What would drivers like to know during automated driving? Information needs at different levels of automation.

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Abstract— **Automated driving changes the role of the driver from an active operator towards a supervisor during partially automated driving and passenger in the highly automated driving mode. To foster successful interaction between humans and automated systems, feedback on automation stages and behaviors is considered a key factor. The present study used a two-step procedure to investigate drivers' information needs during partially and highly automated driving in comparison to manual driving for highway scenarios.**

The first step consisted in an expert focus group on expected information needs. Results showed that independent from specific scenarios, information should provide transparency, comprehensibility, and predictability of system actions. This includes the current system status, the remaining time to a change in the level of automation, the fallback level as well as reasons and a preview for ongoing and subsequent maneuvers.

In the second step, results from the expert focus group were used to set up a driving simulator study. A sample of 20 participants performed three highway trips on the same route either in the manual, partially automated (hands-on, permanent monitoring, no secondary task) as well as highly automated condition (cloze test on a laptop as secondary task). Questionnaires and interviews about information needs were applied after each trip and glance behavior was analyzed.

Information needs showed great variance between the drivers, which can mainly be explained by trust in automation. Partially automated driving was considered more exhausting than the other conditions due to the continuous supervision task. Information needs for the automated conditions were primarily related to the supervision of the system, whereas requested information during manual driving was centered on performing the current driving task. Glance data supported these patterns: during partially automated driving, drivers showed most and longer control glances at the mirrors and instrument cluster. Secondary task engagement during highly automated driving varied in dependence of trust in automation and the perceived complexity of the situation. However, less salient objects in a situation, such as traffic signs, were not perceived and no control glances were performed.

It can be concluded that information needs change for partially and highly automated driving. Requested information is primarily focused on the status, transparency and comprehensibility of system action in contrast to driving-task related information during manual driving. These changes need to be considered in the human-machine-interface (HMI) design for automated driving.

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I. Introduction

Prototypes of highly automated cars are already being tested on public roads in Europe, Japan and the United States [1, 2]. Automated driving promises several benefits such as improved safety, reduced congestions and emissions, higher comfort as well as economic competitiveness and enhanced mobility in the context of demographic changes [3]. These benefits are often claimed on the basis of a technology-centered perspective of vehicle automation, emphasizing technical advances. However, to exploit the potential of vehicle automation, human-machine-related issues are considered a key question [4, 5], shifting the perspective towards a human-centered view on automation. Research on human-automation interaction pointed out already "ironies of automation" [6] that can undermine the expected benefits. Relevant issues mainly relate to the role change in various levels of automation, i.e. mode awareness and transitions from manual to automated control [7, 8, 9], reduced vigilance due to the monotony of supervising tasks in partially automated driving [10, 11], changes in attention allocation and engagement in non-driving tasks [12, 13, 14], out-of-the-loop unfamiliarity resulting in reduced situation awareness [15, 16], mental models of automation [17, 18, 19], trust calibration [16, 20] as well as misuse and overreliance [21, 22]. For reducing negative automation effects and enabling successful human-automation interaction, feedback on automation states and behaviors is considered a key factor [16]. The feedback should make the automation transparent to the users in order to allow them for developing and maintaining a coherent mental representation of the system [18, 19].

The decision process about which information is suitable to make automation transparent should optimally involve HMI-experts as well as users [18]. Based on this, the present study explored the information needs at different levels of automation. In a two-step-procedure, an expert focus group discussion was carried out followed by a driving simulator study with unbiased participants. As the first use-case for automated driving will be the highway, the focus of both parts of the study was on highway driving scenarios (details in the next section). An important research aim was the assessment of differences in information needs between various levels of automation. Therefore, all scenarios were discussed and implemented in the driving simulator study for the conditions manual driving (MD), partially automated driving (PAD) and highly automated driving (HAD).

Definitions of these automation levels are in line with the classification of the BASt expert group [4] as well as the NHTSA classification [23]:

- During MD, the driver continuously accomplishes longitudinal and lateral control without any assistance. (BASt level “driver only”, NHTSA level 0).
- During PAD, the system takes over lateral and longitudinal control for a certain amount of time and/or in specific situations. However, the driver must permanently monitor the system and must be prepared to take over complete control at any time. (BASt level “Partially Automated”, NHTSA level 2).
- During HAD, the system takes over lateral and longitudinal control for a certain amount of time and/or in specific situations as in PAD. In contrast to PAD, the driver is no longer required to permanently monitor the system and eventual take-over requests occur with a certain time buffer. (BASt level “Highly Automated”, NHTSA level 3).

The main research aim for the expert focus group discussion was to collect the expected information needs at the three automation levels. These results were used to construct questionnaires for the driving simulator study. The driving simulator study aimed at assessing the importance of the expected information needs at each automation level from a users’ perspective. In addition to the users’ ratings of the experts’ considerations, interviews were carried out after each trip to collect eventually not foreseen aspects. In addition, glance behavior was analyzed as behavioral indicator for information needs during driving.

II. Research Design and Procedure

The present study used a two-step procedure to investigate information needs during partially and highly automated driving in comparison to manual driving for highway scenarios. The first step consisted in an expert focus group. In the second step, results from the expert focus group were used to set up a driving simulator study.

A. *Focus group discussion*

The focus group discussion involved six experts from Volkswagen AG. Experts’ area of expertise covered HMI-development from a technical and users’ perspective, infotainment as well as the development of electronic components. The discussion lasted about two hours, was recorded using audio and video equipment and fully transcribed afterwards. Two moderators from TU Chemnitz hosted the discussion using an interview-guideline developed in advance. The guideline covered seven specific scenarios during a highway trip (Fig. 1). All scenarios were discussed consecutively with regard to the expected information needs during manual, partially automated and highly automated driving. The transcript was analyzed by scenario and automation level using structured content analysis [24]. Aim and result of the analysis was a catalog of potential information needs for every scenario and automation level.

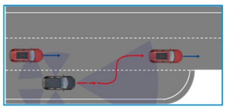
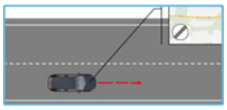
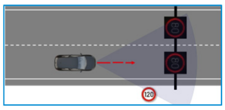
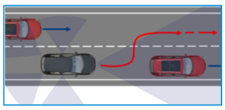
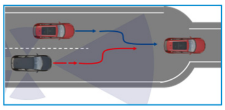
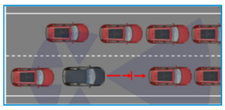
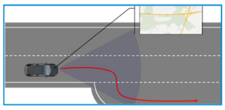
	1) Enter highway: driving on an acceleration lane and entrance on the highway
	2) Free driving: driving without speed limit
	3) Speed limit: driving on highway parts with speed limit signs
	4) Overtaking: overtaking slower vehicles, such as trucks
	5) Construction zone: reduction from two lanes to one lane due to a construction zone
	6) Congestion: heavy traffic and speed reduction to walking speed
	7) Exit highway: leaving the highway using an exit ramp

Figure 1. Highway scenarios

B. *Driving simulator study*

Facilities and simulated route: The driving simulator study was carried out in a fixed-based driving simulator at the Professorship of Industrial Engineering and Innovation Management at TU Chemnitz. The simulation software SILAB 4.0 provided a 180° horizontal field of view (Fig. 2). For assessing glance behavior, mobile Dikablis eye tracking glasses were used with D-Lab 3.01 as analysis software. The simulated route consisted of a 14.2 km long two-lane highway track including all the seven consecutive scenarios mentioned in the previous chapter.

Figure 2. Driving simulator (SILAB 4.0)

Participants: The sample included 20 drivers (9 men, 11 women / 11 students, 9 workers) without any experience of automated driving. Mean age was 30 years (*SD* = 7.1), ranging from 25 to 47 years. All participants had possessed a driving license for on average 12.5 years (*SD* = 7.4) and stated that they had driven an average of approximately 7710 km (*SD* = 8101.5) in the past 12 months.

Procedure: After arriving, participants were informed about the experiment's procedure. Prior to data collection, a written informed consent was obtained. All participants started with a 5 min test drive to get familiar with the driving simulator. Afterwards, all drivers completed three consecutive trips on the same highway track with interviews and questionnaires in between each trip. The first trip (MD) was driven manually by the participants without any assistance. During the second trip (PAD), participants sat on the driver's seat and were driven automatically through the whole route. Activities on pedals and steering wheel had no effect. Participants were instructed to keep their hands on the steering wheel all the time and actively monitor the system. During the third trip (HAD), drivers got the same automated trip as in the second condition. In contrast to PAD, participants were instructed to complete a cloze test presented as Word-file on a laptop, whenever they felt comfortable. The laptop was placed on the right next to the driver's seat at the position of the gear lever. All participants experienced the same pre-recorded trip in the PAD and HAD condition. The automated trips did not include any system errors and no dedicated HMI was implemented. After each trip, short standardized video clips of every scenario were shown to the participants along with the open question on which information was important. Answers were recorded using a voice recorder and were fully transcribed afterwards. In addition, the potential information needs mentioned by the experts in the focus group discussion were transformed into a standardized questionnaire. Participants rated the importance of every type of information after each trip for all the seven scenarios using a percent scale.

III. Results

A. Focus group discussion

Concerning expected information needs, the experts considered some general aspects as important for all automation stages, independent from specific scenarios. Information should provide transparency, comprehensibility, and predictability of system actions. This includes displaying the current system status along with the fallback level and the remaining time until a change in the level of automation is expected or required. In addition, reasons for ongoing and subsequent maneuvers should be provided as well as a preview of the next planned maneuver. The forecast and an early announcement were considered especially important for maneuvers involving lateral dynamics due to the expected higher sensibility of the driver. The experts assumed that drivers will adapt their information needs in dependence of the experience with the system. More detailed information needs are expected during the initial interaction with the automated system, decreasing continuously with greater experience and trust in the system. To tackle this issue, adaptive and configurable information displays were considered a solution, e.g. by selectable information profiles.

In addition, scenario-specific information was mentioned by the experts. For lane change maneuvers (enter/exit highway, overtaking), information about the surrounding traffic was considered important. This includes speed and distance of other vehicles as well as gap detection for lane change maneuvers. For free driving as well as driving on roads with speed limits, the current target speed should be displayed with an explanation (e.g. legal speed limit, weather conditions, narrow bend ahead… etc.). Information on route options, delays and reasons for the situation were considered useful for congestion scenarios.

B. Driving simulator study

Questionnaire and interview data: A mixed methods design was applied [25], combining quantitative data from questionnaires and qualitative data from interviews. Some general trends could be observed over all scenarios: 1) Almost all potential types of information expected by the experts were rated as important by the user (i.e. mean values of 50% or more). 2) However, information needs during automated driving greatly differed between the participants. Analysis of interview data clearly suggests that this variance can mainly be explained by trust in automation. The more trust, the less information is demanded. 3) HAD was experienced as more pleasant than PAD. Interview data showed that the supervision task during PAD was often considered as "boring", "annoying" and also "more exhausting" compared to MD and HAD. Greater demands during PAD were mainly attributed to the necessity of continuous supervision without the opportunity to perform other activities. Consequently, some participants suggested a periodic reminder to "remain attentive" during PAD. 4) In the PAD condition, information needs were consistently rated higher for almost all information types than in HAD condition. In particular, users demanded more information that allowed for monitoring the automation. 5) Information needs differed systematically between the manual and both of the automated conditions: During manual driving, information for performing the specific driving task was rated more important (e.g. speed and distance of surrounding vehicles during entering or overtaking). In the automated conditions, information for monitoring the system became more important (e.g. system status, planned maneuver) than information related to the driving task itself.

Fig 3 shows exemplarily questionnaire results on the relevance of information in the first scenario "enter highway". These findings demonstrate the general trends mentioned before. The first graph shows information asked for all the three conditions MD, PAD and HAD, whereas the second section presents information types which were only relevant for the two automated conditions. All mean ratings were above 50%. The profiles for PAD (light blue) showed a similar shape compared to HAD (dark blue), however, with an overall offset towards higher information needs. For MD (orange), situation-specific information for performing the entering maneuver was rated more important than in the automated conditions (speed, distance and presence of surrounding vehicles). The most important information for the automated conditions was the system status, current as well as planned maneuvers and detected surrounding vehicles.

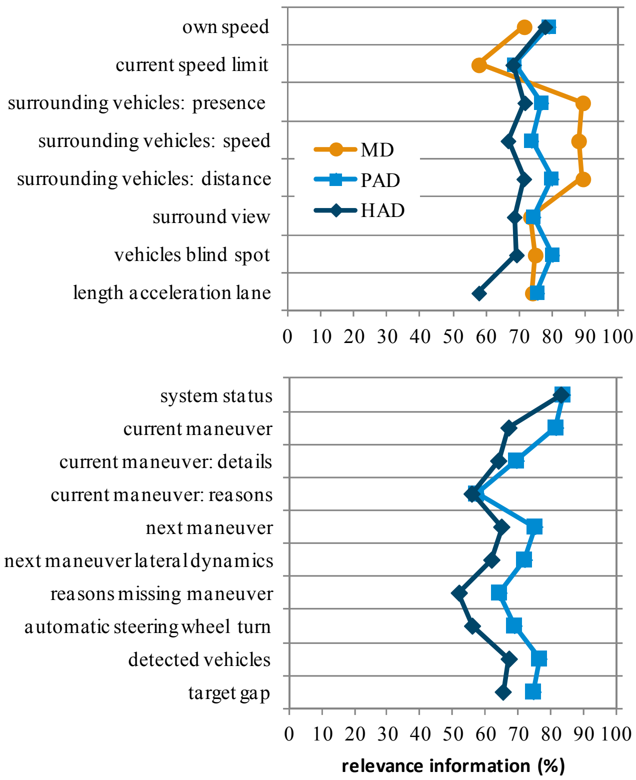


Figure 3. Relevance of information, scenario "enter highway"

Interview data showed that users expect less information needs over time of system use due to higher trust and familiarity with the automation. Therefore, an option to configure the amount of information displayed would be preferred. However, some information should never be removed, which represents a hierarchy of essential information during automated driving from a user's perspective:

1) Status of the system (i.e. active/inactive, remaining time until take-over-request)
2) Degree of certainty that the automation is able to handle the current situation
3) Trip-related information: distance already driven and remaining distance/time
4) Current and planned maneuvers
5) Current speed and current speed limits
6) Oncoming special/critical situations, e.g. construction zone, congestion

Glance behavior: To assess differences in glance behavior between the MD, PAD and HAD condition, the percentage of time spent with control glances was analyzed for the whole trip as well as in detail for every scenario. Control glances include all fixations on the left, right and rearview mirror as well as the instrument cluster. Fig 4 shows the percentage of time spent with control glances for the three automation conditions over the whole trip. Glance time differs significantly between the conditions ($\chi^2(2) = 14.588$, $p = 0.001$). During PAD, most control glances were performed (*Mdn* = 3.4% of driving time) compared to a middle level during MD (*Mdn* = 2.6%) and the lowest level during HAD (*Mdn* = 0.8%). Differences between the three conditions appeared as well in the specific glance patterns, i.e. mean duration of single glances, $F(2, 32) = 8.283$, $p = .001$, $\eta_p^2 = 0.341$. The mean glance time per fixation on an area of interest was significantly longer during PAD ($M = 0.56$s, $SD = 0.18$) compared to MD ($M = 0.39$s, $SD = 0.08$) and HAD ($M = 0.33$s, $SD = 0.25$).

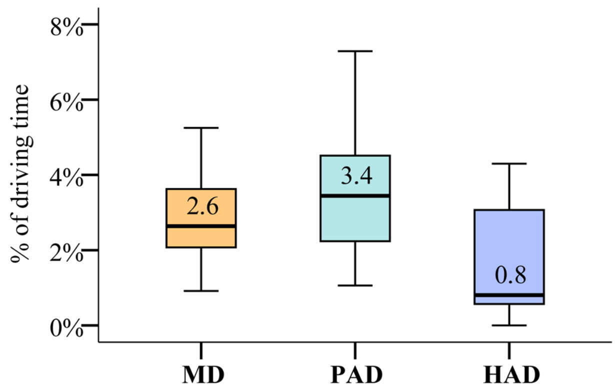


Figure 4. Percent control glance time, whole trip

In addition, the percentage of glance time to the secondary task has been assessed (Fig 5). Results showed that on average drivers spent 73.5% of the HAD time looking at the secondary task (and therefore not at the road respectively the mirrors / instrument cluster). However, the percentages varied markedly between the participants, resulting in a broad range from 5% to 99%. Interview data showed a clear link between the reported trust in automation and the engagement in the secondary task during HAD.

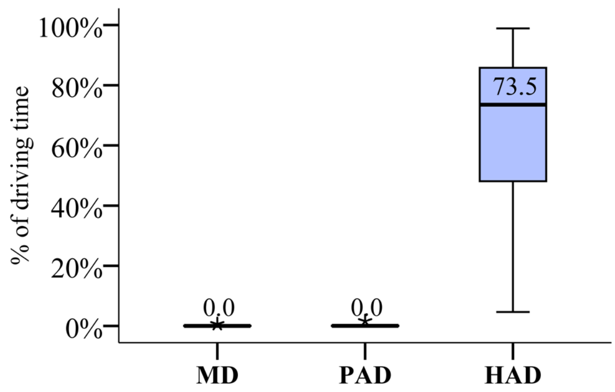


Figure 5. Percent glance time to secondary task

In general, driver adapted their secondary task engagement during HAD according to the perceived complexity of the situation. Most secondary task activity occurred during free driving (*Mdn* = 81.6%) and the subsequent (mostly not perceived) speed limit section (*Mdn* = 86.3%). Lower values were observed for more complex situations such as highway enter (*Mdn* = 40.9%) and exit (*Mdn* = 58.5%), overtaking (*Mdn* = 63.3%), the construction zone (*Mdn* = 67.7%) and congestion (*Mdn* = 68.9%).

Looking in detail at the seven scenarios, the reported overall glance pattern (PAD > MD > HAD) could be observed for all situations, except for the scenario "speed limit". While passing the 100 km/h-sign, most control glances appeared in the MD condition (*Mdn* = 5.8%) followed by PAD (*Mdn* = 4.2%) and HAD (*Mdn* = 0.0%), see Fig 6. The almost absent control glances in the HAD condition resulted from a high secondary task engagement during this situation (*Mdn* = 86.3%). Consequently, the speed limit sign has not been perceived by the drivers and no control glances were performed.

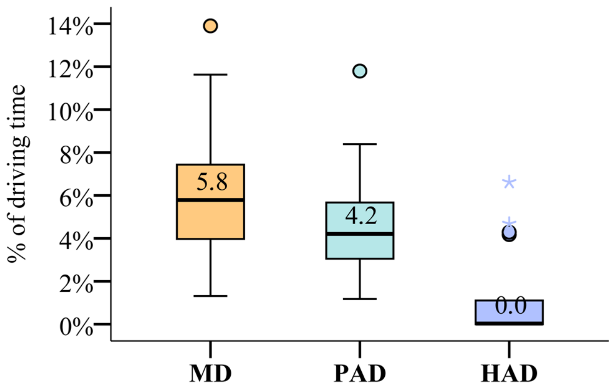


Figure 6. Percent control glance time, scenario "speed limit"

IV. Discussion and Conclusions

The focus of this research was to investigate the information needs during partially and highly automated driving in comparison to manual driving for highway scenarios. Feedback on automation states and behavior is considered a key factor for allowing drivers to develop and maintain a coherent mental representation of the automated system [17, 18, 19], thus enabling successful human-automation interaction [16]. Following a two-step procedure, HMI-experts were involved in a focus group discussion, providing the basis for a driving simulator study.

Results showed that feedback fostering transparency, comprehensibility, and predictability of system actions is considered most important by the HMI-experts. This includes in particular the current system status, fallback level, remaining time to a change in the level of automation, reasons for ongoing and subsequent maneuvers as well as a preview of planned maneuvers. Results from the driving simulator study support these expectations. The user rated almost all information types mentioned by the experts as important. However, the amount of requested feedback during automated driving differed markedly between the participants. Interview data shows a strong influence of trust in automation: the more trust, the less information is demanded. This result is supported additionally by the glance behavior during highly automated driving. In general, the more trust in automation, the more engagement in secondary task activities, resulting in fewer control glances for monitoring the automation. These findings are consistent with the well known importance of trust for the human-automation interaction (overview in [16]). However, analyses at detailed maneuver level showed that drivers adapted their secondary task engagement in accordance to the perceived complexity of the driving situation. During more complex scenarios such as highway enter/exit, overtaking, construction zones and congestion, more control glances and less secondary task activity was observed in the HAD condition. These results are in line with previous findings on attention allocation during high levels of vehicle automation [13], showing that drivers "… are receptive to the changing demands imposed by heavy traffic, focusing more visual attention to the roadway in such conditions." (p. 124). However, less salient objects such as traffic signs can be missed, as the results for the scenario "speed limit" showed. On the other hand, drivers are not required to monitor the system in the HAD condition.

Both experts as well as users expected less information needs over time of system use due to higher trust and familiarity with the automation. Therefore, adaptive and configurable information displays were considered a solution, e.g. by selectable information profiles. However, despite adaptive displays and individual variance in information needs, some essential information was always requested by the users during automated driving: 1) status of the system, 2) degree of certainty that the automation is able to handle the current situation, 3) trip-related information such as distance/time driven, 4) current and planned maneuvers, 5) current speed and speed limits, and 6) oncoming critical situations such as construction zones. The hierarchy of user's essential information demands reflects another central finding of the study. Information needs for the automated conditions were primarily related to the supervision of the system, whereas requested information for manual driving was centered on performing the current driving task (e.g. speed and distance of surrounding vehicles during entering or overtaking). Especially in the PAD condition with the permanent supervisory role, the highest amount of information about system actions was requested. Glance data supported these patterns: Whilst during MD short control glances were performed to handle the current driving task, driver showed more and longer control glances at the mirrors and instrument cluster during PAD to supervise the system. However, the continuous supervision task in the PAD condition was considered "boring", "annoying" and also "more exhausting" compared to MD and HAD. Therefore it is unlikely that drivers will perform constant system monitoring over longer time during PAD. These results go along with previous findings concerning changes in attention allocation and engagement in non-driving tasks [13, 14] as well as reduced vigilance due to the monotony of supervising tasks [10, 11].

It can be concluded that the priorities of requested information change for various levels of automated driving in comparison to manual driving. Information for monitoring and supervising the automation becomes more important than information related to the driving task itself. Information should provide transparency, comprehensibility and predictability of current and future system actions. As both experts and users expect less information needs over time of use, configurable information displays are recommended, e.g. by selectable information profiles. Another aspect mentioned by the users is information about the degree of certainty that the automation is able to handle the current and future situations. This issue could be addressed by "likelihood displays" [16] and there is evidence that the presentation of automation uncertainty improves driver-automation cooperation [26]. A limitation of the current study is the usage of a static driving simulator, where physical motion cannot be experienced. Future research should therefore validate the results using real automated vehicles in test drive settings.

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