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Towards a Framework for Testing Drivers' Interaction with Partially Automated Driving

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***Abstract*— Partially automated driving takes away driving control from the driver in situations which allow complete automation, but leaves final responsibility for safe driving at the human operator. Accordingly, the driver's role changes to supervision, and – occasionally – intervention. For testing required solutions to support drivers' new interaction with partially automated driving systems, this study proposes an assessment framework, aimed for application early within the development process while using driving simulation. We conclude that the assessment aspects within the envisioned framework should be three-fold, i.e. assess (a) Situation Awareness; (b) Accident Avoidance, and: (c) Acceptance. Measurement techniques to test these aspects have been defined. Moreover, six traffic scenarios have been evaluated for their successfulness in creating different levels of difficulty in understanding and solving traffic situations representative for the interaction between partial automation and drivers. While defining the required assessment aspects and confirming the scenarios' relevance, this study is an important step to establish the desired framework.**

Keywords: Automated driving; Driver-interaction; Interface; Assessment; Traffic Scenarios; Driver support; Design.

I. Introduction

Driver Assistance Systems are entering the market which allow automation of both lateral and longitudinal driving control during specific situations within existing infrastructure (e.g. motorway cruising). Because the automation of the introduced systems is restricted by technical boundary conditions (i.e. detection of road lines and detection of a target vehicle) and set system conditions (e.g.: driving on a motorway with speeds below a specific threshold), these systems aim at raising comfort during specific situations – like congested driving. The system conditions are set to ensure a sufficient level of safe system operation. However, situations in which the automation exceeds her boundary limits easily occur due to the changing environment (e.g. road works) or (unexpected) behaviour of other road users [1]. Keeping in mind that the driver remains responsible for safe driving, the driver is required to act as a back-up (and to retrieve control) in case automation fails or stops [2]. As a consequence, this application of system control is referred to as *partially automated driving*. During automation, the role of the driver changes from actively operating the vehicle to supervising the system [3]. However, performing supervisory tasks is not something humans are particular good at. Due to the relation to low vigilance, supervisory tasks cause e.g. slower reaction times and misinterpretation when intervention is needed [2], [4]. Carefully designed driver-interfaces are therefore needed to support drivers in their additional role to supervise the automation and to support them retrieving control safely and adequately when required. A challenge in designing these interfaces lies in the difficulty to assess the contribution potential interfaces have in offering the desired support. This article therefore proposes an assessment framework for testing drivers' interaction with partially automated driving systems, especially with regard to supervision and intervention. It defines required characteristics of the assessment the framework is aiming at. Next to it, the applicability of traffic scenarios created within the framework to provide an assessment-context representative for partially automated driving is evaluated with a driving simulator experiment. Following these results, the paper concludes with recommendations for a next step to validate congruency of the framework's assessment aspects – which will be subject to a future study.

II. Concept of Framework

Implementation of partially automated driving brings along ambiguity: It takes away driving control from the human operator (driver) and at the same time the human driver should preserve final responsibility for safe driving. Saying that, successfulness of partially automated driving will to a considerable extend depend on the question whether conducting supervisory control (including now and then intervention of system-control) will be less effort-taking than human operators driving themselves. At least three aspects influence the answer to this question.

First of all, road and traffic situations encompass highly dynamic and unreliable traffic behaviour. If this behaviour cause frequently transgression of system's boundary conditions (and systems subsequently urging for extra attention and driver's intervention), this will be detrimental to system acceptance. Secondly, system design largely influences correct recognition of changes in environmental or boundary conditions. As a consequence, good system design helps counter fighting false warnings. Thirdly, the appropriateness,

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accuracy and efficiency of the interface-support itself also influence system-acceptance.

An example will explain the last aspect: Automotive developers typically distinguish between 'soft' and 'hard' warnings. 'Soft' warnings encompass pre-warnings for situations which require extra attention or for situations being potentially hazardous, e.g.: warning for low outside temperatures. Hard warnings refer to situations which require immediate intervention to overcome a critical situation. The design of these 'soft' and 'hard' warnings include the modality, intrusiveness and timing of provided information. Their design will influence important aspects like correct understanding of potentially dangerous situations, correct intervention, but also acceptance. If, for example, 'soft' warnings are mistakenly conceived as an obligation to take back control, this would cause irritation and therewith undermine acceptance.

Assessment of offered interface-support is the core subject of our framework. Obviously we don't want to pursuit this aim without neglecting the influence from the other two aspects (traffic situations and system design). Hence, scenarios which provide relevant context within which interface-support for partially automated driving can be tested, are included in our envisioned framework. Defining scenarios representative for the dynamic and diverse character of possible road and traffic situations associated with partially automated driving, allow treatment of system design and traffic situations as control variables within our framework. Before reviewing relevant scenarios, the next section will first summarize the main scope of the envisioned framework.

A. Basic Principles for the Assessment Framework

Due to the large influence offered interface-support has on acceptance of ADAS in general – and thus also of partially automated driving, it is important that our framework will be implemented early within the development phase [5]. Following up on previous considerations basic principles of the envisioned framework are:

- The framework allows comparison between levels and types of support early in the design phase in order to distinguish between appropriateness of interface-solutions. It allows inappropriate solutions to fail fast.
- The framework assumes application within driving simulator experiments. This is due to: (1) the difficulty to test with prototypes in real-world early within the development-phase; (2) For reliably and reproducibly testing controlled environments are preferred; (3) Some of the traffic situations important to partially automation are too dangerous to test in real life circumstances.
- The framework allows to assess driver-interaction with partially automated driving systems. Therefore, scenarios which are representative for the cooperation between automation and drivers' tasks to supervise and intervene are an inextricable part of it.

B. Scenarios for Assessment

Golden rule in driving simulator research is that test conditions include the physical environment, restrictions on available information, time limitations, etc. representable for the real world circumstances [6], [7]. To define scenarios representable for partially automated driving as referred to in the previous sections, we acknowledge that system design of currently developed systems allows automation only on motorways and with relatively low speeds. Therefore the scenarios focus on vehicle automation during congested traffic. On an arbitrary basis we choose the speed-threshold at 50 km/h, meaning that automation would only be available below this speed. Furthermore, restrictions on system's availability are defined by three technical prerequisites: (a) recognition of a target-vehicle, (b) minimum required follow-distance and (c) recognition of road lines. If any of these boundary conditions are not being met, this would cause termination of the automation. To create a set of relevant scenarios, we reviewed a catalogue with more than 30 identified situations requiring human attention and/or intervention [1]. Our defined scenarios (explained below) offer a condensed set of relevant situations, which are generally implementable in driving simulator environments. Important criterion for selection was that they together provide a set with sufficiently different levels of required comprehension and ability to solve a situation in order to be representative for the dynamic and diverse character of possible road and traffic situations associated with partially automated driving. Therefore we distinguish two categories: so called 'hazardous' and 'critical' scenarios.

The next three 'hazardous' scenarios were created to enclose situations with a need for extra attention from the driver, but without the necessity for intervention:

- **Scenario 1a "complex road"** – In this scenario, the ego-vehicle approaches a combined on and off ramp. Although the ego-vehicle continues on the main road, driver's attention is needed because the likelihood that some vehicles will enter or exit the main road simultaneously causes potential danger.
- **Scenario 2a "vehicle passing"** – While the ego-vehicle is driving at the left lane, a vehicle passes at the right and violates traffic rules. Therefore, extra attention is needed.
- **Scenario 3a "speed oscillation"** – Within this scenario, traffic slows down to approximately 35 km/h and later on accelerates again. When speed transgresses 50 km/h attention is needed because the system would terminate if follow-speed would continue to be above the system's speed threshold.

Ideally the set of 'hazardous' scenarios should also encompass a situation with failing road lines, as such situation is likely to occur. (Due to difficulties with implementation of such scenario in our available driving simulator we left it aside for our study.)

Next, three 'critical' scenarios were created to enclose situations which require driver's intervention in order to avoid an accident:

- **Scenario 1b "emergency brake"** – Within this scenario a target vehicle performs an emergency brake unexpectedly with deceleration rates exceeding system boundaries. Without intervention a collision would therefore be inevitable.
- **Scenario 2b "merge out"** – The ego-vehicle drives at an entrance road that transgresses into a combined on and off ramp. Navigation instructions are set to stay on the combined on and off ramp, that is to exit the motorway again. Just before the end of the exit, the target-vehicle decides to change lane. As there is no new target-vehicle, the system requests the driver to take back control and stops automation. Without intervention the vehicle roles out uncontrolled. Hence, accident avoidance involves in this scenario preventing the vehicle from leaving the lane.
- **Scenario 3b "cut in"** – While the ego-vehicle passes an exit, a neighbouring vehicle cuts in unexpectedly and brakes strongly in an attempt to take the exit in time. This is a critical situation because system boundaries for minimum required follow-distance are being violated. Therefore a collision would be inevitable without intervention.

III. Assessment Aspects

Goal of the envisioned framework is to test support offered by interfaces to perform supervisory tasks and to intervene system-control for partially automated driving. Supervisory control is strongly related to driver's understanding how the system reacts to difficult situations in combination with knowledge and understanding of required human (re)actions. As a consequence supervisory control especially requires cognitive capabilities. Intervention, on the other hand, is strongly related to operational capabilities to perform fast and accurate counter-measures to solve a critical situation. Because the interface-support relates to both supervision and intervention tasks and because of its influence on system-acceptance, the assessment aspects within our framework should be three-fold: (a) Provide insight in *situational understanding* of human drivers operating partially automated driving; (b) Measure *performance* when solving critical situations, and (c): Review *acceptance* of offered interface-support. For assessing acceptance of ADAS, Van der Laan, et al. [8] provide a standardized scale, which will also be included in our framework. The scale distinguishes two dimensions: Perceived Usefulness and Satisfaction. The next two sections explain considerations to operationalize assessment of the other two aspects with existing measurement techniques.

A. Assessment of Situational Understanding

To provide insight with regard to the quality and comprehensiveness of the offered support, Situation Awareness (SA) is an important informative measure. Situation Awareness (SA) is being defined by Endsley [9] as a psychological construct, comprising of three levels: (1) The observed presence or absence of elements in the situation; (2) The participants' comprehension of these elements, and (3); The anticipated future state of the elements. Situation Awareness overlaps with the first three processing steps generally involved in driving, i.e.: (i) perception; (ii) comprehension; (iii) projection, (iv) decision making and (v) implementing. This explains why SA is theoretically considered a necessity to enable performance of the complete driving task [10]. Therewith measurement of SA allows a more fundamental assessment of the consequences from the changing drivers role from actively operating the vehicle to supervising the automation.

Based on Salmon, et al. [11] we consider 2 categories of SA measurement methods applicable for our assessment framework:

- **Freeze probe techniques** involve probe-taking during "freezes in a simulation and enable direct and objective measurement of SA. Probe-taking is based on questions and their answers are representative for SA, e.g.: "Is there currently (i.e.: during "freeze) a vehicle on the neighbouring lane?". Within this category, the Situation Awareness Global Assessment Technique (SAGAT) [12] is most commonly used for SA assessment in driving [10].
- **Self-rating techniques** involve self-assessment by participants based on standardized queries. Dis-advantage of self-rating techniques is participant's difficulty or inability to rate levels of SA themselves [12]. Due to the ease of application (fast and low cost) self-rating techniques are nonetheless wide-spread used and the Situation Awareness Rating Technique (SART) [13] is most popular.

Although both techniques are quite well adopted, the reliability and validity of respectively SAGAT and SART measurement methods, are subject to discussion [11]. Most existing studies show results in favour of SAGAT, by e.g. showing better face validity [11]. However, there is hardly any information available from experiments with measuring SA in time-critical driving situations, neither on the specific probes relevant within such studies [14]. For our framework we therefore prefer to not rely on one SA-measurement technique alone. Moreover, we recognise that both techniques are complementary to one another: In addition to objective SA-measurement (based on SAGAT), SART allows assessment how aware drivers perceive themselves to be about the elements relevant for task-performance. This is especially important because drivers appear to show a concerning lack of self-awareness of their SA and any shortfall in it [15], [16].

B. Performance measures

According to Harris "The application of performance testing includes evaluating the design of equipment and systems, particularly where human performance is critical to successful operation" [6]. Performance tests are like the actual task. In our case this concerns final responsibility for safe driving and the task to retrieve control if automation fails or stops. Because attempts to retrieve control could come with a variety of actions, like braking or swerving out, we consider a combination of the following measures important for the assessment of driving performance within our framework: (a) *Accident Occurrence* by observing collision or road-departure; (b) *Collision Avoidance* by observing successful manoeuvring to avoid danger, without accident occurrence; (c) Measurement of *Time-To-Collision* (TTC) at specified moments. The time left until an accident would happen is based on parameters which indicate the severity of impact, i.e.: time headway and deceleration [17]. Therewith, TTC provides numeric data for assessing accident avoidance.

IV. Method

The scenarios in section II have been selected in order to be representative for varying system-design's behaviour as a result of varying traffic circumstances associated with partially automated driving. Therefore, the scenarios have been created as a set with different levels of required understanding and ability to solve situations. A distinction is made between 'hazardous' scenarios (requiring extra attention but no intervention) and 'critical' scenarios in which intervention is required to avoid an accident. A driving simulator experiment has been used to verify whether the scenarios are successful in creating circumstances with the intended differences in level of difficulty. In particular, we assume that the critical scenarios will be perceived more strenuous than the hazardous scenarios. But we are also interested in other differences, like whether scenarios are within their category comparably difficult or not and, if not, why.

A. Task

The task given to the participants was that they were responsible for safe driving, also during system-control. Before the test, each participant was explained what the general boundary conditions are for the system to be able to operate. Therewith, participants got to understand that situations could occur which require extra attention or intervention. The participants were asked to intervene only when an accident seems inevitable to their judgement. In order to include realistic circumstances, participants had functionality at their disposal from a simulated smartphone app shown at the top of the centre console. As participants remained responsible for safe driving, they were advised to divide their attention appropriately. Decisions whether the situations allowed performing secondary tasks was to the participants own judgement.

B. Experimental Design

The independent variable within this experiment was Scenario, which was manipulated within subject: Each participant was confronted with three hazardous situations and three critical situations, according to the scenarios defined in the section II. The participants did not receive prior explanation on what to expect within a scenario. This was to make the situations non-predictable. For the same reason one situation was added in which the participant was also driving automatically, but no critical or hazardous situation occurred. For reasons of practicality, the order of scenarios was the same for each participant, i.e.: 1a; 1b; 2a; 3a; 3b; 2b

The applied dependent variables were: Accident Avoidance, Mental Effort and Demand. Measurement of Accident Avoidance allowed to compare among critical scenarios to what extend participants were able to solve the situation. Because the hazardous scenarios did not involve accident avoidance, this measure had only relevance within the critical scenarios. Mental Effort was used as a dependent variable to assess whether the scenarios evoked different levels of difficulty for supervising and overruling the automation. It was administered immediately after each scenario by using an effort self-report questionnaire: Rating Scale Mental Effort (RSME) [17]. Mental Supply was collected by a sub-set from the SART-questionnaire [13]. The standardized self-report questions refer to perceived need for attention and concentration in order to understand and solve a situation.

Fig. 1. Driving Simulator Environment

C. Simulator Environment

The study was undertaken in a driving simulator comprises 180° viewing angle with 3 projection screens, see figure 1. The projection provided a simulated motorway environment in line with the scenarios described in section II. Mirrors and speed were projected onto the outside screen. Participants were seated in a mocked-up vehicle equipped with common automobile control interfaces, including a physical steering wheel, physical gas and brake pedals and an automatic gearbox. The instruments allowed participants to take full control of the vehicle if necessary. Other vehicles drove in front, aside and behind the simulated vehicle. All vehicles drove with time headways between 1 and 1,5s. at about 50km/h, as to simulate traffic congestion. The position of the neighbouring vehicles was identical within each trial of a specific scenario to ensure that every participants got the same chance of resolving the situation.

D. Participants and Procedure

Among students and university employers twenty-four persons participated in the study. Their age ranged from 20 to 40 years old and the participants had at least one year of driving experience. Per participant the experiment lasted 1 hour with approximately 15 minutes of instruction and training with the driving simulator, six times a 6-minutes trial and an interview. Due to practical reason of the available driving simulator software, participants were driving at the start of each scenario directly automatically with a speed of about 50 km/h. This direct launch was also explained beforehand. At the end of a scenario the simulation paused. The timing of the scenario allowed participants to experience the successfulness of their intervention just in time, without new driving situations being introduced again.

V. Results and Discussion

The scenarios were deliberately designed to resemble different traffic situations and to allow differentiation between hazardous and critical situation: The intention was to create relevant contexts for testing appropriateness of interface-support. Most accidents occurred in scenario 1b, i.e. 8 times (n=24) Scenario 2b denoted no accident and scenario 3b only one. Figure 2 shows that mental effort differed substantially between scenarios. The mean RSME score was highest for scenario 2b (Merge Out) (Mean=42,5; SD=20,3). Results from pair-wise t-tests confirm that in line with their design all three critical scenarios showed significant higher RSME scores than the hazardous scenarios 2a (Vehicle Passing) and 3a (Speed Oscillation)

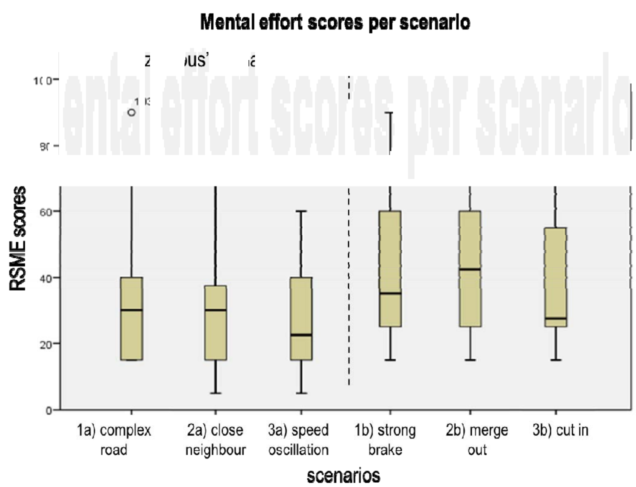

Fig. 2. Mental Effort Scores per Scenario

Among the hazardous scenarios, 1a (approaching complex road) was requiring most effort (M=34,4; SD=20,7). The required effort was comparable to the critical scenarios. Hence, there was no significant difference in RSME score between scenario 1a "complex road" (M=34,4; SD=20,7) and scenario 1b "emergency brake" (M=41,7; SD=24,2); t(22)=1,752, p =0,094. And neither, between scenario 1a and scenario 3b "cut in" (M=36,7; SD=19,5); t(23)=0,548, p =0,589. These results indicate that the perceived effort for 1a in which participants approach a complex road is comparable to the critical scenarios 1b and 3b. This is remarkable, because in contrast to 1b and 3b, scenario 1a "complex road" had not a designed danger for direct collision.

The results show that the scenarios succeeded in providing different levels of 'difficulty'. The critical scenarios generally required more effort than the hazardous scenarios – as was also intended. Most differences in required effort between critical and hazardous scenarios were significant. When comparing measures between the critical scenarios, we see that scenario 1b was based on objective measures (Accident Occurrence) most dangerous. However, it did not require most effort, nor was it perceived most demanding. The most demanding and strenuous scenario was 2b (entering a combined entrance and exit lane). When we continue to review mental effort scores, we see that the hazardous scenario which required most Mental Effort (1a: "Complex road") had scores comparable to critical scenarios. Interestingly, both scenarios with highest scores from each category (i.e. 1a "Complex road" and 2b "Merge out") resemble each other as both involve most change in visual road complexity. The high score for 2b "Merge out" is remarkably, since within the critical category this scenario had least danger of collision. The high score for scenario 1a could be explained by order-effects: it was the first scenario participants encountered and they were then inexperienced on what to expect. Although order-effects could indeed have influenced scores, the other scenario with highest RSME-scores (2b) was for each participant the last one. Due to the similarity between both scenarios with respect to visual road complexity, a plausible explanation is that gradually evolving complex road situations are perceived more strenuous as a very sudden and dangerous but short traffic event.

Furthermore, we see that these scenarios did in general not require very high levels of mental effort. For reference; the standardized RSME score defines a level of "85" as "great effort" and "112" as "extreme effort". Mean scores for scenarios ranged between 20 ("just a little") and 40 ("some effort"). Although there were large individual difference, there were no scores higher than 90. These relatively low scores could in general being explained by using the driving simulator environment as it takes away the real risks of reduced performance.

VI. Concluding Remarks

Assessment of interface-support for drivers' interaction with partially automated driving is characterized by three aspects: (1) offering support to drivers in cognitive capabilities especially during supervision; (2) support of intervention-capabilities, and (3) the influence interface-support itself has on acceptance. We therefore conclude that the assessment aspects within the envisioned framework should be three-fold too, i.e. assess (a) Situation Awareness; (b) Accident Avoidance, and: (c) Acceptance. Measurement techniques to assess these aspects have been defined. To take also account for the influence system design and traffic circumstances have on driver-interaction with partially automated driving, six traffic scenarios have been created within the framework. The scenarios have been selected to embody different system-design's behaviour as a result of varying traffic circumstances. Herewith, the intention was to create different levels of required understanding and ability to solve a situation. Differences in mental effort associated with the scenarios confirm the framework's successfulness in creating relevant contexts representative for the cooperation between partial automation and drivers' tasks. The mental effort associated with the scenarios is however, generally speaking, low. This is likely due to the dominantly 'calm' driving situations, i.e. motorway driving with low speeds. Comparison of the traffic characteristics anchored in the scenarios revealed that mental effort was associated with visual change much more than with actual danger of an accident. As we had difficulties creating rather heterogeneous road environments – e.g. adding more variety in road layout and signs, we presume that a 'richer' environment would probably have helped raising perceived effort to more realistic levels. However, application of the framework is focussing on comparable assessment between interface-concepts, therefore it is particularly important that the scenarios denote identifiable different levels of difficulty – which they do. As perceived effort could have been influenced by scenarios' sequence, we recommend to randomize their order during future application of the framework. While defining the required assessment aspects and confirming the scenarios' successfulness to create contexts representative for the interaction between partial automation and drivers, this study is an important step to establish the desired framework. For its further implementation a recommended next step is to validate congruency between assessment aspects during a test-trial with preliminary interface-concepts. Herewith, development of the framework is an important contribution to help developers creating adequate interface-solutions drivers are in need for when interacting with partially automated driving.

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