

# THE INFLUENCE OF DRIVER FATIGUE ON TAKE-OVER PERFORMANCE IN HIGHLY AUTOMATED VEHICLES

**Dr. Christina Kreuzmair**

**Dr. Christian Gold**

**Marie-Lene Meyer**

BMW AG, Knorrstraße 147, 80788 München

Germany

Paper Number 17-0199

## ABSTRACT

**Research Question/Objective:** Current advanced driver assistant systems combine the strengths of a human driver with the benefits of technical advancements. By raising the vehicle automation level, new human factors challenges emerge. Considering level 2 automation, where the driver is required to continuously monitor the system and remains responsible for vehicle safety, automation effects like overtrust and underload emerge and low vigilance and attention levels could impair driver performance. When reaching level 3 automation, the driver will still be needed as a fall back level for the automated system. Here, various automation effects could impair driver take-over performance and thereby controllability of the overall system, which is a combination of the system's reliability and driver's availability. To ensure the safety of the automated function, in-depth knowledge of the driver's current state, and hence driver's availability is essential. Moreover, both new standardized evaluation approaches and a common comprehension of the safety relevant parameters are necessary. In order to gain a better understanding of drivers in take-over situations, fatigue is examined in a driving simulator. **Methods and Data Sources:** The paper summarizes the different existing methods to assess driver state and controllability of level 3 systems, and how aspects such as fatigue influence the driver within take-over situations. In a driving simulator study different fatigue levels were established by means of slight sleep deprivation combined with hypovigilance and rated on the Karolinska Sleepiness Scale. Driver performance was assessed in regard to timing and quality aspects of the take-over. **Results:** The results indicate a correlation between fatigue and drivers' take-over performance and proves the validity of the applied fatigue measures. **Discussion and Limitations:** Fatigue was investigated in the driving simulator which may have limited validity. Fatigue presents particular challenges to the experimental setup, as it is difficult to be established artificially. **Conclusion and relevance to session submitted:** The proposed paper examines human performance in a highly automated driving situation under the influence of different fatigue levels which helps to assess the safety of future automated vehicles.

## INTRODUCTION

The increasing development of automated driving functions has shaped the discussion of autonomous driving and evoked a broad variety of research questions, including implications on the driver from a human factors perspective. With partial driving automation on the road, the next level will be reached by highly or conditional automated systems (Level 3, [1]), where the driver does not have to continuously monitor the system, but be available to occasionally take over vehicle control should the system limits be reached. This take-over includes a reorientation of a potentially distracted driver to the driving task, the relocation of hands and feet to the driving position, a buildup of situational awareness, selection of an adequate response to the system limit and response execution. While some system limits may be predictable in a timely manner, others may be detected very near term and therefore offer a limited time budget of only few seconds. Within this time-budget the different steps of taking over control have to be accomplished by the driver. As cognitive resources and physical capabilities are limited, factors influencing the time-budget or the complexity of the take-over impair the performance of the driver and the level of controllability of the situation.

### Driver State

Developing highly automated driving applications and the corresponding opportunities for the driver to remove himself out of the loop have raised several questions regarding the effects of highly automated driving on the driver's state [2]. In SAE automation level 3 the driver is no longer requested to continuously monitor the driving environment and is explicitly allowed to take him/herself out of the loop and to direct his/her attention to defined non-driving related tasks (NDRT). However, he is still responsible for taking over control of the vehicle when the system reaches its limits. To determine whether the driver is still able to take over the driving task, and to predict driver's reaction and performance in response to the take-over request (TOR), the driver state needs to be monitored. As the driver maintains the fallback level of the system, he must maintain a reasonable state to be able to appropriately respond to the TOR and is, for example, not allowed to fall asleep. Hence, the misuse of the system in order to sleep while driving in an automated mode may increase and should be addressed by driver monitoring [3].

### Fatigue

Driver fatigue is a contributing factor in an estimated 10-20% of road accidents ([4]; [5]; [6]). For manual driving it is assumed that the risk of accidents is quintupled due to fatigue [7]. Likewise, fatigue can be expected to also impair driver performance in take-over situations and thereby increase possible associated risks. Although yet to be verified, it can be assumed that high levels of driver fatigue constitute an intolerable driver state for level 3 automated vehicles.

In order to understand the specific effects of automation two different types of fatigue have to be distinguished [3]. Passive fatigue mainly results from monotony and underload conditions and may therefore even be promoted by automation. In contrast, active fatigue in the sense of exhaustion and stress by a high workload can be potentially reduced by automation. Additionally, the workload and the effects of automation on the driver state especially depend on the NDRT that is being performed while driving in automated mode. Considering the respective arousal level created, both underload and overload may occur [8]. While distracting tasks and tasks with significant workload have already been investigated in the context of take-over performance [9] [10] underload and fatigue as a consequence thereof are rather unexplored. Therefore, the focus of this study was to investigate passive fatigue to explore what happens to the driver when driving with highly automated systems without any NDRT.

### Controllability Measures

For the examination of different influencing factors on take-over performance, valid and reliable variables have to be evolved. The effect of influencing factors will then be expressed in the variance of the particular variable. In traditional driving studies, as well as in controllability studies of level 3 automated vehicles, different measures have been established to draw conclusions regarding controllability and driver performance. Among others, the time to collision (TTC) functions as a surrogate safety measure [11], or the occurrence of crashes as pass/fail criteria [12]. All measures have in common, that a correct interpretation depends on the scenario. High accelerations, for instance, can imply an overreaction of the driver, which must be avoided, but also a distinct driver input is necessary and desirable to avoid a crash or critical situation. In order to generate comparable measures and a generic but nonetheless valid controllability assessment, information and results can be merged into a comprehensive rating, analog to performance

evaluation of manual driving [13]. The authors are currently not aware of any similar approach available for assessing take-over performance in highly automated vehicles to that detailed in this paper.

## METHODS

### Driving simulator study

A driving simulator study was conducted to record take-over performance as well as driver state and behavior in level 3 conditional automated driving. The experiment was conducted in a motion-based driving simulator. Driver fatigue was assessed by different measures and correlated with the driver's performance in take-over situations to explore potential effects of fatigue on controllability during conditional automation.

### Measure of fatigue

Driver fatigue was assessed both by the driver and the investigator (expert rating) by means of the Karolinska Sleepiness Scale (KSS) [14] which showed a high validity [15]. The KSS is „a 9 point verbally anchored scale“ [14] measuring fatigue from 1 „alert“ to 9 „extremely sleepy – fighting sleep“. For this study the scale was extended by introducing 10 „beginning sleep“ for considering drivers in the experiment that actually fell asleep. As the KSS was developed for self-reported fatigue, the latter was not included in the scale, but can be assessed by the investigator with a very high degree of certainty.

While driving in automated mode on a highway, participants rated the fatigue level on the KSS every 6 minutes, whereas the investigator performed an assessment every 3 minutes during the drive by observing participants' behaviour.

Moreover, to assess driver's fatigue level, the eye aperture was measured by means of two different measurement systems. First, via copper coils fixed at the upper and lower eye-lid of a driver, which measure the distance between the eyelids via induction. Second, by a camera based eye tracking system (Smart Eye Pro 6.1.13), which calculate for example the percentage of eye-closure by means of image processing. Both measurement methods utilize the eyelid aperture angle as an indication for fatigue by deriving the proportion of time with eyes closed (PERCLOS), which has been demonstrated as a valid approach in various studies [16]. PERCLOS was calculated for continuously shifted time increments of 3 minutes. Additionally the eyelid closure index was calculated, based on an algorithm also classifying the driver's fatigue [17]. The fatigue rating is extracted considering the last 15 blinks. Both

PERCLOS and eyelid closure index are calculated based on the data of the two measurement methods.

### Procedure and experimental setup

To evoke fatigue, the experiment started at 6 a.m. and drivers were instructed not to go to bed before 12 p.m. the night before the experiment. Moreover, drivers should refrain from consuming coffee on the experimental day.

First, each participant familiarized themselves with the system in a short acclimatization drive. During that drive the investigator explained the functionality of the system and the participants experienced two TORs. The first take-over was not meant to trigger any reaction, but demonstrated the appearance of the TOR. The second TOR triggered a take-over of the participant to become familiar with the system in a take-over situation. Both TORs occurred without representation of a specific system limit and served for illustration purposes only.

The basic idea of the experiment was to use highly automated driving without any additional task to make the driver tired and get her/him to sleep. Thus, the participants drove a long, monotone, highly automated drive with a speed of 120 km/h (approx. 75 mph) on the motorway during night simulation. As the development of fatigue is inter- and intra-individually highly variable, a state dependent experimental plan was used. Triggering of the take-over situations was dependent on the fatigue development of each driver. The duration of the different fatigue levels was variable, depending on the driver.

Once the investigator assessed via expert rating that a driver reached the next fatigue level (KSS-value of the respective fatigue value) during the highly automated drive, a take-over scenario was triggered. Accordingly, the driver reached a take-over scenario approximately 1 minute after each fatigue assessment.

After the take-over scenario the driver could activate the highly automated system again and proceeded in the highly automated driving mode until he/she reached the next higher fatigue level based on the expert rating which again triggered a take-over. Thus, the factor fatigue was implemented as a within subject variable and the driver experienced the take-over situation in up to four different fatigue levels:

- "Baseline": The first take-over was triggered shortly after the participants began driving in the highly automated mode. At this stage, the drivers are alert ( $KSS \leq 5$ ) and experience initial contact with a take-over situation.

- "Slight fatigue": The second take-over was triggered the first time the expert rated the subject's fatigue with a KSS value of 6 or 7.

- "Fatigue": The third take-over was triggered the first time the expert rated the subject's fatigue with a KSS value of 8 or 9.

- "Beginning Sleep": The first time the expert rated fatigue incurred a KSS rating of 10, the final take-over was triggered.

The experiment was finished as soon as the driver had reached the highest drowsiness level and the last take-over had taken place or when the defined maximum time for the drive (2.5h) was reached.

The experimental setup consisted of two versions of the drive which differed in the complexity of the take-over scenarios. Thus, the complexity of the take-over scenarios was a between subject variable. Participants in the simple situation had to drive through road works after the TOR had been issued. Thereby, drivers had to follow a narrowed and slightly curved road pathway. In the complex situation, drivers approached moving roadworks within their lane and had to change lanes as a response to the TOR in order to pass the roadworks. Moreover, an approaching car in the target lane had to be noted and considered for the lane change.

The take-over quality was assessed by the investigator on a 9-point scale. The assessment was based on an overall impression of the driving situation under consideration of both, system behaviour and driver behaviour. Criteria for allocating a rating between 1 and 3 ("poor") were: the occurrence of a collision, incurrence of self-endangering conditions, threatening others or leaving the lane. A rating of 4, 5 or 6 ("intermediate") was assigned when the driver became very slow or took over very insecurely. An appropriate take-over was assessed with 7, 8 or 9 ("good").

Furthermore, the take-over performance was assessed based on timing and quality metrics. A hands-on detection measured the time between the TOR and the point in time when the hands grasped the steering wheel. A second timing metric was the take-over time, measured from the TOR to the moment when the driver started a maneuver as a reaction to the TOR. According to Gold et al. [18], exceeding a steering wheel angle of 2 degrees or a brake-pedal actuation of more than 10 percent was considered the start of the maneuver. The quality of the take-over was assessed by the maximum longitudinal and lateral acceleration that occurred within each take-over scenario.

### System behaviour

For the study, a highly automated system was used which takes over lateral and longitudinal control. This highly automated system allows the driver to

remove the feet from the pedals and allows hands-free driving. The driver could activate the system by pressing a button at the steering wheel.

The system behavior for take-over situations was developed as follows:

- 176 meters before the system limit was reached, a TOR was presented.

- The TOR consisted of an acoustic (urgent beeping) and a visual warning (red hands encompassing a red steering wheel) displayed on the instrument cluster.

- Simultaneously with the TOR, the system initiated a deceleration at a rate of 3.7 m/s<sup>2</sup>, which can still be considered comfortable [19]. The timing of the TOR was parameterized in a way that the vehicle came to a stop at the position of the defined system limit, in case of the absence of a driver input.

Within the take-over situation, participants had several possibilities to deactivate the system. They could either press a button, apply a steering input, speed up or brake more strongly than the system.

## RESULTS

N=22 participants, 10 female and 12 male, between 26 and 65 years (mean=37.95, standard deviation=12.81) took part in the study and were considered in the results. However, eye lid closure measures of N=2 participants could not be fully assessed due to interference by subjects.

All participants were recruited from a test person panel and had attended an extensive simulator training program (minimum 2.5 hours) to reduce potential driving simulator effects.

On average, drivers had slept 4.3h the night before and rated their sleepiness on a scale from 1-9 with a mean of 5.27 when they arrived. Only six out of twenty-two participants had ever used assistance systems such as Adaptive Cruise Control.

Nevertheless, 19 out of 22 participants had participated in experiments with highly automated driving before. Since the triggering of the TOR depended on the subjects' state of fatigue, the number of TORs varies among conditions (Table 1). If drivers did not reach higher levels of fatigue during the drive, the last TOR was performed at the same level of fatigue as before (repeated measurement).

**Table 1.**  
**Amount of take-over scenarios among conditions**

	Simple	Complex	Total
Baseline	11	10	21
Slight fatigue	13	12	25
Fatigue	19	12	31
Beginning sleep	2	4	6
Total	45	38	83

Regarding the assessment of driver fatigue, both subjective and objective measures were taken into account. Subjective measures resulted in a strong correlation between driver's and expert's last KSS rating before each TOR ( $r(79)=.792, p<.001$ ). PERCLOS and lid closure index were calculated based on data from objective measures such as copper coils and eye tracking. Further analyses resulted in a satisfactory correlation between both PERCLOS measures ( $r(2372)=.591, p<.001$ ). Regarding lid closure index, both objective measures indicated a strong correlation ( $r(2310)=.721, p<.001$ ). Furthermore, highly significant correlations between the expert's KSS rating and the aggregated measures of PERCLOS ( $r(2356)=.465, p<.001$ ) and lid closure index ( $r(2127)=.604, p<.001$ ) were revealed. Therefore, the expert's sleepiness rating was considered "Ground Truth" for any further analyses.

### Performance Measures

Various analyses yielded differences regarding take-over performance among hands-on and take-over time as well as maximum longitudinal and lateral acceleration between sleepiness levels and conditions.

In simple take-over situations hands-on times vary little between 1.08 and 1.82 seconds while in complex take-over szenarios reaction times increase in proportion to sleepiness levels (See Figure 1).

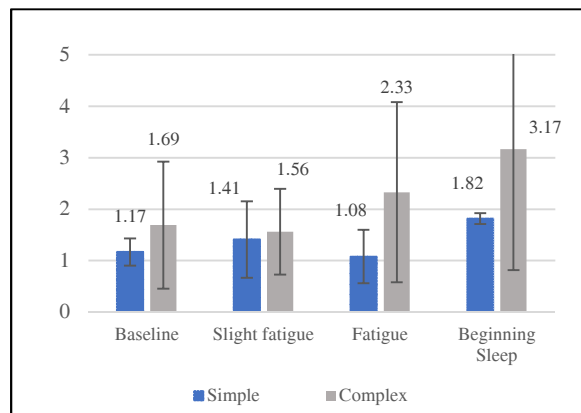


Figure 2. Hands-on times and levels of sleepiness.

Still, only hands-on times in level "fatigue" yielded a significant difference between simple and complex take-over situations ( $t(12.66)=-2.38, p=.034$ ).

In simple as well as complex take-over scenarios, take-over times appear to decrease from the "baseline" to "slight fatigue" to "fatigue" and only increase at "beginning sleep" (See Figure 2). An analysis of variance regarding take-over times in complex scenarios revealed significant differences in take-over times between sleepiness levels

( $F(3.33)=3.037, p=.034$ ). Post-hoc comparisons using a Tukey HSD test did not result in significant differences between single levels of sleepiness but indicate potential learning effects in the complex condition, expressed in a reduction of take-over times between "baseline" ( $M=2.97, SD=1.51$ ) and "fatigue" ( $M=1.75, SD=0.85$ ) ( $p=.072$ ).

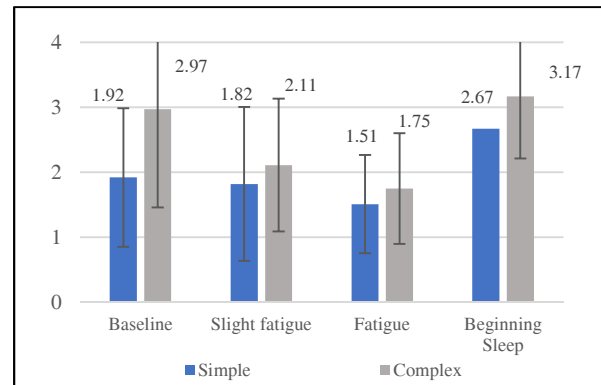


Figure 1. Take-over times and level of sleepiness.

As depicted in Figure 3, mean longitudinal accelerations vary only slightly over different levels of sleepiness or complexity of take-over scenarios. No significant differences were revealed throughout the analysis.

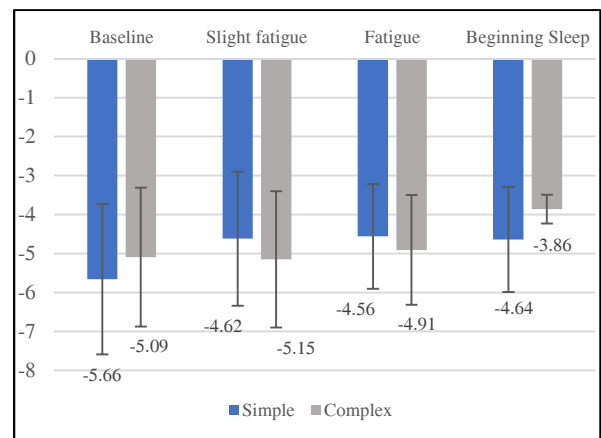
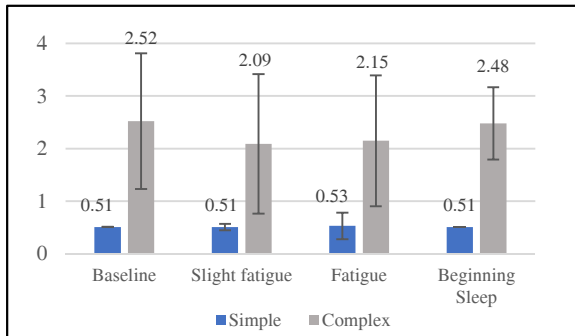


Figure 3. Longitudinal acceleration and sleepiness levels.

Regarding lateral acceleration, no significant differences between the sleepiness levels of simple or complex take-over situations were revealed (See Figure 4).

Nevertheless, several t-tests yielded highly significant differences between simple and complex take-over scenarios according to sleepiness level ("baseline":  $t(9)=-4.923, p=.001$ ; "slight fatigue":  $t(11)=-4.139, p=.002$ ; "fatigue":  $t(11)=-4.458, p=.001$ ; "beginning sleep":  $t(4)=-3.835, p=.019$ ), illustrating an influence of the scenario on the take-over quality.



All in all, differences in performance measures for **Figure 4. Lateral acceleration and sleepiness levels.**

subjects between the first, second, third and fourth TOR in the form of learning effects (decreasing hands-on times) were expected. An analysis of variance resulted in significant differences regarding hands-on measures in complex take-over scenarios ( $F(3, 33) = 3.711, p=.021$ ). However, post-hoc comparisons using the Games-Howell test did not result in significant differences, but indicate that “baseline” ( $M=1.69, SD=1.24$ ), “slight fatigue” ( $M=1.56, SD=0.91$ ) and “fatigue” ( $M=1.45, SD=0.79$ ) levels differ from the “beginning sleep” ( $M=3.31, SD=2.10$ ) level in terms of increasing hands-on times.

On top of the performance measures reported above, the quality of the take-over situation was assessed based on an expert rating.

These ratings were classified into three groups, “poor”, “intermediate” and “good” take-over quality. An analysis of variance showed significant differences between the groups of ratings regarding longitudinal ( $F(2,44) = 4.281, p= .020$ ) and lateral acceleration ( $F(2,44) = 10.476, p< .001$ ) in simple take-over scenarios. Post-hoc analyses using the Bonferroni post-hoc criterion for significance indicated that the average longitudinal acceleration was significantly stronger in “poor” take-over situations ( $M = -8.07, SD = 0.46$ ) than in “good” take-over situations ( $M = -4.36, SD = 1.78$ ).

In complex take-over scenarios, an analysis yielded significant differences between the expert’s rating regarding lateral acceleration ( $F(2,37) = 12.701, p< .001$ ). Post-hoc comparisons using Bonferroni test indicate that “good” take-over situations ( $M=1.49, SD=0.82$ ) significantly differ from “intermediate” ( $M=3.09, SD=1.40$ ) and “poor” ( $M=3.40, SD=1.25$ ) take-over situations.

## CONCLUSION

All measures of fatigue, the KSS rating of experts and drivers, the eyelid closure index and the PERCLOS index correlated with one another and

thus demonstrated validity of the measures. These methods are therefore suitable to assess driver fatigue, either for human factors experiments, or as an input for parameterization of driver assistance systems and automated driving functions. In accordance to literature [20], the results demonstrate learning effects, leading to increased take-over performance with additional iterations. These effects seem to overlap with a potential deterioration of take-over performance due to fatigue. Thereby, the setup was not able to detect and statistically prove a significant influence of fatigue. Especially high fatigue levels were expected to prolong the take-over reaction. Although extremely high recorded values for hands on time noticeably occur in case of very high KSS values (e.g., maximum hands-on time of 6.67 occurred in level 10), the very low number of participants that reached level 4 (See Table 1) and the interference with sequence effects hinder statistical verification. Either extensive training of the take-over situation to reduce sequence effects or the consideration of only one take-over situation per participant could help to identify potential fatigue-related issues when looking at take-over performance.

Moreover, the results signalize that the expert’s rating on take-over quality match performance measures such as longitudinal and lateral acceleration in particularly “poor” and “good” take-over situations. This leads to the conclusion that experts can distinguish especially “poor” and “good” take-over situations correctly, while it is not yet possible to accurately assess “intermediate” take-overs. Further development of an expert rating method could result in more sensitive ratings. Finally, the results emphasize that the complexity of take-over situations has a significant influence on the take-over performance, as the two situations employed show differing results in regard to measured maximum accelerations.

## REFERENCES

- [1] SAE J 3016 (2014). *Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems*. Society of Automotive Engineers. doi:10.4271/j3016\_201401
- [2] Schömig, N., Hargutt, V., Neukum, A., Petermann-Stock, I., & Othersen, I. (2015). The interaction between highly automated driving and the development of drowsiness. *Procedia Manufacturing*, 3, 6652-6659. doi:10.1016/j.promfg.2015.11.005
- [3] Neubauer, C., Matthews, G., Langheim, L., & Saxby, D. (2012). Fatigue and voluntary

- utilization of automation in simulated driving. *Human factors*, 54(5), 734-746. doi:10.1177/0018720811423261
- [4] Dingus, T. A., Klauer, S. G., Neale, V. L., Petersen, A., Lee, S. E., Sudweeks, J. D., ... & Bucher, C. (2006). *The 100-car naturalistic driving study, Phase II-results of the 100-car field experiment* (No. HS-810 593). doi:10.1037/e624282011-001
- [5] Thoren, C. T., & Gundel, A. (2003). Müdigkeit als Unfallursache im Stadtbereich—eine Befragung von Unfallbeteiligten. *Somnologie*, 7(4), 125-133. doi:10.1046/j.1432-9123.2003.00003.x
- [6] Evers, C., & Auerbach, K. (2005). Verhaltensbezogene Ursachen schwerer Lkw-Unfälle. *BERICHTE DER BUNDESANSTALT FUER STRASSENWESEN. UNTERREIHE MENSCH UND SICHERHEIT*, (174).
- [7] Klauer, S. G., Dingus, T. A., Neale, V. L., Sudweeks, J. D., & Ramsey, D. J. (2006). The impact of driver inattention on near-crash/crash risk: An analysis using the 100-car naturalistic driving study data. *PsycEXTRA Dataset*. doi:10.1037/e729262011-001
- [8] Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of comparative neurology and psychology*, 18(5), 459-482. doi:10.1002/cne.920180503
- [9] Gold, C., Berisha, I., & Bengler, K. (2015, September). Utilization of drivetime—performing non-driving related tasks while driving highly automated. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 59(1), 1666–1670. doi:10.1177/1541931215591360
- [10] Radlmayr, J., Gold, C., Lorenz, L., Farid, M., & Bengler, K. (2014, September). How traffic situations and non-driving related tasks affect the take-over quality in highly automated driving. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 58(1), 2063–2067. doi:10.1177/1541931214581434
- [11] ISO International Organization for Standardization. (2013-07-23). Intelligent transport systems – forward vehicle collision warning systems – performance requirements and test procedures (Vol. 03.220.01; 35.240.60; 43.040.99) (No. 15623:2013). ISO International Organization for Standardization.
- [12] van den Beukel, A. P., & van der Voort, M. C. (2013, October). The influence of time-criticality on situation awareness when retrieving human control after automated driving. In *Intelligent Transportation Systems-(ITSC), 2013 16th International IEEE Conference on* (pp. 2000-2005). doi:10.1109/itsc.2013.6728523
- [13] Kaussner, Y., Kenntner-Mabiala, R., Hoffmann, S. & Volk, M. (2016). Driving performance of elderly drivers in comparison to middle-aged drivers during a representative, standardized driving test in real traffic. *Zeitschrift für Verkehrssicherheit*, 3, 73-76.
- [14] Åkerstedt, T., & Gillberg, M. (1990). Subjective and objective sleepiness in the active individual. *International Journal of Neuroscience*, 52(1-2), 29-37. doi:10.3109/00207459008994241
- [15] Kaida, K., Takahashi, M., Åkerstedt, T., Nakata, A., Otsuka, Y., Haratani, T., & Fukasawa, K. (2006). Validation of the Karolinska sleepiness scale against performance and EEG variables. *Clinical Neurophysiology*, 117(7), 1574-1581. doi:10.1016/j.clinph.2006.03.011
- [16] Putilov, A. A., & Donskaya, O. G. (2013). Construction and validation of the EEG analogues of the Karolinska sleepiness scale based on the Karolinska drowsiness test. *Clinical Neurophysiology*, 124(7), 1346-1352. doi:10.1016/j.clinph.2013.01.018
- [17] Hargutt, V. (2003). *Das Lidschlussverhalten als Indikator für Aufmerksamkeits-und Müdigkeitsprozesse bei Arbeitshandlungen* (No. 233).
- [18] Gold, C.; Dambock, D.; Lorenz, L.; Bengler, K. (2013): Take over! How long does it take to get the driver back into the loop? In: *Proceedings of the Human Factors and Ergonomics Society Annual Meeting 57* (1), S. 1938–1942. doi: 10.1177/1541931213571433
- [19] Winner, Hermann; Hakuli, Stephan (2015): Handbook of Driver Assistance Systems. Basic Information, Components and Systems for Active Safety and Comfort. 2., korr. Aufl. Wiesbaden: Springer Verlag, zuletzt geprüft am 02.11.2015. doi:10.1007/978-3-319-12352-3
- [20] Gold, Christian; Bengler, K. (2014): Taking Over Control from Highly Automated Vehicles. In: *Proceedings of the 5th International Conference on Applied Human Factors and Ergonomics, AHFE 2014, Krakow, Poland 19-23 July 5*. doi:10.1177/0018720816634226