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Take-Over Requests for automated driving

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Abstract

Automated driving is no longer a future scenario. Several automotive OEM have already presented automated vehicles, which do not require driver's constant attention on the road. But, there are still some challenges to solve before series vehicles can pass from assisted driving to highly automated driving [1; 2].A principal research question to deal with is how to design Take-Over-Requests (TOR) with respect to the human machine interface (HMI) and reaction times to comply with a TOR. On this account, a driving simulator study with 44 drivers has been conducted at the Fraunhofer Institute for Industrial Engineering. The study took place in a highly automated driving vehicle which controlled longitudinal and lateral control on a highway scenario. Approaching a construction site different TOR strategies were presented. Within this study the time users needed to react on a TOR was measured for a highway scenario. The drivers were fully distracted by a secondary task, a challenging quiz game on a mobile phone. The different TOR strategies comprised a variation of the location for TOR presentation (integrated mobile phone orin-vehicle HMI) as well as a variation of the TOR modality (TOR with brake jerk/without brake jerk). This paper will present and discuss the results in terms of reaction times and driver behavior strategies to comply with the TOR. It delivers advice on the design of transition strategies between automated and manual driving.

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*Keywords:*Highly automated driving; Take-Over Requests; TOR; Reaction time; Transition strategies

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1. Introduction

Due to the rapid technological progress automated driving will become reality on public roads within a few years. Today carmakers already presented prototypes ofhighly automated driving cars on international exhibitions. Although the vehicle will drive automated to a large extent, the OEMs still have to consider the possibility of limitations by certain situations the system will not be able to handle (e.g., exiting highway or changing weather conditions).

In today's cars the driver is responsible to be able to control his/her vehicle at all times, and as a result most cars demand to keep hands on wheel while driving [3]. With the planned amendment of Article 8 of the Vienna Convention of Road Traffic [4] the driver now has the possibility to shift focus from driving task to non-driving related tasks while driving automated. This regulation is valid under the condition, that the driver can override the automated system at any time. This action of overriding can be system initiated or driver initiated. In both cases the driver has to react by taking over the steering, accelerating and/or breaking from the system. Is the request system initiated, the take-over has to be performed within a time frame before reaching the system boundary. Thus, the system has to consider a safety buffer for the transition time after presenting the TOR in order to provide the driver with enough time for taking over the driving task.

Previous studies dealing with the research of take-overs measured the reaction time of drivers under a consistent TOR strategy involving visual and acoustic warnings. Petermann-Stock [1] showed that 8.8 seconds seem to be a sufficient transition time (from TOR presentation until system boundary is reached) in a traffic jam scenario, even for extremely distracted drivers. Damböck[2]stated 8 seconds to be a good timeframe for a comfortable transition in a highway scenario.

Fraunhofer IAO has a large experience in the design of driver assistance systems and driving simulator studies. On this account, we've wanted to reproduce the results from the literature with a new focus on the Human-Machine Interface (HMI) of automated cars. Within a driving simulator study at the laboratory of Fraunhofer IAO two principal research questions had to be answered:

- Is a safety buffer of 10 seconds enough for the driver to take-over the driving task comfortably?
- How does the design of the TOR strategies influence the take-over?

2. Method

Based on the literature findings a driving simulator study has been conducted where drivers had to perform a secondary task (non-driving related task) in an automated driving scenario. After presenting the Take-Over Request the system kept driving automated for 10 second until reaching system boundary (construction site with change in lane marking).

Four conditions of TOR strategies have been varied and tested:

- Integration of a mobile phone into the TOR strategy/ no integration,
- Additional break jerk/ no additional break jerk.

2.1. Subjects

A group of 44 drivers participated in the presented study. Four of the test drives had to be excluded from the study because of simulator sickness of the drivers (2x) and technical issues (2x). The remaining 40 subjects consisted of 23 male and 17 female drivers, aged between 19 and 53 years old (Mean=26 years; SD=5.0 years).

Fig. 1. (a) Immersive driving simulator; (b) Dashboard with instrument display and storage compartment.

2.2. Simulator

For the test environment the immersive driving simulator of Fraunhofer IAO (Fig. 1a) was used. The four main projection screens cover a field of view of 180° to the front with extra 75° to the left. Three more screens are added to provide images for the rear-view mirrors. The degree of reality is furthermore enhanced by surround sound and a motion system. This motion system allows for 15 cm lifting in each wheel and is suitable to represent a break jerk. The dashboard contains a reconfigurable, digital instrument cluster and a storage compartment in the center (Fig, 1b). Relevant driving parameters are logged by the simulation software SILAB and the driver's movements are recorded by cameras on the dashboard and additionally in the foot well.

2.3. Implemented automation

Referring to the BASt(BundesanstaltfürStraßenwesen) definition of highly automated driving [5], the integrated automation (introduced to the participants as "Highway-Chauffeur") provides longitudinal and lateral control of the car on a highway course. Once activated, the driver does not need to monitor the system, but must take over control in case of a Take-Over Request.

After a period of manual driving the "Highway-Chauffeur" was activated and the driver could feel the steering wheel stiffening and moving by its own. A characteristic sound comes with the activation as well as a visual indicator in the vehicle HMI (see Section 2.6).

2.4. Test scenario

While driving highly automated the subjects were asked to perform a quiz game on a mobile phone (Fig. 2a). After a few minutes the system initiated a TOR and handed over the control to the driver. Every Take-Over Request consisted of an acoustic gong and an on-screen warning in the vehicle cluster HMI. The TOR strategy has been varied by showing an on-screen warning on the mobile phone or/and an additional brake jerk. In total every subject went through 4 sections of automated driving followed by a take-over.

After TOR presentation the automated driving mode stayed active for 10 seconds until system boundary was reached (end of road with construction site lane marking that required a lane change).

Fig. 2. Subjects playing the quiz game while driving automated.

Fig. 3. (a) Sections of the course; (b) Beginning of the construction site.

The course was a European two-lane highway with a 100 km/h speed limit throughout. Starting on a driveway, the participants drove through four main sections in which the “Highway Chauffeur” was active (Fig. 3a). At the end of each section the same construction site was reached, where the driver had to take over the manual control again. After TOR presentation the longitudinal control was active until the driver operated the break or accelerator pedal, the lateral control was reduced to a level of 30% efficiency and afterwards powered down linearly. At the same time the speed limit in the simulation was set to 80 km/h first, then to 60 km/h (Fig. 3b).

2.5. Vehicle HMI

The central display in the instrument cluster serves as the common HMI for the communication between driver and vehicle. To determine which elements of visual information should be included, especially for automated driving, current research vehicles have been analyzed in a benchmark. The custom built-in HMI presented in this study is based on three recurring elements that were found throughout the benchmark, and which are also recommended by Flemisch [6]:

- *Automation Scale:*shows the active degree of automation (DOA) in a scale of possible degrees (manual driving, adaptive cruise control, “Highway-Chauffeur) (Fig. 4)
- *Automation Monitor:*basic representation of the host vehicle in the current situation (Fig. 5a)
- *Message Field:*used to indicate the TOR visually. Because of its importance, it fades over the other elements of the vehicle HMI and contains a message in text form as well as a custom designed icon (Fig.5b)

Fig. 4. (a) Automation scale: Manual driving; (b) Automation scale: “Highway-Chauffeur” active.

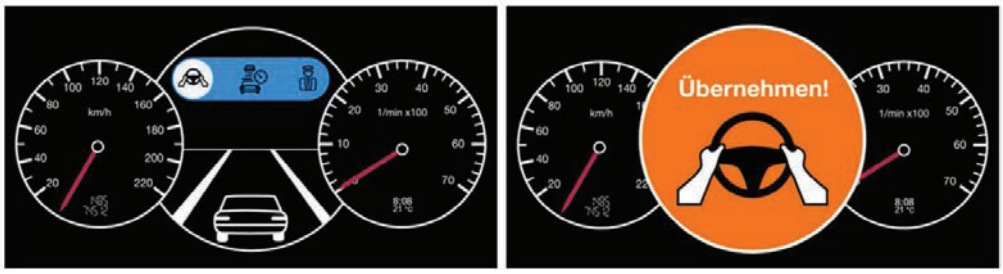

Fig. 5. (a) HMI with automation scale and automation monitor; (b) HMI with message field faded in.

Fig. 6. (a) Elements of basic TOR: On-Screen Warning + acoustic gong; (b) Extended TOR: Mobile phone integrated, brake jerk.

2.6. Variation of TOR strategies

By default every TOR included an on-screen warning in the vehicle HMI and an acoustic gong. The TOR has been enhanced by different components for the test conditions:

- *Integration of mobile phone:* For the condition with the integrated mobile phone the TOR message of the dashboard was also mirrored to the mobile phone. In this case the quiz function was faded out and the TOR screen was faded in.
- *Brake jerk:* With a delay of 1s after TOR a brake jerk was applied to the vehicle.

In the course every subject went through all possible conditions of TOR variation, which are:

A. Mobile phone integrated + no brake jerk;
B. Mobile phone integrated + brake jerk;
C. Mobile phone not integrated + no brake jerk;
D. Mobile phone not integrated + brake jerk.

3. Results

All 40 subjects were able to take over control of the vehicle within the 10 sec after the TOR presentation, no matter which variation of the TOR was used. Response times measured are in a range between 1.4 s and 6.7 s (Median=3.5 s). The boxplot in Figure 7 shows the distribution of these reaction times. Regardless of the required response time all users performed the lane change without any incidents.

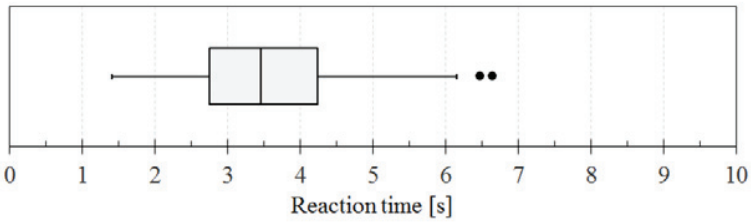

Fig. 7. (a) Distribution of reaction times.

In order to analyse the effect of the TOR conditions on the reaction times an ANOVA with repeated measures was carried out ($F_3 = 1.21$; $p = 0.31$; partial $\eta^2 = 0.03$). Used Means and standard deviations of the reaction times are shown in Figure 8 based on the variations of the TOR described in section 2.6. A significant effect of the TOR strategy on reaction times could not been identified.

Table 1. Mean reaction times for TOR conditions.

Scenario/TOR	A	B	C	D
Mean [s]	3,441	3,418	3,775	3,487
SD [s]	0,973	1,149	1,543	0,952

In addition to the quantitative data on reaction time, it was also interesting to look at the driver's behavior. Video analysis of the drivers showed, that most of the users reacted relaxed on the TOR presentation. Often, they took the time to finish the quiz question, placed the mobile phone on the passenger seat or in the dashboard storage and then took over the steering without any hectic movements.

While there was no effect of the break jerk on reaction time, the TOR strategy had an effect on the reaction mode. When there was an additional break jerk, most of the users reacted with acceleration instead of steering or breaking (e.g., 58% breaking, 30% steering in condition B compared to 33% breaking and 60% steering in condition A).

From the post questionnaires we've experienced, that most of the users (70%) perceived the take-over as comfortable and not overextending.

The transition time of 10 seconds was rated as appropriate by two-thirds (68%) of the test participants. Only one out of 40 participants would accept a shorter time than the stated 10 seconds. Furthermore, one third (30% of drivers) would recommend a longer transition time after experiencing the test scenarios.

The basic TOR HMI in the dashboard and the audible warning was perceived as a Take-Over request by 39 drivers out of 40. While the integration of the mobile phone into the transition strategy has been noticed by 83% of the drivers only half of the users noticed the additional break jerk. Furthermore, TOR presentation on the mobile phone increased the subjectively perceived safety for more than two-thirds (70%) of the users.

78% of the drivers rated the automated driving mode as a benefit in comfort. But, only half of the drivers would use such a system in a real car.

4. Conclusion

From the driving simulator study it could be shown that the results from the literature [1; 2] are reproducible. For predictable take-over scenarios a transition time of 10 seconds seems to be enough for all drivers to take over the driving task comfortably. Even a reduced safety buffer would be feasible, but would probably not be well accepted by the users, considering that a longer safety buffer was proposed by one third of the participants.

From the results it was obvious that if there is enough time for the user to react (fixed transition time) than it does not matter where and how exactly the TOR is presented (considering that a basic TOR strategy has to be present). If the user knows that there is enough time for taking over, then the take-over happens without any hectic

movementsorperceived stress. Hence, this study provides evidence for fixed take over times which always guaranty the same amount of time to a distracted driver to take over control again.

A basic HMI strategy, consisting of multimodal (visual and audible), perceivable stimuli is mandatory for Take - Over Requests regardless of the transition time. Further enhancements of the transition strategy (mobile phone integration/ additional break jerk) can lead to an increased acceptance and perceived safety, but seem to have no effect on the response time.

The results described in this paper apply to the specific highway scenario, the described non-driving related task and the highly distracted driver's state. For generalising the results, further research is required for different non-driving related tasks and driver states. Still a critical question is how to handle sleepiness and even sleeping as a realistic non-driving related task. Will a transition time of 10 seconds be enough for taking over when the driver is sleepy or actually sleeping? Should the system prevent the driver from falling asleep or adapt the safety buffer when detecting a sleepy driver? For the next steps Fraunhofer IAO is searching funding to conduct further research on driver monitoring in automated driving scenarios, as well as transition strategies for different driver states in order to infer recommendations for the handling of worst case scenarios (e.g. sleeping during automated drive).

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