Evaluation of simulated Level 2 hands-free driving in real traffic – an innovative method for an early SOTIF Human Factors assessment of ADAS under realistic driving conditions

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Objective: Recent activities in the development of assisted and automated driving involve vivid discussions about the necessity to evaluate the interaction between the driver and the system, especially while using high performant SAE Level 2 functions (see SAE, 2016). The assessment of safety in use of these systems is fundamental and includes several methods that can be applied to evaluate the controllability of the systems, e.g., simulation, driving simulator studies, and realistic driving studies on test tracks or in real traffic. In early development stages, it is barely possible to assess the functions in real traffic. However, some research questions need to be addressed early and can be answered the most appropriate by studies in real traffic. Therefore, a method to simulate new SAE Level 2 and even Level 3 systems in test vehicles has been developed.

Method: A new method to assess driver behavior and controllability of system limits in real traffic is presented: By using assisted driving functions of series vehicles, higher assisted functions can be simulated in the user interface and additional functional features can be implemented, such as automated lane changes that can be triggered by a trained safety driver sitting on the passenger seat. Thereby, it is possible to assess fundamental Human Factors aspects, such as mode confusion, overreliance or overtrust, under highly realistic study conditions or even assess controllability of lateral steering errors in real traffic. A realistic driving study to assess controllability of such system limits while driving SAE Level 2 hands-free is presented.

Results: Simulating new SAE Level 2 functions by using special test vehicles and trained safety drivers enables researchers to evaluate the driver's interaction with these functions under controlled and very realistic conditions. The results of such studies can help to identify risks and, thereby, define appropriate measures to address and minimize them. Moreover, hypotheses about driver behavior can be tested and validated to support a safety-oriented development process. The results of the presented study on controllability of sudden steering errors show that attentive drivers are able to control system-detected as well as system-undetected lane drifts while driving SAE Level 2 hands-free. Differences in reaction times were significantly correlated with if the steering error occurred and an urgent warning was triggered or if the lane drift was undetected by the system and no warning was issued.

Conclusion: Evaluating driver behavior in real traffic while using SAE Level 2 systems is necessary to assess safety in use of these functions before introducing them into the market. Simulating new systems in series vehicles helps getting important insights into driver behavior while using such functions. System limits to be expected can be presented and controllability of the resulting situations can be assessed as well as driver reactions in terms of reaction times and quality of intervention.

Keywords: SAE Level 2 Hands-Free Driving, Safety in Use, Human Factors

INTRODUCTION

In recent years, SAE Level 2 driving functions, which equals Partially Automated Driving (PAD), is getting more and more attention in media and an increasing number of highly performant Advanced Driver Assistance Systems (ADAS) are flooding the market. While some OEMs already took it to the next level and have introduced Level 3 (Highly Automated Driving, HAD), still, there are major challenges which must be faced in the field of PAD. Technology is improving progressively and rapidly which makes it possible to provide drivers PAD in more and more complex situations and include features, such as hands-free driving. Yet, the driver is still accountable for the safe guidance of the vehicle and must stay attentive at any time as well as be prepared to intervene immediately, when the system suddenly fails, or system limits occur. Several studies have shown that automation can have a negative impact on the driver's behavior, such as loss of skill (Stanton & Marsden, 1996), loss of situational awareness (Endsley, 1999; Clark et al., 2017) or overreliance on the automation (Parasuraman & Riley, 1997), as the driver's role is shifted from an actively performing to a passive monitoring task (Parasuraman & Riley, 1997; Parasuraman et al., 1993). Studies on the controllability of system limits of PAD apart from studies in driving simulators but in real traffic are scarce. When PAD is active, the system supports the driver with active steering, hence, steering errors or system limits can occur that require steering input by the driver, i.e., because the car is following the wrong trajectory or is leaving the lane due to missing lane markings. There are few studies that investigated the driver's reaction to these situations while driving SAE Level 2 and none that have been carried out in real traffic. A most recent study by Schneider et al. (2022) assessed controllability of lateral drift failures while driving SAE Level 2 hands-free on the test track. Naujoks et al. (2014) investigated the driver's reaction to a sudden take over request while driving a Level 2 hands-free system in the driving simulator. Different lateral guidance system limits that were caused by either ending lane markings, poor lane markings in construction sites or due to high curvature occurred. Several driving simulator studies examined the driver's reaction behavior to sudden obstacles in the road such as broken-down vehicles or lost cargo (Gold et al., 2013; Strand et al., 2014; Naujoks et al., 2015). Other authors carried out studies to investigate the driver's reaction time to system limits compared to system malfunctions (i.e., vehicle following the wrong trajectory vs. vehicle leaving lane) (DeGuzman et al., 2020; Sieber et al., 2015), also in a driving simulator environment.

METHOD

Methods for the assessment of safety in use of ADAS

The necessity of developing new and innovative methods to assess rapidity and quality of the driver's intervention, when system limits occur, is manifest. Reaction times to such events and take over quality need to be assessed to identify measures that are necessary to increase controllability and establish functional limits, e.g., in terms of lateral and longitudinal dynamic parameters. These are crucial to increase the driver's time budget when system limits occur while the driver is using PAD to prevent accidents and fatalities. Adequacy of different methods to assess controllability of system limits depends on several factors. Crucial are the maturity of the respective system, the claim on the validity of the results which highly depends on the stage of development, the research question to be answered and the current state of knowledge in the respective field of research. Derived from these key aspects Figure 1 shows the variety of assessment methods. In early stages, literature reviews, online surveys and expert evaluations are used to support the early development process and address upcoming research questions. Most of the studies cited above are driving simulator studies which is a highly powerful tool to examine quality of human behavior in interaction with ADAS, PAD and HAD in a controlled environment. Certain isolated research questions are predestined to be conducted on the test track, e.g., parking maneuvers or highly dynamic maneuvers which for safety reasons cannot be tested in real traffic. Other research questions require a more realistic test environment, which includes driving in real traffic on the road. Realistic driving studies, especially in real traffic, necessitate a high functional maturity of the considered system as well as an elaborated safety concept. By means of personal, technical, and organizational measures, realistic driving studies can be designed in a safe way and risks can be minimized to an acceptable low level. The L3EC method (marked in bold letters in Figure 1) can be applied in an early development stage under realistic test conditions which increases validity of the results and minimizes limitations due to an artificial laboratory test environment or simulated situations instead of real situations on the road.

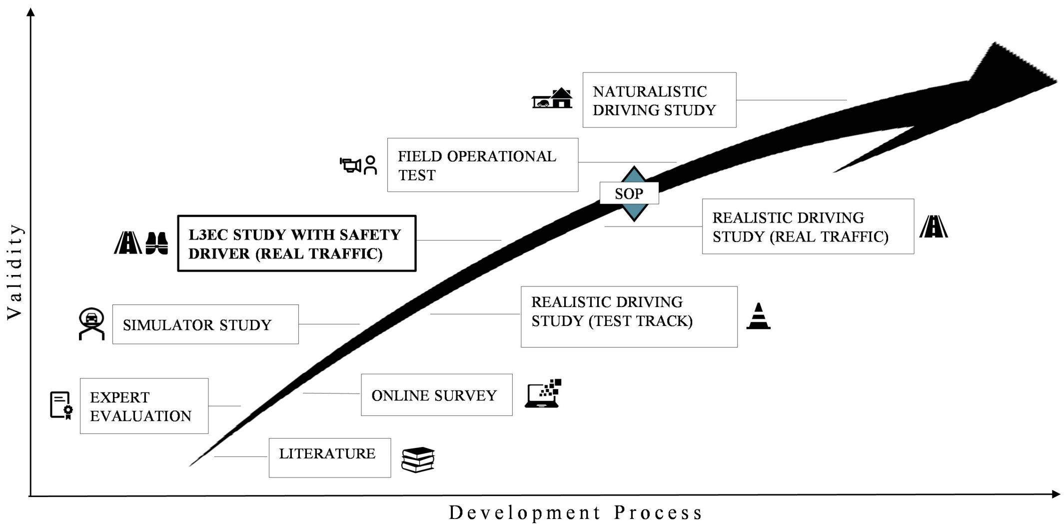

Figure 1. Methods for the assessment of safety in use of ADAS.

In the following section a study in the L3EC which has been carried out in real traffic with the main goal to assess controllability of system-detected and system-undetected steering errors, is presented.

Study set up and study design

By using the L3EC method, assisted driving functions of series vehicles, which are equipped with driving school pedals and additional mirrors and displays, higher assisted functions can be simulated in their behavior and interaction in regard to the user interface. Moreover, additional functional features can be implemented, such as automated lane changes that can be triggered by a trained safety driver sitting on the passenger seat. Therefore, additional switches are installed on the right side of the passenger seat so that the safety driver can give clearance of the function, issue warnings or even trigger error injections to simulate sudden steering errors. Additional cameras are installed to record traffic surrounding to all four sides of the vehicle (front view, rear view, right side, left side) as well as two more cameras facing the driver and one GoPro camera which is recording the driver’s hands.

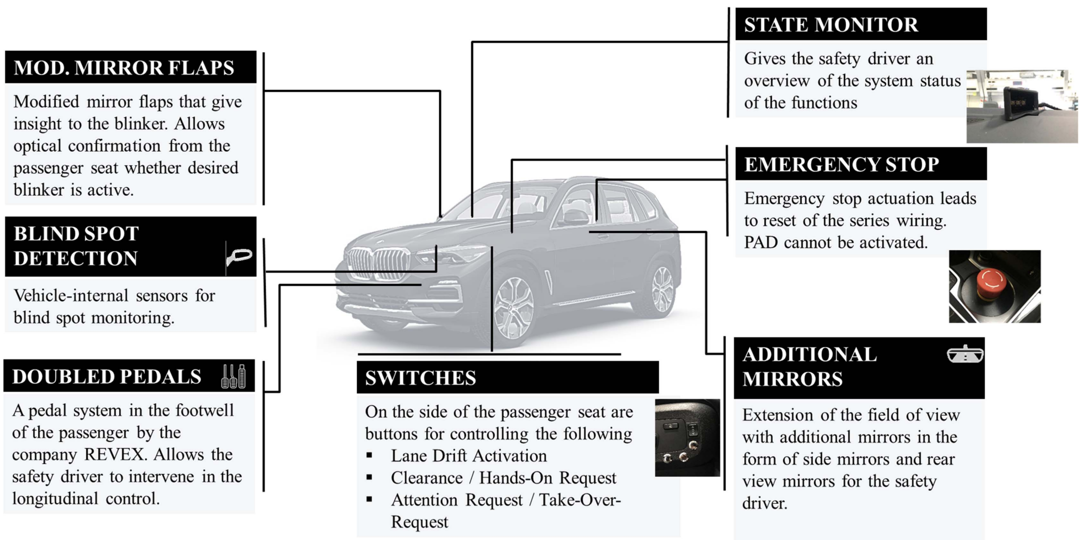

Figure 2. The Level 3 Experience Car.

The L3EC has been initially set up to facilitate a HAD (SAE Level 3) experience in real traffic under safe conditions and with real customers. With the introduction of Level 2 hands-free functions, a new experience of PAD is brought to the customer, allowing the driver to completely take his hands off the steering wheel. However, sudden steering errors can still occur, forcing the driver to put his hands back on the steering wheel and intervene immediately to take back control over the vehicle. By using the L3EC, a realistic driving study was carried out, in which the safety driver was able to trigger a sudden steering error that would result in the vehicle leaving lane, if the driver did not take over and steer back into the ego lane. Thereby, conditions under which the system limit would occur could be controlled completely by the trained safety driver who was also able to intervene by steering or using the pedals in case of emergency or if necessary. The safety drivers were specifically trained by BMW driving instructors to be able to control highly dynamic driving maneuvers from the passenger seat by using the pedals or grabbing the steering wheel from the passenger's side. The test drives have been executed in Phoenix, Arizona, with 8 Power Users of PAD and 12 drivers without any experience with PAD (= Non-Power Users). Drivers were declared as Power Users, if they were using PAD several times per month, and Non-Power Users were drivers with no experience with PAD at all. The participants have been recruited by a market investigation agency and the study has been conducted by an independent research institute. Every test drive consisted of one manual driving section, three PAD sections and two sudden system limits which were triggered by the safety in the first and the third PAD section. In between the different sections, the drivers had to drive off the highway to make a U-Turn and then drive back on the same highway. Figure 2 shows the study procedure which was split equally in the respective sections (~10 min. each section). The manual baseline was permuted, so that half of the drivers drove manually before, and half of the drivers drove manually after the PAD section to control possible sequence effects.

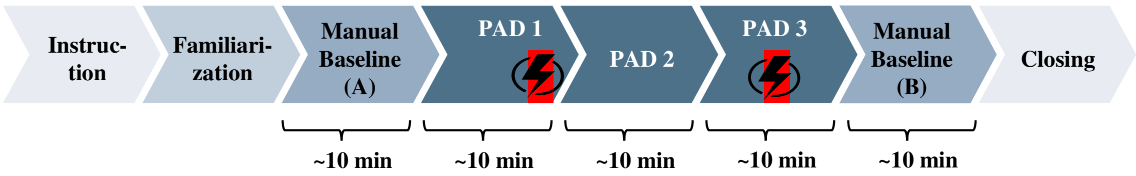

Figure 3. Study design and test procedure.

Drivers were told to obey traffic rules and activate and use the hands-free feature whenever it is available. Moreover, recommended speed was ~ 65 – 70 mph, if there was no other speed limit, and to keep up with the flow of traffic. Depending on time of day, traffic density and actual speed, the duration of each driving section varied between 7 and 10 minutes. The lane drifts were triggered at predefined spots to ensure reproducibility of the system limits for each participant. The first lane drift was combined with a take over request, whereas the second lane drift was undetected by the system and, therefore, was not issued with any warning. To minimize any risks for driver, passengers or other traffic participants, the safety driver made sure that there were no surrounding vehicles or lost cargo and debris on the shoulder, as the vehicle would always drift towards the shoulder on the right side of the road. PAD hands- was simulated by using the PAD hands-on lane keep assist function in the series vehicle. The capacitive hands-on detection was deactivated as soon as the simulated PAD hands-free was activated by the driver by pressing a button on the steering wheel. Driving PAD hands-on was still possible and clearance of the hands-free system was controlled and provided by the safety driver. By pressing a button on the right side of the passenger seat, the safety driver could give and take away availability of the hands-free function. The HMI was freely programmable and availability of the function as well as all other functional statuses were presented to the driver in the instrument cluster as well as by LED lights on a small display on the side of the safety driver. A warning cascade was integrated that would be triggered when the driver has been inattentive for a few seconds, and which escalated with urgent take-over requests when the driver did not react to the initial warning due to being inattentive. The warning cascade is shown in Figure 4.

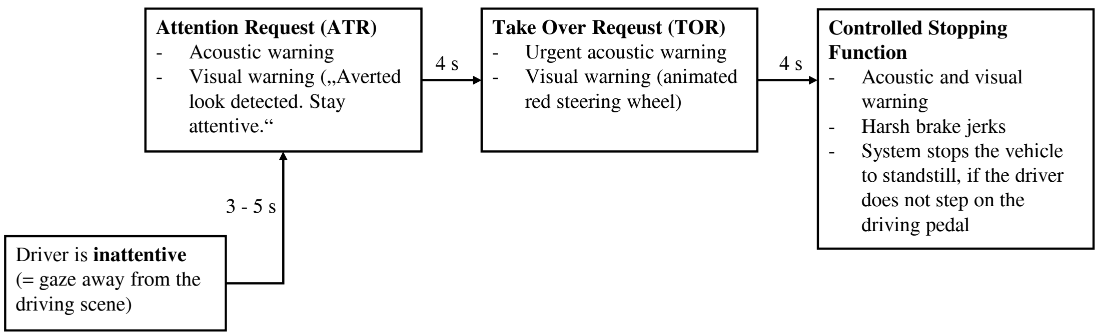

Figure 4. ATR warning cascade.

Reaction times, take over quality and necessity of safety driver intervention were evaluated to assess controllability of sudden steering errors while driving PAD hands-free. Differences in reaction time to lane drifts with an urgent take over request and lane drifts without a warning (= undetected system boundary) were evaluated. Lane drifts were only triggered when the driver was attentive and was not currently issued by an ATR or when other safety functions were currently active (= acute intervention of a safety system, e.g., emergency braking). Thereby, the impact of error variance on the test results, e.g., due to heterogeneous driver states while the system boundary occurred, was minimized and the results only represent controllability of these steering errors without consideration of other Human Factors aspects. Aberrant driver states, such as extreme fatigue, inattentiveness, or driver distraction, i.e., caused by driver engagement in secondary tasks, were not considered or tolerated during the test drive. Moreover, post interviews after the test drive were evaluated to get a deeper insight into how drivers perceived the system limits and get more information about the driver's mental model, e.g., concerning responsibility or necessity to permanently stay attentive and monitor the driving scene.

RESULTS

Reaction times

Reaction times were defined as time between the start of the lateral movement during the lane drift and (1) hands-on and (2) the first steering input by the driver. Data were evaluated by video analysis and time frames were clicked in 17 ms steps. In the following, results of the study are presented. Videos of two drivers were missing. Therefore, N was reduced to $n = 18$. Figure 5 shows reactions times to both lane drifts, with and without warning, as well as duration until hands-on solely and duration until first steering input of the driver. Difference between these values were minor, which means that drivers started steering immediately as soon as they put their hands back on the steering wheel.

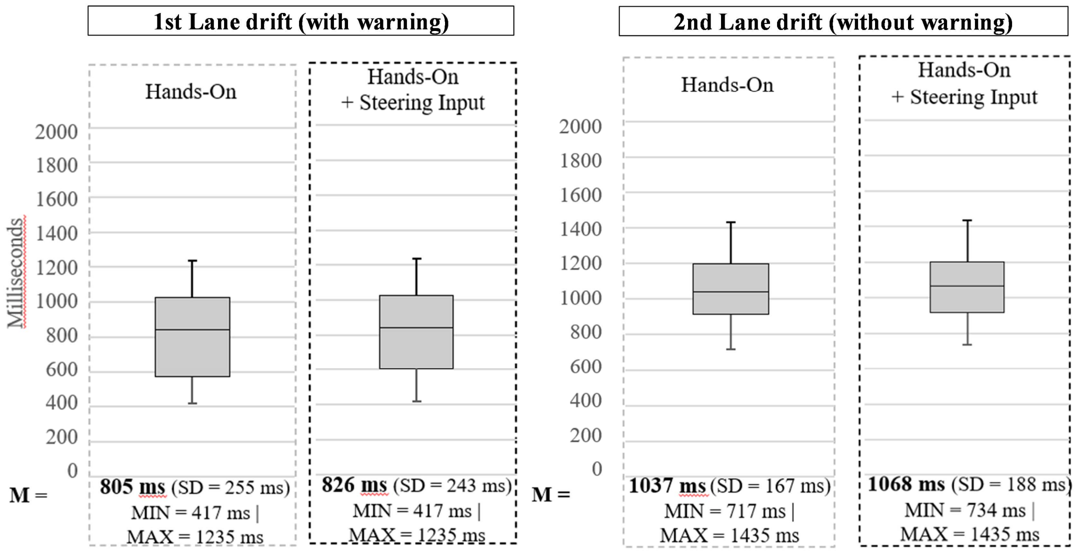

Figure 5. Reaction times to lane drift with and without TOR.

The drivers' reaction times varied between 417 and 1435 ms. There was a significant difference between reaction times to system-detected lane drifts with warning and system-undetected lane drifts without warning. Reaction times (hands-on + steering input) to the detected lane drift by the system with an issued warning were significantly shorter than reaction times to the undetected lane drift by the system without warning (U: 70; $p < 0.05$). There was no significant difference between reaction times with or without warning depending on the fact if the driver was an experienced Power User or an unexperienced Non-Power User. There was never a necessity for the safety driver to intervene during any of the lane drifts before the driver intervened. Both drifts, with and without warning, were controllable by all drivers. Some drivers reacted very strongly, which was one reason for some stabilizing safety driver interventions. Yet, none of the drivers started swerving or lost control over the vehicle and there were no crashes or near crashes, which indicates a sufficiently good take over quality. In the present study, a series Level 2 hands-on function was used to simulate a hands-free feature. The hands-on function allows cooperative steering and can be easily overridden by small steering inputs. In the series version of the simulated Level 2 hands-free system, additional technical measures are implemented to support stability and controllability of steering errors that require quick driver interventions, e.g., a slow ramp out of the steering torque. In the study, several drivers left the ego lane due to the lane drift and crossed the lane marking towards the shoulder with one wheel. There was enough space between the ego lane and the concrete wall or crash barrier next to the shoulder so that leaving the ego lane or crossing the lane marking was not dangerous. This might be an effect of subjective risk assessment by each driver. Figure 6 shows the road sections and impressions of the traffic situations, on and in which the drifts were triggered.

Figure 6. Road sections for the lane drifts

Post Interview

After the test drive, participants were asked questions about their experience with the system and the lane drift situations they were confronted with. There were striking errors in the mental model of some participants concerning accountability for the driving task, necessary monitoring behaviour and expectancies on warnings when system limits occur. Even though there were wrong beliefs about and false answers to the items on the topics mentioned above, the video evaluation of the drivers' behaviours in terms of monitoring behaviour or engagement in secondary tasks was unobtrusive. Moreover, all drivers – even if they stated in the post interview that they were not accountable for the driving task – reacted quickly to the lane drifts by grabbing the steering wheel and steering back into the ego lane. Figure 7 shows the answers of Power Users and Non-Power Users to the respective items on accountability, monitoring behaviour and expectancy towards the system on warnings in the event of a system limit.

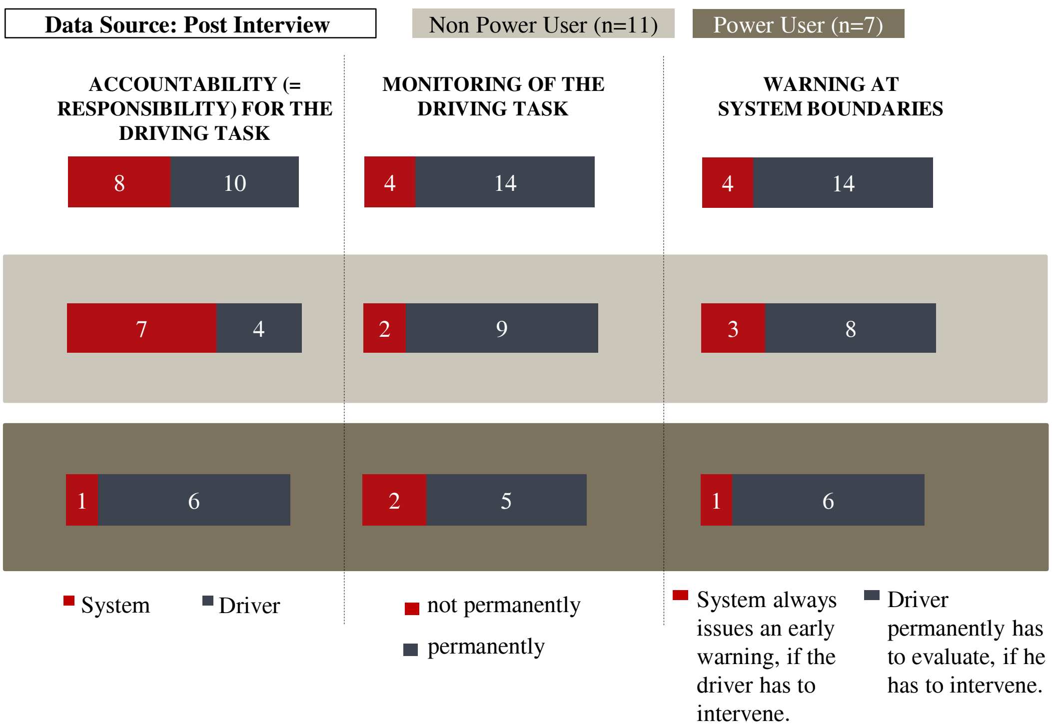

Figure 7. Post Interview on accountability, monitoring behaviour and system limits.

SUMMARY AND DISCUSSION

The L3EC is an innovative method to assess controllability of system limits in a realistic driving environment, which can and will occur to customers in their vehicles after market introduction of SAE Level 2 hands-free features. Knowing how drivers react in these situations is crucial during the development process of SAE Level 2 functions, most importantly, before their launch in the respective markets. Risks are minimized due to full control about the timing and surrounding conditions during the lane drift by the safety driver as well as due to additional safety measures which were integrated into the test vehicle, such as additional pedals and mirrors.

The goal of the presented study was the controllability assessment of PAD system boundaries while driving hands off under realistic traffic conditions. Results show that sudden system limits that require an immediate reaction and steering intervention are controllable by an attentive driver. Nevertheless, some drivers reported wrong beliefs and an incorrect mental model about responsibility, monitoring of the driving task and readiness for driver intervention to sudden events. Good performance of the system, being able to drive hands-free as well as external factors, such as low traffic density, were listed as reasons for why drivers thought they were not responsible for the driving task or didn't have to permanently monitor the driving task, when the system was active. The results indicate an impact of experience with PAD on the correctness of the driver's mental model. More Non-Power Users thought that the system was responsible instead of the driver, whereas only one Power User had a wrong belief about responsibility for the driving task. Therefore, it can be assumed that the driver's mental model can be corrected with growing experience with PAD and that there may have been an effect of first-time usage in the data of the present study. Reaction times to lane drifts were shorter, when an acoustic and visual urgent warning was triggered, when the system limit occurred, than when there was no warning. Take over quality was good, independently of system-detected or system-undetected situations, and drivers were able to control the vehicle and steer back into the ego lane without swerving or the necessity of an intervention by the safety driver. In the presented study, the lane drifts were only triggered in situations, in which the driver was attentive and when there was only low density of surrounding traffic and no object or other vehicle was in the corridor, into which the vehicle would drift after the steering error was injected. Therefore, there was no immediate danger and reaction times might have been shorter than how they were observed in the present study, if there was another object, vehicle, VRU (= Vulnerable Road User) or barrier next to the vehicle. Thus, a follow-up study has been carried out, with a similar study set up but with lane drifts, that were triggered by the safety driver, when the ego vehicle was close to another object. The study has shown that reaction times were significantly shorter, when there is an immediate risk of collision, than when there is enough space to evade until a concrete crash barrier next to the shoulder or another object would be reached. Results of this study will be published separately and will not further be discussed in the present paper. These results, along with the results of the present paper, show that drivers react instinctively, when there is an immediate threat, no matter, if they are convinced that they are responsible or if the system is responsible. False use of the system, which can e.g., lead to being less attentive to the driving scene or engaging in non-driving relevant tasks, can of course impact controllability as dangers may not be perceived in time. Long-term effects on the driver's behavior by the usage of these functions need to be observed in Field Operational Tests and Naturalistic Driving Studies.

REFERENCES

Clark, H., McLaughlin, A. C., & Feng, J. (2017, September). Situational awareness and time to takeover: exploring an alternative method to measure engagement with high-level automation. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 61, No. 1, pp. 1452-1456). Sage CA: Los Angeles, CA: SAGE Publications.

DeGuzman, C. A., Hopkins, S. A., & Donmez, B. (2020). Driver Takeover Performance and Monitoring Behavior with Driving Automation at System-Limit versus System-Malfunction Failures. *Transportation Research Record,* 0361198120912228.

Endsley, M. R. (1999). Level of automation effects on performance, situation awareness and workload in a dynamic control task. *Ergonomics, 42*(3), 462-492.

Gold, C., Damböck, D., Lorenz, L. & Bengler, K. (2013). "Take over!" How long does it take to get the driver back into the loop? *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 57, 1938-1942.

Naujoks, F., Mai, C. & Neukum, A. (2014). The effect of urgency of take-over requests during highly automated driving under distraction conditions. In T. Ahram, W. Karowski & T. Marek (Eds.), Proceedings of the 5th International Conference on Applied Human Factors and Ergonomics AHFE 2014 (pp. 2099-2106). Krakau: AHFE Conference.

Naujoks, F., Purucker, C., Neukum, A., Wolter, S., & Steiger, R. (2015). Controllability of Partially Automated Driving functions–Does it matter whether drivers are allowed to take their hands off the steering wheel?. *Transportation research part F: traffic psychology and behaviour, 35*, 185-198.

Parasuraman, R. & Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 39*(2), 230-253.

Parasuraman, R., Mouloua, M., Molloy, R. & Hilburn, B. (1993). Adaptive function allocation reduces performance cost of static automation. In R. S. Jensen & D. Neumeister (Eds.), 7th International Symposium on Aviation Psychology (pp. 37-42).

Schneider, N., Ahrens, L., & Pruksch, A. (2022). *Controllability of lateral drift failures while driving with SAE Level 2 Advanced Driver Assistance Systems.* In: 14. Tagung Fahrerassistenz, München.

Sieber, M., Siedersberger, K. H., Siegel, A., & Färber, B. (2015, September). Automatic emergency steering with distracted drivers: Effects of intervention design. In *2015 IEEE 18th International Conference on Intelligent Transportation Systems* (pp. 2040-2045). IEEE.

Society of Automotive Engineers. 2016. "Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles." SAE International, Warrensdale, PA.

Stanton, N. A. & Marsden, P. (1996). From fly-by-wire to drive-by-wire: safety implications of automation in vehicles. *Safety Science, 24*(1), 35-49.

Strand, N., Nilsson, J., Karlsson, I. M., & Nilsson, L. (2014). Semi-automated versus highly automated driving in critical situations caused by automation failures. *Transportation research part F: traffic psychology and behaviour, 27*, 218-228.