License to Supervise. Influence of Driving Automation on Driver Licensing.

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ABSTRACT

To use highly automated vehicles while a driver remains responsible for safe driving, places new – yet demanding, requirements on the human operator. This is because the automation creates a gap between drivers' responsibility and the human capabilities to take responsibility, especially for unexpected or time-critical transitions of control. This gap is not being addressed by current practises of driver licensing. Based on literature review, this research collects drivers' requirements to enable safe transitions in control attuned to human capabilities. This knowledge is intended to help system developers and authorities to identify the requirements on human operators to (re)take responsibility for safe driving after automation.

Keywords: Automation, Driving Performance, Supervision, Transition, Workload.

1 INTRODUCTION

At an increasing pace automotive industry is introducing vehicles that allow automatically driving (Broggi, Zelinsky, Özgüner, & Laugier, 2016) (Shladover, 2017). This development receives considerable attention from authorities and policy makers (Anderson et al., 2016) (Kyriakidis, Happee, & de Winter, 2015), because it may resolve mobility problems: Driving automation could increase traffic efficiency and reduce road accidents (Hoeger et al., 2008). Automated vehicles may also reduce the ecological impact of road transport (Wadud, MacKenzie, & Leiby, 2016), increase the access to mobility for elderly or disabled persons and reduce urban needs for parking (Litman, 2014).

Basic building blocks for longitudinal and lateral control have been available for years in advanced driver assistance systems (ADAS). However, safe implementation of complete automation requires highly reliable machine-based sensing of the environment in combination with faultless understanding of its environment and decision-making. Due to the highly complex traffic circumstances, current systems do not meet these requirements (Butmee & Lansdown, 2017) (Bengler et al., 2014) – leaving an important task at the driver to supervise safe system operation. Implementation of automated driving is therefore targeted from levels of so called 'semi' or 'partial' automation to 'high' automation – but not (yet) full automation (Gasser & Westhoff, 2012) (McGehee et al., 2016) (Shladover, 2017). This implementation means that the driver remains responsible.

For the foreseeable future, automated vehicle technologies, will continue to rely on a "responsible" driver to oversee the technology, capable of resuming control and having the foresight to make many (yet to be defined) strategic operational decisions. However, this responsibility in combination with reduced involvement in the control task causes a changed, yet difficult, role for the driver. That is: The driver's task changes to a supervisory role during automation with the necessity to retake control during transition from automation to self-driving

(Merat & Lee, 2012). However, this new role is not something humans are good at. Supervision, for instance, is accompanied with low vigilance and behavioural adaptation (Merat, Jamson, Lai, Daly, & Carsten, 2014), causing e.g. slower reaction times, misinterpretation (Martens et al., 2008) (Jamson, Merat, Carsten, & Lai, 2013) or skill degradation (Toffetti et al., 2009). Intervention is impaired by reduced Situation Awareness and increased Workload. Studies revealed that it takes considerable time to prepare for safe take-over when not being actively involved in the driving task (Radlmayr, Gold, Lorenz, Farid, & Bengler, 2014) (Gold, Damböck, Lorenz, & Bengler, 2013) (Zeeb, Buchner, & Schrauf, 2015). To summarize, partial automation creates a gap between drivers' responsibilities and human capabilities for safe vehicle operation when using driving automation. This gap is not being addressed by current practises of driver licensing.

Assessment of driver's proficiency (i.e. driver licensing) is essentially based on assuming a driver who is actively controlling the vehicle with minor assistance from machine-controlled functions. However, the changing role of the driver may require additional criteria to be assessed. Examples are proficiency in system supervision and the ability to safely retake control (Van den Beukel, 2016). Authorities for driver licensing in the Netherlands basically assess control-output irrespective of any assistance functions being used. For assessment of driver's proficiency a main concept employed is: "keeping a safe 'Spacial Cushion'" (CBR, 2008). Such Spacial Cushion is a trade-off from speed, distance (both lateral and longitudinal) and anticipation. The aim of this research is to investigate if assessment of keeping a safe Spacial Cushion can also be applied for the assessment of the driver's supervisory role. Good anticipation is closely related to Situational Awareness (SA), especially Level 3 SA "Projection of future state" (Endsley, 1996). Situation Awareness, Distance and Speed, have been studied in many experiments in order to assess their influence on take-over behaviour and safe driving of automated vehicles. Therefore this research conducts a literature review to collect evidence whether the three aspects of a Spacial Cushion (i.e. Distance, Speed and SA Level 3) allow to univocally assess the driver's new role. The results are intended to help system developers and authorities to identify the requirements that enable human operators to remain responsible for safe driving when operating automated vehicles.

2 METHOD

Our literature review is based on a narrative review of quantitative evidence of the parameters that define driver's proficiency to retake control after automated driving. We defined automated driving as any system in which the automation has taken over both longitudinal and lateral control during road travelling. Articles were collected based on a combination of search items. Studies were selected for closer consideration based upon specific criteria, resulting in 68 articles. This approach is explained below.

Our literature search is conducted with Google Scholar, because this search engine has broad coverage and features full-text search. To select studies that involve driving automation, searches were based on any of the keywords "driving automation", "automated driving", "autonomous driving", "driverless", "robotic cars" or "self-driving". These words were combined with "transition", "take-over", "workload", "driver control", "situation awareness", "accident avoidance", "secondary task", "eye-tracking" and "hands-on-the-wheel". We selected studies from 2006 onwards. Studies solely focusing on automation of exceptional manoeuvres (like parallel parking) were excluded.

We selected studies for closer consideration if at least one of the following aspects were being assessed:

1. Reaction time after a take-over request;
2. Situation Awareness;
3. Hazard detection;
4. Driver response to solve (potentially) critical traffic situations;
5. Performance level of non-driving tasks;
6. Eye-movement;
7. Hand position (on/off steering wheel);
8. Occurrence of driver's initiated (de)activation of automation.

The ability to take-over control is influenced by timing aspects, i.e. the urgency of an event and driver's reaction time (1). To assess the effectiveness of retaking control the driver's Situation Awareness (2) is an informative measure. Based on Endsley (1996) Situation Awareness (SA) is defined as ''the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future". A variety of methods exist to measure SA. We selected only studies that used Freeze Probe techniques, like SAGAT (Jones & Endsley, 2004). This is because Freeze Probe techniques show best face validity and most reliable results compared to other SA-measures (Salmon et al., 2009) (Van den Beukel & Van der Voort, 2017). Hazard detection (3) is included in the first two levels of SA, i.e. perception and understanding. We also included studies that measured hazard detection separately.

With regard to driver response (4), we included studies that measured brake-action, steering-action to avoid danger, and combinations of braking and steering. To assess performance levels of non-driving tasks (5) we included studies that quantified the involvement in non-driving tasks. Performance of non-driving tasks may also be associated with hand-position on or off the steering wheel (7). Measurement of eye-movement (6) allows to assess driver's awareness of critical situations. Eye gaze patterns are useful for inferring workload, with reduced variance of gaze serving as an indicator of higher workload (Victor, Harbluk, & Engström, 2005). Drivers' initiatives for (de)activation of the automation (8) is indicative for their involvement in the driving task and their anticipation of system boundaries.

For above selected measurements both driving simulator studies and studies in real cars are eligible. However, our review does only account for studies in which transitions take place. Studies were considered if published as journal article, book chapter, conference proceedings, doctoral theses or reports from research projects. To retrieve the complete manuscripts we used in addition to Google Scholar also Web of Science, Scopus and ResearchGate. For reasons of practicality publication language was restricted to English, German or Dutch. In total, 68 articles were selected to include in our review. However, this number does not yet include review of the reference lists of the selected studies in order to consider further relevant studies.

3 RESULTS

Most studies measured take-over behaviour either after a take-over request, or after a critical event taking place, requiring the driver to intervene in order to avoid an accident.

Reaction Time and Driver Response

Louw, Merat, and Jamson (2015) assessed Reaction Time and both lateral and longitudinal acceleration after a take-over event occurred while driving automatically. The study showed that automated driving caused longer reaction times and more agitated reactions witnessed by stronger lane deviations and more severe braking reactions (Louw et al., 2015). Merat and Jamson (2009) researched if full automation influences drivers' response after experiencing three different events that required an intervention. In all three situations Reaction Time was faster for manual drivers than drivers of an automated vehicle. Feldhütter, Gold, Schneider, and Bengler (2017) assessed Reaction Time, Take-over Time, maximal longitudinal and lateral deceleration, Gaze behaviour and Time-to-Collision while participants took up a secondary task. During secondary task uptake, Reaction Time and Take-over Time were longer indicating that it takes additional time to switch attention to the road. Without secondary task, participants monitored the road more frequently, but during prolonged driving the monitoring time reduced.

In addition to Reaction Time Merat et al. (2014) researched time needed to obtain stabilized control of the vehicle after automation. According to their study 35-40 seconds were required for the human driver to achieve stabilised lateral control irrespective of whether handover from machine control had been planned or was in response to a critical event. Gold et al. (2013) researched Take-over Times and demonstrated that the time required to efficiently regain control in response to a critical event was *increased* between 2.1 to 2.89 seconds compared to response times while manually driving. Under traditional manually driving conditions a basic advise is to have at least 2 seconds time-difference with vehicles in front in order to accommodate delayed response actions due to reaction times. Applying the finding of studies like Gold et al. (2013) would mean that drivers of automated vehicles are advises to keep at least 4 seconds time-difference with a vehicle in front.

Driving Performance: Speed and Distance

Some studies found no adverse influence on Reaction Times, but impaired driving performance after retaking control. Despite immediate response to an handover signal, Merat and Jamson (2009) found that drivers braking response in an automated condition was not as effective as in the manual condition. Most likely this was due to reduced situational awareness. Also Zeeb et al. (2015) found no influence of distraction on reaction time. However the take-over quality in terms of lateral disturbance in lane position was larger for distracted drivers. These findings seem to indicate that establishing motor readiness may be carried out almost reflexively, but cognitive processing of the situation is impaired by driver distraction. According to (Gold et al., 2013) the more time given, the longer it takes the driver to intervene. If less time is available, the more disturbance in obtaining stabilized vehicle control occurs. This fact may emphasize the importance of driver's understanding of the system's boundaries. If drivers try to make full use of the given time budget, they need to estimate the remaining time. Thereby factors like the driver's sensitivity to the remaining time budget, or the perceived criticality and urgency of the situation comes into play. Conditions that may impact performance include the number and type of critical incidents, traffic density, feedback, distraction, and fatigue (Merat & de Waard, 2014).

Situation Awareness and Attention

Miller et al. (2015) assumed that drivers' attention would benefit from a sufficient level of arousal. To have sufficient arousal (not necessarily for driving monitoring but more in general) participants were therefore purposely invited to engage in secondary tasks. This was compared with drivers' road monitoring in situations with low arousal (i.e. drowsiness). From Miller's study it may concluded that using secondary tasks to have drivers available at a sufficient attention level causes contra productive effects: The secondary task uptake either keeps drivers alert but unaware or without such task drivers may be aware of driving but their attention is weakened due to being bored. Equally, Jamson et al. (2013) revealed that drivers in an automated condition showed 2% higher drowsiness than in manual conditions and confirmed the adverse influence of fatigue and task underload on drivers' performance for supervising automated vehicles. Fletcher and Zelinsky (2009) assessed the driver's monitoring role based on comparison between relevant traffic events and driver's gaze direction. If the gaze-direction did not correspond with an event this was an indication of inattention to the event. However, the opposite cannot be concluded due to 'look-but-did-not-see' problems: If the gaze direction corresponded with an event drivers were nonetheless regularly inattentive.

Behavioral adaptation

Jamson et al. (2013) also revealed that drivers adapt their supervising performance to traffic circumstances. In heavy traffic conditions drivers gave more attention to the supervision task in comparison to conditions with low traffic density. With higher automation drivers are also less wanting to overtake (resulting in longer travel time). While drivers who experience automation tended to refrain from behaviours that required them to temporarily retake manual control (such as overtaking), drivers were significant less moment exposed to low time-to-collision than with manual driving. Thus far, automation improved safety margins in car following, however this was restricted to increased journey and higher involvement of drivers with in-vehicle entertainment tasks than they were in manual driving, affording less visual attention to the road ahead. This might suggest that drivers are happy to forgo their supervisory responsibilities in preference of a more entertaining highly-automated drive. However, they did demonstrate additional attention to the roadway in heavy traffic, implying that these responsibilities are taken more seriously as the supervisory demand of vehicle automation increases.

4 CONCLUDING REMARKS

This study reviewed if the three aspects contained in the concept of a Spacial Cushion, i.e. longitudinal and lateral Distance, Speed and SA Level 3 would allow for assessment of the driver's supervisory role. The conclusion from this review is that if such assessment is applied to human-machine cooperation, it will not provide a sufficient and unambiguous picture. This is because this assessment cause fundamental contradictions with regard to distance and anticipation. That is, machine controlled functions may allow shorter time-distances due to faster reaction times. However, human fall back requires time-distances to be even longer than during manual operation. Our review showed considerable empirical evidence that drivers need additional time to get back in the control-loop after automation. Based on several studies, the *additional* response time requires at least 2 seconds (and considerably more when drivers are completely disengaged from driving). This means that taking the traditional Spacial Cushion as a reference for the assessment of drivers of automated vehicles is an insufficient parameter for measuring supervisory performance. Furthermore, the concept of a Spacial Cushion may overlook driver's understanding of system boundaries and anticipation to potential changes in the machine's operational field. To assess the driver's role in automated driving, it is therefore recommended to renew the definition of retaining a safe Spacial Cushion and to add assessment of driver's perception and understanding of system performance (i.e. System Awareness Level 1 and 2).

Studies reviewed in this research were based on systems that required driver's responsibility to comply with speed limits. Drivers also needed to resume manual control if they wanted to overtake a vehicle. This may have positive influences on traffic safety as drivers seem to prefer a steady traffic flow with constant speed over manual control if this is required to overtake vehicles. However, while technology advances automated take-over manoeuvres become available. Further research on the consequences if speed and distance choices in automated vehicles come under shared responsibilities between driver and vehicle is strongly needed.

Results of this literature review are intended to help system developers and authorities to identify requirements that enable human operators to remain responsible for safe driving when operating automated vehicles. The outcome of this research may have a large and diverse impact. First of all, the research helps developers and authorities (e.g. authorities for driver licensing or infrastructural planning) by improving their understanding of the limitations of automated driving systems with respect to human capabilities for retaking control. Furthermore, it supports conclusions whether operation of automated vehicles is sufficiently backed up by current levels of required driving proficiency (i.e. driving license criteria). Further research is needed to identify if additional drivers' training is recommendable to operate automated vehicles. More generally, the results focus both on (new) criteria for drivers' proficiency as well as criteria for systems' conditions in order to assume safe operation. These findings could influence allowable operating range for automated driving in terms of duration, road type, traffic situations and driving conditions.

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