

DEVELOPMENT OF A MODULAR TOOL FOR SAFETY ASSESSMENTS OF HUMAN-MACHINE-INTERACTION FOR ASSISTED DRIVING FUNCTIONS (SAE LEVEL 2)

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ABSTRACT

Per definition, SAE Level 2 (L2) Systems perform both the lateral and longitudinal vehicle motion control with the expectation that the driver completes the Object and Event Detection and Response (OEDR). Since every system performs also parts of the OEDR itself and this amount of OEDR also varies between different L2 systems depending on the intended system design, it cannot be taken for granted that drivers automatically understand their roles and responsibilities in interaction with the system. Especially highly reliable L2 systems performing a greater amount of OEDR while at the same time requiring only little driver input over time can make it difficult for drivers to correctly identify their role and responsibility.

Until now, neither application-oriented assessment methods nor design guidelines for OEDR related system design features taking safety of human-machine-interaction into account are available. The objective is therefore to deliver a standardized tool for the assessment of human-machine-interaction-related safety of vehicles with L2 systems currently available on the market. To evaluate the impact of different system design aspects on safety of human-machine-interaction and also to be able to differentiate between system designs, a holistic, standardized and application-oriented assessment procedure is proposed. The novel tablet-based assessment tool focuses not only on available standards and guidelines but measures also concrete user behaviour and user understanding in interaction with the L2 systems. The aim is to gain further insights which cannot be measured directly by simple checklist instruments.

For preparation, based on international standards, literature reviews and expert consultations, a first checklist-based expert-evaluation for currently available vehicles with L2 systems was developed. These assessments are focusing on different sources of user information (e.g. user manual), human-machine-interface design as well as the prevention of unintended use by different driver monitoring techniques. The checklist-tool was developed in cooperation with experts of different EuroNCAP test laboratories and validated in a common expert workshop to gain high level of standardization and agreement. However, to assess safety of human-machine-interaction holistically beyond these rather explicit forms of information design criteria, also implicit forms of driver-vehicle-communication via vehicle dynamics, functional behavior or reliability play an important role and should be taken into account. Therefore, the main and novel methodological aim is to consider also interaction related processes regarding user's understanding of roles and responsibilities when applying automated driving functions as well as user's awareness of automation modes or traffic situations in the modular tablet-based assessment tool.

INTRODUCTION

Safety of continuously automating functions strongly depends on and results from successful driver-vehicle-interaction. This effect is particularly strong in case of parallel automation as provided by SAE Level 2 (L2) systems. The human driver and the respective functions can be considered as socio-technical systems requiring prolonged collaboration to ensure safety and enhanced comfort. Vehicle automation in this case is not simply relieving drivers of routine tasks by replacing him or her with continuously automating functions but introducing also new tasks and responsibilities [1]. According to SAE J3016 Assisted Systems (SAE L2) can be defined as "the sustained and ODD [Operational Design Domain]-specific execution by a driving automation system of both the lateral and longitudinal vehicle motion control subtasks of the DDT [Dynamic Driving Task] with the expectation that the driver completes the OEDR [Object and Event Detection and Response] and supervises the driving automation system" [2, p.17]. This means that the system continuously assists the driver in performing the lateral and longitudinal vehicle motion control, for example by combining adaptive cruise control (ACC) and lane centering functions. The driver performs the part of the DDT not performed by the system (mainly the OEDR), supervises the system and intervenes as necessary to maintain safe operation of the vehicle. Nevertheless, every system performs also parts of the OEDR itself, for example reducing speed if a vehicle in front slows down or providing steering torque if lane markings indicate a curve. This amount of OEDR performed by the system and the expectation that the driver completes the remainder of OEDR varies between

different systems and depends largely on the intended system design [3]. In order to create recommendations and assessment criteria for human-machine-interaction in line with this variation, the first objective is to determine different L2 assessment categories with different interaction related requirements.

HOW USERS UNDERSTAND DRIVING AUTOMATION

The driver's understanding of his/her role and tasks within the interaction with the L2 system can be described by the term mental model, a "rich and elaborate structure, reflecting the user's understanding of what the system contains, how it works, and why it works that way" [4, p. 12]. The concept of mental models is strongly related to various psychological constructs and cognitive processes, for example attention and perception, situational awareness, learning and experience, problem solving or trust, reliance and acceptance [5, 6]. The development of a correct mental model concerning the driver's role in interaction with and concerning the functionality of a continuously automating function is one of the most important requirements for safe and adequate use, trust and acceptance [7]. Inaccurate mental models on the other hand are linked to inadequate monitoring behavior [8]. A key human factors issue for L2 systems in terms of mental models is therefore to support drivers develop appropriate reliance on the system, make drivers understand that in terms of secondary task involvement it is not different to manual driving and that the system is not capable of performing all driving situations safely and therefore can fail immediately [1].

Humans and Automation

Meta-analyses show that the effect of automation on human performance in general depends largely on the degree of automation [9]. Although higher levels of automation have been found to improve routine task performance and workload, it negatively affected performance in case of system failures or unexpected events as well as situational awareness in this case. The authors therefore conclude that if manual performance by the human operator is required at some time, as it is by definition for L2 systems, the automation should be designed to keep the operator involved in the decision and action selection as well as the action implementation tasks [9]. Active task involvement, for example by a functional design requiring prolonged hands-on collaboration, seems to be more effective than only passive task involvement, for example by only visual monitoring of displays and traffic situations, and may help the driver understand his/her role in interaction with the system correctly [1]. This involvement seems to be of particular importance, since the performance reduction is often reported to be related to reduced monitoring behavior of the human operator. In this case, it is difficult for humans to monitor a reliable system permanently or to be out of the loop for some short time and then intervene immediately to perform difficult and critical tasks. Therefore, especially for L2 systems, as Seppelt and Victor [1, p. 140] conclude, it is important to consider that "the better the automation, the less attention drivers will pay to traffic and the system, and the less capable they will be to resume control".

Based on the definition of Merat and colleagues [10] the driver using any L2 function should be at least *On the Loop*, which means that he/she is not physically in control of the vehicle but continuously monitoring the driving situation. This driving situation does not only comprise the surrounding environment and traffic but also the performance of the automated driving function. The authors describe the concept of being *In*, *On* or *Out of the Loop* as a continuum rather than a distinct state which requires a lot of experience and knowledge for a driver to handle all situations safely and at the same time gain a maximum of comfort. Since the intensity of cognitive control may be different in different driving situations, the driver needs experience on a meta-level when to invest how much cognitive effort. In manual driving this is a well trained routine task. Drivers normally know when extensive monitoring is required and automatically decide from a moment to moment basis. When using automated or assisted driving functions this automatic decision may be interrupted. Since the driver is not physically in the control loop this makes it somehow more difficult to assess all driving related information immediately and correctly. Human-machine-interaction in this case is not limited to visual or auditory information communicated via displays and speakers only but in broader sense also includes every kind of information processing between the human being and the vehicle [11]. Besides rather explicit forms of information design in display and control elements, also implicit forms of communication, for example vehicle dynamics or system behavior and reliability within different situations and contexts as well as any haptical communication (e.g. how strong is the steering wheel resisting input of human driver when the system is active) play an important role.

Roles and Responsibilities in redundant parallel automation

It cannot be taken for granted that drivers automatically understand their roles and responsibilities when using continuously automating functions. Knowledge concerning system limitations as well as reacting correctly towards potential hazardous situations is the result of an extended learning process [12]. Especially the

redundant parallel automation of L2 functions can be ambiguous, since the proportion of OEDR performed by the system depends largely on the system design and its limitations. Even when driving the same route every day, the same system can behave completely different depending on different situational factors, for example weather, lighting, surrounding traffic or speed conditions. Furthermore, the relationship between the designer and the user of the function is of specific relevance. Designers of automation expect users to behave in a certain way to interact appropriately with the function to ensure safe and comfortable use. However, these assumptions or expectations can diverge from the way users actually behave and interact with the automation [13]. Therefore, trust and reliance need to be carefully taken into account when designers define the ideal or intended use or try to anticipate the actual use of automation. A safe human-machine-interaction strategy should make sure that designers and drivers have one common understanding about how to make use of the respective function.

MISCONCEPTIONS AND HUMAN FACTORS PROBLEMS RELATED TO ASSISTED DRIVING

Misconceptions regarding these basic functionalities can lead to dangerous situations and accidents as for example the fatal crash of a Tesla Model S operated in Autopilot mode in May 2016 in Florida (investigated by the US National Transportation Safety Board (NTSB)) has demonstrated [14]. The Tesla driver was travelling with active Autopilot on a US highway when an oncoming semitrailer truck crossing his travel lanes to make a left turn into a local road. The Tesla crashed into the right side of the semitrailer and went underneath it. The roof of the car was torn off. The driver died in the accident. The agency concludes that the Autopilot system did not brake for the crossing truck because it was not designed to do so, but that the driver's pattern of use of the Autopilot system suggests a misunderstanding of his role in interaction with the system as well as over-reliance on the system's capabilities [14]. As a result, the driver did not pay as much attention as required in the respective situation and did not react to the crossing truck. The Autopilot system on the other hand was not able to monitor the driver's inattention and intervene effectively.

Besides these tragic misconceptions, at the same time more and also more different kinds of continuously automating functions requiring collaboration between the human operator and the vehicle appear and will come to the market in the foreseeable future [11]. Here, a common trend is observable that small and simple tasks formerly performed manually by the driver are now automated and performed by a continuously automating function. The BMW Driving Assistant Plus in the BMW 5 Series 2016 Version for example was able to adapt speed to traffic sign recognition if the driver confirmed via control input and was not able to adapt speed (based on GPS information or camera detection) prior to entering a curve or in front of a roundabout. The 2019 Version of the System, now called Driving Assistant Professional, for example in the X5 (2018) or 3 Series (2019) is able to adapt speed to traffic sign recognition without any driver input (if this option is chosen by the driver) and is also able to adapt speed prior to entering a curve or in front of a roundabout. The Tesla Autopilot Software Update 9.0 in the US is introducing a function called "Navigate on Autopilot" [15]. The function "guides a car from a highway's on-ramp to off-ramp, including suggesting and making lane changes, navigating highway interchanges, and taking exits" [15]. Although Tesla strongly claims that the driver is always responsible and should pay attention while using this function, it is obvious that the driver is taken even further out of the DDT (because more OEDR is performed by the function) and pushed into a passive monitoring task with less frequent interactions.

Altogether, these are only small and very simple changes but represent a common trend: Tasks formerly performed by a human driver are now automated, which at first sight seems to be an enhancement in system performance, but as was already mentioned: "the better the automation, the less attention drivers will pay to traffic and the system, and the less capable they will be to resume control" [1]. Therefore, just because it is technically possible to automate an even small and very simple task, from a human factors perspective it is not always beneficial to do so.

Automation related task changes

The example of the system automatically reducing speed prior to entering a roundabout demonstrates different human-machine-interaction related problems or concerns: First, the feedback a driver gets in this situation is reduced and/or qualitatively different compared to approaching a roundabout driving manually. Besides purely visual information of the road scene or vehicle displays, the manual driver perceives also proprioceptive feedback, for example the feelings of reduced speed because of his/her actions in pressing the brake pedal. When the system is reducing speed ("feet-off"), only visual information is left, which can make it more difficult to assess the situation and decide whether to brake or speed up in case another car is already driving in the roundabout [16]. The automation in this case distances the driver from the process of approaching a roundabout,

a very ordinary task in daily driving can be more challenging just because a source of informal or implicit feedback is taken away.

Second, to monitor an automated system approaching a roundabout is basically a passive observation task where at the end the driver has to decide whether to do something, for example to brake or speed up, or to let the automation control the speed through the roundabout. This task is qualitatively very different compared to monitoring the situation actively when controlling the vehicle manually [17, 18]. In the manual control condition, perception actively supports control actions, and control actions guide the way of perception [19]. However, this process is disrupted by only monitoring automation guiding the vehicle.

Third, the driver's mental model may be inadequate to guide expectations and control inputs. For example, the automation control algorithm in the described situation approaching a roundabout could be designed to decrease speed early and continue with a constant low speed into the entrance of the roundabout without further deceleration or acceleration. However, a driver's manual control strategy as well as his/her mental model of the function and situation might be very different. Anticipating vehicle actions as well as system limits may therefore be complicated or even fail in this case [20]. Previous experiences and well developed mental models simplify the interaction but it needs some time and learning until they are developed holistically [7].

Last, by developing functions which automate very easy and ordinary tasks of a human driver, as slowing down when approaching a roundabout, designers are running the risk of creating clumsy automation. The term refers to a concept where automation makes easy task easier, but harder task harder [21]. As Bainbridge [22] reports, users are often left with the most difficult tasks of a certain operation because designers are not able to automate them. However, because easy tasks are automated, the user is disrupted from the process and the context of performing the operation as a whole, which makes it difficult to respond correctly to the left over difficult tasks only. Reducing speed when approaching a roundabout is a simple task and the decision to brake or speed up depending on the traffic inside the roundabout often is done in one go with it. However, performing the decision task only without feet on brake or accelerator pedal before is a change in the structure of the task, which can make this isolated task more complicated compared to performing the whole task at once.

The mentioned problems or concerns do not necessarily mean that a function reducing speed prior to entering a roundabout is something bad or dangerous per se. It is intended to demonstrate that vehicle automation, even when focusing only at L2 functions, is a continuum of automating different tasks of driving. Since the driver is always responsible for safe driving when using these functions, he/she is supposed to perform all tasks the function is not designed for and also to intervene if the function makes a mistake. These two tasks are structurally different to driving manually, which can make it harder for drivers to behave correctly, especially in difficult or accident-prone driving situations, which in general occur very rarely.

Automation mode related problems and driver behavior

Besides these problems related to the concrete task execution of driving, also errors concerning the perception and understanding of the automation mode or status can occur. The aspects of mode confusion and mode related errors basically result from two factors: poor monitoring behavior combined with poor feedback. Research concerning automation in aviation shows that unexpected mode changes of autopilot systems often surprise pilots and sometimes even remain unnoticed [23]. In automated driving similar problems could arise. Therefore, feedback as well as an intuitive monitoring strategy should support the driver in understanding the current system mode or state and help him/her to be able to react immediately to system initiated mode changes.

Negative effects of automation can also result on a behavioral level. Behavioral adaptation is a phenomenon well known by social-psychologists. Diffusion of responsibility, also called the bystander effect or pluralistic ignorance, describes an instance of behavioral adaptation where a person is less likely to act and take responsibility in a certain situation (e.g. an emergency) if other persons are present or available which could probably also take responsibility [24]. The effect is linked to lower performance of individuals working in groups and can also be transferred to human-machine-interaction related tasks where the human operator and the machine are working together. Hence, with respect to driving automation, subjective responsibility diffusion can lead to drivers spending less effort in controlling and monitoring the driving situation while the automation is active, since these tasks are also at least partially performed by the machine. Clear communication of roles and responsibilities can only support drivers in monitoring and interacting with the system whilst holistic L2-design designated to sustained driver involvement is the most promising approach.

DEVELOPMENT OF A MODULAR ASSESSMENT TOOL FOR ASSISTED DRIVING FUNCTIONS

Taking the afore-mentioned human factors related problems and concerns as well as the available guidelines, standards and assessment criteria into account, it becomes clear that assessment of safety of human-machine-interaction for the large bandwidth of L2 systems currently available on the market is not as easy as it might seem at first sight. Therefore, the first aim of this research is to develop and validate standardized assessment instruments which focus on two aspects: 1. design of the human-machine-interface (HMI) as well as 2. design of the functional behavior per se (e.g. functional reliability, steering quality, automated tasks, etc.) from a human factors perspective. The second aim is to deliver guidelines and requirements for the functional design of automated driving functions taking not only HMI design principles into account but also the influence of implicit information on the development of mental models and driver behavior. To do so, measures and instruments focusing on these aspects have to be developed first.

A first collection of standards, guidelines and best practices regarding the design of rather explicit forms of communication via classical visual-auditory or visual-vibrotactile HMIs for automated driving functions can be found in the recent paper of Naujoks and colleagues [25]. However, taking also implicit forms of communication via functional behavior into account two problems arise: First, no guidelines or standards concerning this form of driver-vehicle-interaction are available in the field of automated driving so far. Second, also methods measuring the influence of system settings or behavior on the driver's mental model and behavior are not available so far.

Due to its various facets especially the measurement of a driver being *On the loop* is difficult [10]. Since the driver is not physically in control of the vehicle a detection of drivers' physical activity based on in-vehicle sensors seems insufficient. Many studies on automated driving therefore focus on measuring drivers' visual behavior and try to assess quality and quantity of monitoring behavior by analyzing gaze or fixation patterns with eye-tracking camera systems. Nevertheless, since monitoring traffic situations and system performance and reacting to an upcoming system limit are very complex cognitive tasks, relying only on eye-tracking measurements doesn't reflect this process adequately [8]. Observing driver behavior as well as interviewing drivers about their understanding may support the assessment of the quality of monitoring behavior. However, without further standardization or routine this methodology can be very time and resource consuming in preparation, execution and analysis of required driving trials with subjects. Such tools are therefore mainly used in research projects but seem to be inappropriate for applied contexts, for example in NCAPs or type approval, at first sight. Therefore the development of a standardized modular assessment tool including observations and interviews of drivers and focusing on the special needs of applied contexts is proposed. The aim is to bundle advantages of different methods without unnecessarily inflating the effort but at the same time reaching a reliable and valid assessment result.

Checklist-based expert evaluation

Based on international standards, literature reviews and expert consultations, a first checklist-based expert-evaluation for currently available vehicles with L2 systems was developed. These assessments are focusing on different sources of user information (e.g. Is the correct use of the function described precisely and in plain language in the user manual and is it in general easy to read?), human-machine-interface design (e.g. Is the activation straightforward?, Does the driver get appropriate feedback about current status?) as well as the prevention of unintended use by different driver monitoring techniques (e.g. Does the system effectively promote proper use by means of driver monitoring?). The checklist-tool was developed in cooperation with experts of different Euro NCAP test laboratories and validated in a common expert workshop to gain high level of standardization and agreement.

Results indicate that at least two different kinds of L2 systems can presently be identified: One category of systems (category A), which only support drivers to some extent by providing limited steering torque, as well as another category of systems (category B), which enhance assistance and actively reduce frequency of driver response execution by precise adaptation of speed and/or steering torque required at specific road sections (e.g. by means of GPS-based digital maps or vehicle fleet based learning algorithms). The co-operative systems of category A involve drivers in the driving task by design. The systems allow and require driver input, for example steering in curves. Driver out of the loop phenomena are less likely to occur because of the need for the driver to permanently interact with the system. Experience of system limitations is clear and frequent. Driver disengagement from the driving task is prevented by prolonged hands-on cooperation with the system. Driver activity (e.g. steering) in this case is seen as an indicator of driver attentiveness. Since a greater amount of OEDR is performed by the driver, requirements regarding human-machine-interaction are lower compared to systems which relieve the driver more frequently from performing OEDR. A basic status indication as well as simple hands-on detection in this case may be sufficient to keep the driver focused on performing the DDT.

Systems of the other category B offer drivers a broader use and comfort, but at the same time from a safety perspective require additional measures to actively keep the driver in the loop. Driver engagement and activity have to be ensured since often no permanent interaction with controls (e.g. steering wheel) is required. Since a larger amount of OEDR is performed by the system (compared to systems of the other category), the driver may experience greater difficulties in understanding the permanent role of parallel OEDR execution. Driver out of the loop phenomena are likelier if no additional instruments are implemented to keep the driver interacting with the vehicle or responding to objects and events in the driving environment. A goal-oriented and effective status feedback and warning strategy has to be defined to make sure that drivers are able to react immediately and appropriately even in rare events. However, especially for these systems it is difficult to assess the safety of human-machine-interaction by means of a checklist based method only, because there is a fine line between driver In, On or Out of the Loop if no permanent interaction and hands-on collaboration is required. Assessments of a driver's correct understanding of his/her role and responsibility cannot be carried out by HMI design checklists only.

Development of a tablet based observation and interview tool

Since the described checklist based procedure is focusing on design criteria only, further assessments should also include observational and interview measures of user studies taking into account interactional processes regarding users' understanding of roles and responsibilities when applying automated driving functions as well as users' awareness of automation modes or traffic situations. A first standardized observational tool for assessing safety of human-machine-interaction for automated driving is currently being validated in a simulator study. The semi-automated, tablet based application allows human factors experts to directly observe and assess the interaction of naïve users with any automated driving function. This scenario based procedure allows the observation of interactional behavior in average traffic situations. For example the matter of assessment might be whether a driver distracts him/herself or is unsure about how to put his/her hands on the steering wheel while the system is active. Based on these observations conclusions concerning reactions in difficult situations can be drawn and also observed. Three observation categories (system control related problems, general vehicle guidance related problems, system monitoring behavior and misuse) with different observable behavior patterns are proposed. A general rating of driver-vehicle-interaction performance based on the rating scale of Neukum and Krüger [26] can be used to assess the accomplishment of interaction related critical and non-critical situations, for example activation or deactivation of system, monitoring behavior while system is active or reaction in case of system limits. Besides observation, the tool also supports the assessor's decision by delivering standardized questionnaire items. These items focus on the role and understanding of the driver in certain situations as well as on trust, comfort and usability. Results of the validation of the whole tool will be published in the near future.

CONCLUSION

L2 systems require the driver to perform the part of the DDT not performed by the system (mainly the OEDR), supervise the system and intervene as necessary to maintain safe operation. Since every system performs also parts of the OEDR itself and this amount of OEDR varies between different systems and depends largely on the intended system design, it cannot be taken for granted that drivers automatically understand their roles and responsibilities. Misconceptions on the other hand can lead to dangerous situations and accidents and should therefore be avoided by safe human-machine-interaction design. However, a common trend is observable that small and simple tasks formerly performed manually by the driver are now automated and performed by a continuously automating function. This kind of automation changes the structure of the whole task of safe interaction and can make it difficult for drivers to react if something unexpected happens. Therefore, to assess safety of human-machine-interaction holistically, different assessment methods should be taken into account. This includes besides rather explicit forms of information design criteria in display and control elements also implicit forms of communication via functional behavior and task reliability. The aim of this research is to develop on the one hand standardized methods for measuring and assessing the influence of these implicit forms of information on human-machine-interaction as well as on the other hand guidelines and requirements for the functional design of automated driving functions taking not only HMI design principles into account but also the influence of implicit information on the development of mental models and driver behavior.

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