic-Institute expect a high potential risk if the Pilot-Assist fails, leaving the vehicle without control and a driver that may not be aware of that. It is of interest how drivers will react during the transition of control from Pilot-Assist to driver. However, this transition has not been studied much. To study this transition, driver simulator tests were performed and the results of these tests were implemented in a model that simulates the transition. It was found that the initial response of all the drivers was to steer in order to keep the vehicle on the road. However, the steer response of every driver was different. It was also found that drivers are significantly more bored while driving with an active Pilot-Assist. A more realistic driving simulator and different test scenarios are needed for further research.

Zusammenfassung

Heutzutage werden immer mehr Autos mit einem so genannten „Pilot-Assist" ausgestattet. Die Niederländische Polizei-akademie und das Niederländische Institut zur Kriminaluntersuchung (NFI) erwarten ein hohes potenzielles Risiko, wenn der Pilot-Assist versagt und das Fahrzeug ohne Kontrolle und gleichzeitig ohne Kenntnis des Fahrers weiterfährt. Es ist interessant heraus zu finden, wie die Reaktion des Fahrers sein wird, wenn die Übergabe der Lenkung von Pilot-Assist auf den Fahrer unerwartet stattfindet. Dieser Übergang wurde jedoch nicht viel untersucht. Um diesen Übergang untersuchen zu können, sind Fahrsimulator-Tests durchgeführt worden und die Ergebnisse dieser Tests sind in einem Modell implementiert. Das Modell simuliert den Übergang. Es wurde festgestellt, dass die erste Reaktion aller Fahrer die gleiche war und zwar dass alle zu lenken begannen mit dem Gedanken das Fahrzeug auf der Straße zu halten. Das Lenkverhalten jedes Fahrers war jedoch unterschiedlich. Es wurde auch festgestellt, dass Fahrer sich deutlich mehr langweilen bei dem Fahren mit aktivem Pilot Assist. Ein Fahrsimulator mit einer realistischeren Darstellung der Wirklichkeit, zusammen mit verschiedenen Testprotokollen, sind für die weitere Forschung zum Fahrerverhalten erforderlich.

[1] This technical paper was submitted for the 29th Annual Congress of the European Association for Accident Research (EVU) and has undergone the standard EVU peer review. As the congress has been postponed due to the Covid 19 pandemic, the paper is published awaiting oral presentation.

Introduction

Over the last few decades, the automotive industry has introduced so-called Advanced Driver Assistance Systems, also known as ADAS. These systems have the ability of detecting various traffic situations with the use of sensor data and vehicle states. Based on that, some of these systems can control the vehicle movements (both lateral and longitudinal) to help the driver manoeuvre through demanding traffic situations [1]. The range of possible ADAS applications is very wide and the systems can support the driver in one specific driving task (such as lane keeping, distance control or speed control) up to more advanced support where complete driving tasks are taken over by the system (steering, throttling and braking, e.g. Pilot Assist) [2]. It has been found that these systems raise traffic efficiency and reduce energy consumption. Furthermore, such advanced driver assistance systems may reduce the number of traffic accidents [3] [4]. However, highly automated driving systems can cause concentration problems for the driver, such as complacency and loss of situational awareness [5].

The J3016 standard of the SAE (Society of Automotive Engineers) has defined six levels of driving automation, starting with SAE Level Zero (no automation) up to SAE Level Five (full vehicle autonomy). It serves as the industry's most-cited reference for automated-vehicle (AV) capabilities [6]. For the levels two, three and four, the driver is partially (or not) driving the vehicle when the (partially) automated driving systems are engaged, even though the driver is seated in "the driver's seat". An example of such partial automation (Level 2) is a Pilot Assist which controls the vehicle's longitudinal (accelerating and braking) and lateral motions (steering). The partially automated driving systems are restricted by technical boundary conditions and given that, the driver remains responsible for safe driving [7] [8]. This partial automation requires the driver to be ready to act as a backup (and to retake control) in case the boundary limits are exceeded (i.e. the automation stops/fails). As a consequence, the role of the driver changes from actively controlling the vehicle to observing and supervising the system with an occasional intervention on steering and vehicle speed (transition of control).

It is expected that this transition of control is different for many drivers since every driver behaves differently. Some drivers may react immediately, and some may take quite some time to respond as they are not mentally ready. Furthermore, drivers can be engaged in unrelated driving tasks, like reading, paying attention to their phone/navigation or sleeping, even though this is forbidden by law [7] [8]. Moreover, it has been argued that the levels two, three and four of driving automation may be hazardous because the human is obligated (by legislations [8]) to monitor the automated driving systems while nothing happens [9] [10]. As a result the responses of the driver can be slow (compared to manual driving) during a critical event which may have an influence on road safety (it can lead to accidents) [5] [11].

The Netherlands Forensic Institute (NFI) and the Dutch Police Academy, both part of the Dutch Ministry of Justice and Safety, are interested in the influence of this transition in traffic. It is expected that there is a high, potential risk when automated driving systems suddenly fail while indicating that they are still functioning properly. The vehicle will be left without control and a driver may not be aware of that since the driver will not be warned by the system. Because of this high potential risk, the NFI and the Police Academy want to have more knowledge about this transition from automated driving systems in control to driver in control.

The goal of this preliminary research is to get initial insights in the transition of control from the Pilot Assist to the driver retaking control of the vehicle after the system fails, while indicating that it is still working, i.e. the driver will not be warned. The transition will be investigated in terms of driver's reaction, i.e. input to vehicle, reaction time and stability loss and the level of conditioning of a driver, i.e. how will the reaction of the driver be affected if a driver drives longer with an active Pilot Assist. This preliminary study should conclude how further research on the topic should be conducted.

Outline

At first, the methodology of the study is explained. After that, the results of the study are presented, followed by a discussion on the results. At the end, conclusions and recommendations are drawn for further research on the topic.

Methodology

This section describes the methodology used in this study in order to acquire the desired results to reach the stated research goal.

It is of importance to know how a driver will respond when the automated driving systems, e.g. Pilot Assist, of a vehicle suddenly fail, while indicating that it is functioning properly. The vehicle will be left without control and a driver may not be aware of that since the driver will not be warned by the system. The driver's response during this transition is observed using driver simulator tests. With the simulator tests, it should become clear what type of initial reaction a driver will have during the transition of control, e.g. steering or braking. Furthermore, the purpose of the simulator tests is to get insights into the level of conditioning of a driver, i.e. will the driver's reaction change, e.g. steering more aggressively, if a driver drives longer with an active Pilot Assist.

To gain more knowledge about the transition of control from Pilot Assist to driver, also a mathematical model is created. With the help of this model it is more convenient to perform parameter studies in further research in order to simulate multiple test scenarios without the need of driving simulator tests. Models represent certain aspects of reality in a condensed and comprehensible way and are less expensive and time consuming than real life tests [21]. The results of the simulator experiments are used for the simulations with this mathematical model.

Simulator study

On-road testing is a globally accepted method for driving assessments. It provides many benefits because it represents real driving in a real-world context [12]. But on-road testing also has its limitations [13]. On-road testing can often be time consuming, expensive and may have adverse effects that could lead to dangerous driving situations for certain types of tests. In addition, researchers cannot control for environmental conditions such as light, weather and traffic [14] [15]. On-road testing can be considered as too dangerous for this study, since the Pilot Assist should be switched off during the test (which could lead to emergency situations).

A driving simulator provides a convenient and safe method for assessing driving behaviour without creating a high-risk situation for driver, car and environment. In addition, driving simulation allows the evaluation of a wider range of driving situations, especially those that are dangerous or physically threatening which is the case in this study [15]. And finally, driving simulators also allow for assessment under the same conditions for every test [16].

In order to use a driving simulator as an assessment method, the validity of a driving simulator was studied using various previously performed studies. The studies performed use the terms "*absolute validity*" and "*relative validity*". Absolute validity implies that the same scale effect exists between real life and the simulator and no significant differences are found [17]. Relative validity implies that only the same trend of an effect exists between a simulator and real life [17] [18].

After examining the performed studies, it can be concluded that a driving simulator has good relative validity in comparison to on-road testing on both vehicle behaviour and driver behaviour aspects for this study [15] [17] [19] [20].

When taking the risks of on-road testing and the outcomes of the literature study into account, it is chosen to perform driving simulator tests instead of on-road testing.

Participants

11 test subjects participated, and their age ranged from 20 to 64 years and their driving experience ranged from 3 to 46 years. All participants had a valid Dutch driver license and were either a student or an employee of the HAN University of Applied Sciences (Automotive Engineering). To prevent the test subjects from being extra alert during the test, none of the test subjects were familiar with the project and they were informed with a fictive research topic.

Scenario & system description

The study was undertaken in a self-developed non-moving-base driving simulator as shown in Figure 1. The simulator uses PreScan, to simulate the environment and the used sensors, in combination with Matlab Simulink, for the vehicle model. The vehicle, an Audi A8, is a predefined vehicle of PreScan which is a Single-Track model with linear tyre behaviour, roll and pitch. The vehicle model is expanded with a Pilot Assist consisting of longitudinal control (Cruise Control) and lateral control (Lane Keeping System).

Figure 1: Non-moving-base driving simulator set-up.

With the use of a Logitech G29 game console, consisting of a force feedback steering wheel and three pedals: clutch, brake and accelerator (left to right), test subjects could give inputs to the vehicle. The driver can activate and deactivate the Pilot Assist by pressing buttons on the steering wheel or only deactivate the system by braking. The driver was informed visually with a lamp on the dashboard about the (de)activation of the automated driving system, i.e. the driver can see if the system is active or not. Moreover, the test subjects could see the vehicle speed and engine RPM.

To evaluate the reaction of the driver during the transition of control, the active Pilot Assist was switched off by the test supervisors without indicating that the system fails. The lamp, which shows that the Pilot Assist is active or not, was not turned off, indicating that the system is still in control which is not the case. The driver had to notice/observe that the system was not working (i.e. the car started to decelerate and the driver was steering the car again) and had to take over control without getting any warning of the vehicle. Since the driving simulator is a non-moving-base driving simulator, the driver could only notice this deceleration visually by looking at the surroundings and the vehicle velocity on the dashboard.

The point of deactivation was at the start line (see Figure 2) just before the vehicle enters a corner to the right, when driving clock-wise. The point of deactivation was the same for every test driver, such that the traffic situation will have a minimal influence on the driver's reaction. The time of deactivation was different, i.e. the test drivers were driving a different number of laps with an active Pilot Assist before it was switched off. This to get insights into the level of conditioning of a driver.

The simulated environment is a large lap (±6 km) consisting of a two-lane provincial road with a speed limit of 80 km/h and with ideal weather and road conditions. Driving one lap at 80 km/h will approximately take 4 minutes and 30 seconds. The layout of the lap is shown in Figure 2.

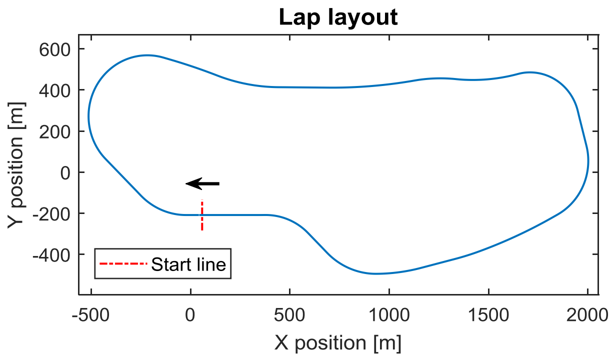

Figure 2: Lap layout of the simulated road.

Experimental design & procedure

First the drivers got some time to drive freely in the simulated world to get familiar with the system. After familiarization, the test driver has driven some laps with and some without the Pilot Assist activated. A global planning of the test drive is explained in more detail below.

Lap 1	Driving a lap without the help of Pilot Assist.
Lap 2 – X	Driving with the Pilot Assist and at a defined moment in time the Pilot Assist is switched off and the driver is expected to take over control.
Last Lap	After deactivation and retaking control, the driver is asked to drive one more lap with an active Pilot Assist system.

In reality the steering wheel will rotate when Lane Keeping Systems are in control. However, it was not possible to actuate the G29 force-feedback steering wheel and the test subjects were therefore asked to steer along with the (active) Pilot Assist to simulate this behaviour. However, the Pilot Assist is actually steering the vehicle. The driver only had to imitate this rotation of the steering wheel, so the vehicle doesn’t respond to the steering of the driver.

During the test, the drivers were informed by the test supervisors when to drive manual or when they had to activate the Pilot Assist. The vehicle states and driver inputs were logged and the drivers were filmed during the test. After the test, the drivers had to fill in an evaluation form.

Model simulations

A mathematical model is created, with the help of Matlab Simulink, to simulate the transition of control from the Pilot Assist to the driver. With the help of this model, it is more convenient to perform parameter studies in further research.

Scenario & Simulation

The vehicle used in the model simulations includes a Pilot Assist, consisting of a longitudinal controller (Cruise Control) and a lateral controller (Lane Keeping System). This Pilot Assist system will be active at the beginning of the simulation, i.e. de Pilot Assist is in control of the vehicle. The system will be deactivated mid-corner and the driver (model) becomes active and must retake control.

The response of the driver depends on his behaviour and states and can/will have influence on the vehicle stability. The driver parameters *reaction time* and *steering gain* (later explained) will therefore be changed to study the influence on the (vehicle) (in)stability during the transition of control. Furthermore, the vehicle will drive on a straight road followed by a curve to the right (radius of 300 meters) with a vehicle speed of 80 km/h. The road consists of two lanes with a constant lane width and clearly visible, continuous road lines. Furthermore, ideal weather and road conditions are assumed.

Vehicle Model

The vehicle model applied in the present research study is a Single-Track model[2] which is the simplest representation of a vehicle and because of its simplicity, it is used as a first step in vehicle performance analysis for applications such as those involving active steering control [22]. This vehicle model should have both lateral and longitudinal vehicle inputs since both the Pilot Assist and the driver can control the vehicle’s lateral and longitudinal motions. The semi-linear Single-Track model (linear Single-Track model with non-linear tyre behaviour) considers longitudinal (**x**), lateral (**y**), and yaw (**ψ**) motion under the assumption of negligible lateral weight shift, roll, pitch and compliance steer. Furthermore, the vehicle is front wheel driven, only the front axle is steered and the steering angle input corresponds to the steering angle of the front wheels (axle).

The Single-Track model used in this study consists of a non-linear tyre model that generates the tyre forces on the wheels of the vehicle. A non-linear tyre model is used in order to account for sliding phenomenon that may occur during the transition. In this particular model, the tyre forces are determined with help of the MF-tyre model from TNO Delft-Tyre. MF-Tyre is the Delft-Tyre standard implementation of the reknowned Pacejka Magic Formula that includes the latest developments like representation of the effects of inflation pressure and estimation of combined slip behaviour [23] [24]. The MF-tyre model can be implemented in Simulink in the form of a block.

Driver Model

Besides the vehicle model, a driver model is needed in order to model a human driver to simulate the transition of control from Pilot Assist to the human driver. A common driver model used in many modelling problems is a transfer function, were the driver exhibits a first-order behaviour and a delayed time response [22] [25] [26]. The driver model is split into two sub-controller models, a longitudinal and a lateral controller in order to model a realistic transition from Pilot Assist to driver since both can control the longitudinal and lateral motions of a vehicle through steering, accelerating and braking. Both the driver sub-models, longitudinal and lateral respectively, are given by a transfer function:

$$D_{long}(\mathrm{s}) = \frac{\mathrm{T(s)}}{\mathrm{e}_{vx}(\mathrm{s})} = \frac{\mathrm{G_{dT}}}{\tau_{\mathrm{L}} * \mathrm{s}+1} * e^{-\tau_{\mathrm{d}} * \mathrm{s}} \quad (1)$$

$$D_{lat}(s) = \frac{\delta(s)}{e_p(s)} = \frac{G_{dp}}{\tau_L * s+1} * e^{-\tau_d * s} \quad (2)$$

with a gain $\boldsymbol{G}$, a reaction (delay) time $\boldsymbol{\tau_d}$ and a lag time $\boldsymbol{\tau_L}$ which is the required time for muscle

[2] This is a different single-track model as used in the driving simulator. The software of the driving simulator didn’t allow for a non-linear tyre model.

activity (neuromuscular lag time) due to neuromuscular restrictions [22].

The two driver's inputs, two outputs and four parameters for both models are respectively:

$e_{vx}(s)$	Longitudinal velocity error input	[m/s]
$e_p(s)$	Lateral preview path error input	[m]
$T(s)$	Driver applied torque output	[Nm]
$\delta(s)$	Driver corrective steering output	[rad]
G_{dT}	Driver torque-gain.	[Nm/ms^{-1}]
G_{dp}	Driver steering gain.	[rad/m]
τ_L	Lag time	[s]
τ_d	Reaction (delay) time	[s]

The reaction time and the lag time will be the same for both sub-models, 0,1 [s], since it is the same driver who is controlling the vehicle. However, the gains (and units) for longitudinal and lateral control will be different, 125 [Nm/ms^{-1}] and 2.5 [rad/m] respectively.

Results

This section contains the results of the simulator tests together with the outcomes of the model simulations.

Simulator results

The aim of the simulator tests was to get clarification on the driver's response during the transition of control and to get insights into the level of conditioning of a driver. The experiments yielded three types of test results: data (vehicle states and driver's inputs), video material and the answers to the evaluation forms.

Driver's input during transition of control

With the Matlab data, video material and evaluation forms it has been found that all participants provide a steering input to the vehicle as an initial reaction after the Pilot Assist system has failed. Only five test subjects have given throttle in addition to the steering action and only one braked. Also, only one test subject still had his/her feet at the pedals at the moment of transition. However, the steering input was always the initial reaction and the braking/accelerating input was on average approximately 8 seconds later. This can be observed clearly in Figure 3, where a typical response of the test drivers, from the moment the Pilot Assist is deactivated, is shown. The test subjects indicated that the position of the vehicle on the road had their highest priority and the vehicle velocity was of a lower urgency.

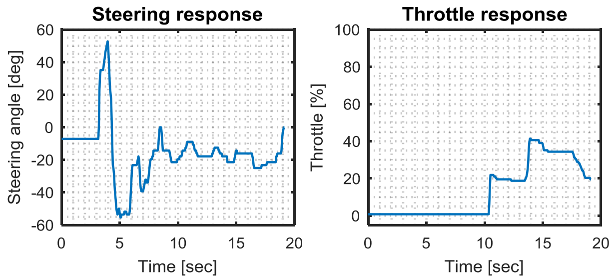

Figure 3: Typical driver response.

Furthermore, the results of the evaluation forms indicated that drivers are not scared when the Pilot Assist fails, even though they sometimes get far on the other side of the road or end up on the roadside. However, many test drivers indicated that they might be more shocked if there would have been up-coming traffic (i.e. a more realistic traffic situation).

The results show very different responses of the drivers. Some drivers seem to notice the failing Pilot Assist system relatively quick and immediately try to control the vehicle's position on the road. Other drivers are looking for confirmation or try to activate the system again and take quite some time to retake control. The results of this different way of behaviour can, for example, be seen in Figure 4, which shows the vehicle's CoG position from the moment the Pilot Assist fails. Note that this is the corner to the right from the described scenario, i.e. the drivers are driving from right to left in the Figure. Test subject 5 swings across the road (the CoG is even getting off the road) while Test subject 2 stays between the lines. Test subject 8 on the other hand drives straight ahead which indicates that the subject is making a steering action much later than subject 2 and 5.

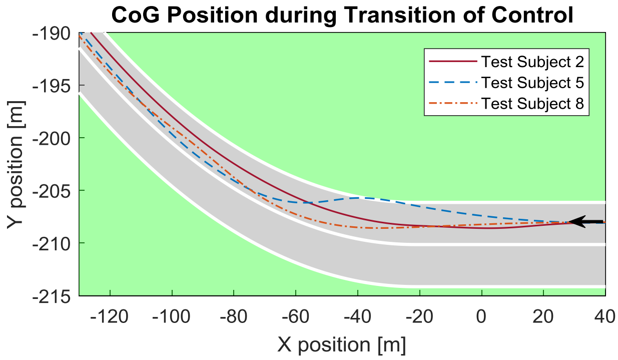

Figure 4: CoG position during transition of control (driven from right to left).

Level of Conditioning of a driver

The video material is analysed to see if the behaviour of a driver changes when driving longer with an active Pilot Assist, especially on boredom and fatigue. In order to give a graphical representation of this level of conditioning, all the video material is analysed and moments of interest are plotted over the timeline of the test. While analysing the video material, it became clear that most of the moments of interest could be divided into three categories. Itch, Body Movement and Bored. Itch is a moment of interest where the driver has an itch and starts scratching. It is chosen to take this as a moment of interest since it was of interest to see if more itches occur when driving with an active Pilot Assist system. Moments of interest under the label Body Movement are moments in time where the driver changes its body position. This can either be changes in position of hands on the steering wheel or changes in sitting position, etc. The bored category are moments in time where the driver shows signs of boredom. These signs can be:

- Looking to surroundings (not at road)
- Yawning / sighs / sleepiness
- Not actively steering along with the system
- Grabbing phone or doing other not driving related activities

A timeline of a test driver is shown in Figure 5. In the upper plot it can be seen at what moment in time, a moment of interest occurs. In the lower plot, all the moments of interest for this driver are summed per lap. It can be seen that there is a big difference between the first lap (driver is driving manually, zero moments of interest) and the following laps (Pilot Assist active).

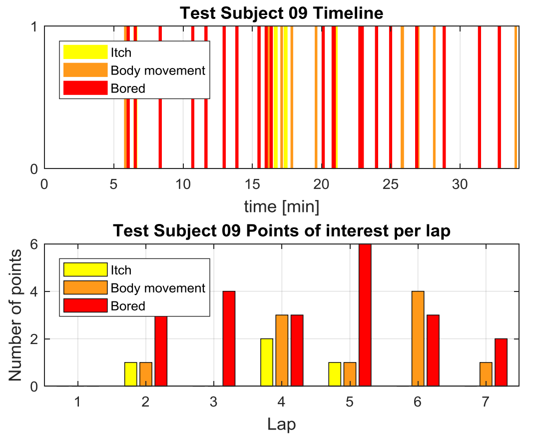

Figure 5: Typical timeline of moments of interests in terms of level of conditioning.

An average of the number of moments of interest of every test driver per phase of the test (driving manually, driving with Pilot Assist active and driving with Pilot Assist active after deactivation of the system) is taken and shown in Figure 6.

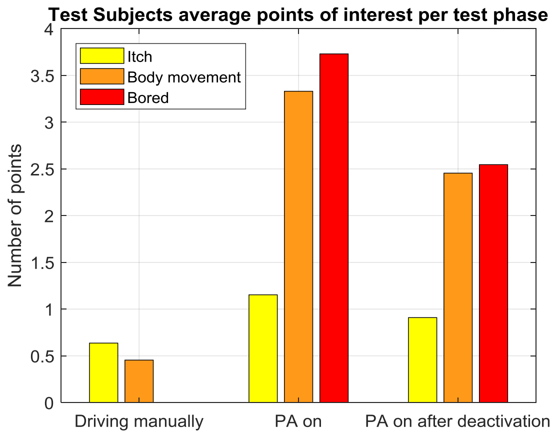

Figure 6: Average points of interest per test phase.

It can be seen that the number of points of interest is way higher when a person is driving with an active Pilot Assist. The results of the video processing also showed that the average first sign of boredom a test driver showed, when driving with the Pilot Assist, occurred after approximately 2 minutes. The longest it took a test subject to get bored when driving with the Pilot Assist was approximately 4,5 minutes.

Model Simulation Results

The influence of the driver’s reaction time and steering gain on the vehicle (in)stability during the transition of control is evaluated with the driver-vehicle model as a first parameter study. Since the simulator results show that a driver's initial reaction is steering, the driver model will only control the vehicle's position, i.e. the driver only steers and doesn't accelerate or brake.

In total, 455 simulations have been conducted, all with a different steering gain, ranging from 1.0 to 4.0 [rad/m] in steps of 0.25 [rad/m]. For every simulation (and gain), the reaction time is changed from 0.1 to 3.5 [s] in steps of 0.1 [s]. The transition of control is evaluated in terms of (vehicle) stability loss, i.e. when is a driver out of control. A driver has lost stability (i.e. is out of control) when the vehicle doesn't return to a steady state situation [22]. The circles in Figure 7 show the combination of the reaction times and gains were the driver is turning from a stable situation to an unstable situation during the transition of control. A line has been fitted through these circles and the shape of the curve corresponds to literature about stability of a driver model [22]. In addition, the area under the curve is the region were the model will be stable for any given combination of driver steering gain and reaction time. The red area is the region where the model will become unstable (above the curve) for a certain reaction time and steering gain. The combinations around the line can be stable but will be very oscillatory.

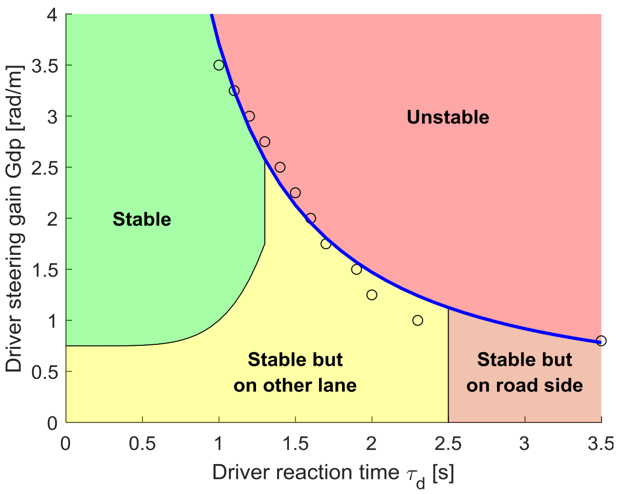

Figure 7: Stability plot for simulation model.

The area under the blue curve in Figure 7 is the stable region which means that the driver will return the vehicle to a steady state situation. However, this doesn't automatically mean that this will be a safe situation. For some combinations of reaction time and steering gain, a driver is able to get the vehicle back to a steady state situation. However, a driver will possibly drive on the other road lane since the driver reacts to late or steers not enough. This is indicated with the yellow area in Figure 7. In addition, the vehicle's left front wheel will touch the roadside on the left side of the road for a reaction time of 2.5 [s] (orange surface). An even longer reaction time will result in the vehicle completely getting of the road. So even if the model is stable, it is a very dangerous situation. The green area is the region where the driver can bring the vehicle back to a steady state situation without the vehicle leaving its own lane.\

Discussion

In this section, the above results will be discussed in terms of driver reactions during the transition of control, level of conditioning and stability loss, since this was the aim of this preliminary research.

It has been found that all participants provide a steering input to the vehicle as an initial reaction after the Pilot Assist has failed. Also, the test drivers indicated that the position of the vehicle had their highest priority, and other tasks, e.g. vehicle speed, were of a lower urgency. However, it is likely that the test subjects were not aware of the dropping vehicle speed, since they can only notice this from the dashboard. In reality, the vehicle will provide the driver with information (vibrations, motions, etc.) [22] which the simulator cannot do. It is therefore not certain if in general a driver will only control the position of his vehicle during the transition or whether the driver will also provide a second input such as braking or accelerating. This depends on the type of situation and the realism of the simulator.

None of the test subjects got scared although some of them were driving on the other lane or ended up on the roadside. This can probably be blamed on the driving simulator. Due to the lack of computing power it was not possible to simulate other (up-coming) traffic or realistic behaviour when the vehicle drives over the line or on the roadside. A more realistic traffic situation/simulator can probably result in a driver that reacts more scared which can have influence on the transition of control.

The simulator test results show that test drivers got bored (i.e. conditioned) while driving with (partially) automated driving systems. As showed in Figure 6, the moments of interest (boredom) occur much more when driving with an active Pilot Assist compared to driving without an active Pilot Assist. The Figure also shows that even after deactivation of the Pilot Assist, moments of boredom still occur which can imply that the test subjects were not that scared of a sudden fail/stop happening again. Furthermore, the results show that the average time it takes for a test driver to show the first symptoms of boredom is approximately 2 minutes. This could indicate that drivers easily get bored and are conditioned very quickly. However, the test subjects were asked to steer along with the system during the test. This could make the test drivers extra alert on driving due to this.

The test results show no trends indicating that the level of conditioning has influence on the reaction of the driver during the transition of control. This could be due to the specific simulated scenario and the limitations of the driving simulator. It is also possible that this is due to the extra alertness of the driver as described above. Another reason can be that there is no trend between the level of conditioning and the type of reaction of a driver, but this cannot be verified yet. It is therefore of interest to study this more in further research.

Finally, when looking at the model results it can be seen that a driver can be in an unsafe situation for a combination of steering gain and reaction time in the yellow surface of Figure 7. When taking the results of the simulator tests in consideration, which show that a driver gets bored relatively quick when driving with a Pilot Assist, it can be wondered if this combination is met relatively easy. Especially in terms of reaction time. It is however discussable if a driver will have a low steering gain during a transition of control which possibly can be an emergency situation. However, the reasonings above only apply to the specific simulation scenario of this model (corner to the right with a radius of 300 meters at 80 km/h). It can be of interest for further research to validate if the driver model is a good representation of a real driver in a similar situation. This is later discussed in the recommendations section.

Conclusions

The results have shown some interesting trends for the specific simulated and modelled situations of the transition of control. Test drivers initially focus on their position on the road and are not scared. Furthermore, drivers will get bored when driving (semi) autonomous, like with a Pilot Assist, which can affect their reaction time and the level of stability. However, correlations between the level of conditioning and the driver’s reaction are not found, i.e. will the reaction of the driver be affected if a driver drives longer with an active Pilot Assist. This could possibly be due to the specific simulated situation and the limitations of the driving simulator. The next section will therefore discuss some recommendation for further research that result from this preliminary research on the transition of control.

Looking back at the stated goal of this research which was to get initial insights in the transition of control from Pilot Assist to driver and give recommendations as a step towards further research, it can be concluded that the overall goal of the research is met. The initial insights of the transition became clear to the Dutch Police Academy and the Netherlands Forensic Institute and the recommendations that are written can be used as a base for further research.

Recommendations

The aim of this preliminary study was to be able to conclude how further research on the topic should be conducted. Therefore, recommendations should be written. The main findings of the discussion section together with their corresponding recommendations for further research are listed below.

As stated in the discussion section, none of the test subjects got scared during the transition of control. This could be due to the driver not being aware of the potential risk and danger of a failing Pilot Assist. A possible reason for this is the limited realism of the driving simulator. Due to limited resources, it was not possible to provide a more realistic driving simulator in this study. However, a driver that has a more realistic feeling of driving a vehicle could possibly react more scared when the Pilot Assist fails. For example, the sense of speed for a driver in the simulator could be improved. This can be done by providing a wider viewing area (three screens or surround view). Furthermore, car noise could be implemented, so that the driver can hear that the speed is decreasing due to less noise and lower engine RPM noise. More surrounding buildings and greenery so that the driver has more reference points to see how fast he or she is driving. It is also possible to add surrounding traffic. Force feedback in the steering wheel could also be added. For example, the steer should start shaking when the car drives off the road.

It was also concluded that no trend was found between the level of conditioning and the driver's reaction. The first reason can be referred back to the realism of the driving simulator. Since the steering wheel was not actuated, the driver had to steer along with the active Pilot Assist system. This may have resulted in extra awareness of the driver. An actuated steering wheel that actually rotates when the Pilot Assist is active can be a solution to this. In addition, different test scenarios can also be a possible solution. An example of a different test scenario could be a road with roundabouts in between. The driver is asked to activate the Pilot Assist on the road segment in between the roundabouts and to steer by himself on the roundabout. At a certain point in time the Pilot Assist system will be deactivated and the driver has to take over control. Possible research topics can be to see if a driver gets more conditioned the more often it has to activate the system. It can also be studied if a driver gets more bored the more often it has to activate the system. And with that possible boredom it can be studied if a driver reacts differently in correlation with how often they have to activate the system.

When looking at the model simulations it is stated that it is not possible to conclude if the driver model used in the model simulations is a good representation of a real driver in a similar situation. A possible solution can be to validate the driver model by comparing its response to the responses of the test drivers. To be able to compare these responses, the driving simulator could use the same vehicle model as used in the model simulations. Both driver reactions (from a real driver and from the model) can be compared more convenient this way since all other simulation conditions are the same.

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