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How to assess driver's interaction with partially automated driving systems – A framework for early concept assessment

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ABSTRACT

The introduction of partially automated driving systems changes the driving task into supervising the automation with an occasional need to intervene. To develop interface solutions that adequately support drivers in this new role, this study proposes and evaluates an assessment framework that allows designers to evaluate driver-support within relevant real-world scenarios. Aspects identified as requiring assessment in terms of driver-support within the proposed framework are Accident Avoidance, gained Situation Awareness (SA) and Concept Acceptance. Measurement techniques selected to operationalise these aspects and the associated framework are pilot-tested with twenty-four participants in a driving simulator experiment. The objective of the test is to determine the reliability of the applied measurements for the assessment of the framework and whether the proposed framework is effective in predicting the level of support offered by the concepts. Based on the congruency between measurement scores produced in the test and scores with predefined differences in concept-support, this study demonstrates the framework's reliability. A remaining concern is the framework's weak sensitivity to small differences in offered support. The article concludes that applying the framework is especially advantageous for evaluating early design phases and can successfully contribute to the efficient development of driver's in-control and safe means of operating partially automated vehicles.

1. Introduction

The automotive industry has started to introduce driver assistance systems that allow the automation of both lateral and longitudinal driving controls during specific situations (e.g. motorway cruising) within the existing infrastructure. The systems combine existing subsystems, such as Adaptive Cruise Control (for longitudinal control) and Lane Keeping (for lateral control). Although such combinations enable full automation, their application is restricted by technical boundary conditions (e.g. detection of road lines and adjacent vehicles) and, for safety reasons, by system-design conditions (e.g. driving on a motorway at speeds below a specific threshold) (Naujoks et al., 2015). Due to the limitations on the availability of the system, it is considered a partially automated system (Gasser and Westhoff, 2012). In this application, exceeding the boundary limits is likely to occur due to changing environments (for example, road works) or the behaviour of other road users. Given that the driver remains responsible for safe driving, this partial automation requires the driver to be ready to act as a backup (and to retake control) in case the automation fails or stops. As a consequence of the partial automation, the role of the driver changes from actively operating the vehicle to supervising the system with an occasional intervention. Given that the need for intervention can occur unexpectedly, and requires a fast response, this task is difficult and creates a high workload (Martens & Van den Beukel, 2013; Stanton et al., 2011). Further, humans are not particular good at performing supervisory tasks since these are associated with low vigilance leading to slow reactions and errors in deciding when intervention is needed (Kaber and Endsley, 2004; Ma, 2006). Carefully designed driver-interfaces are therefore needed not only to support drivers in this additional supervisory task, but also to support them in safely and adequately retaking control when required. Given this dual characteristic of the changed driver's task, it is desirable that interfaces offer at least two distinctive types of support: (1) support for supervisory tasks to improve the cognitive understanding of how a system reacts to different situations (Jamson et al., 2013); and (2) support related to operational capabilities to react rapidly and adequately to resolve a

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critical situation (Martens & Van den Beukel, 2013). Given that an assessment framework to evaluate potential interfaces with regard to this combination of aspects is not readily available (Geyer et al., 2014), the overall aim of this study is to propose such a framework. Initially, appropriate assessment aspects for both types of desired support will be determined. The subsequent challenge is to validate if the proposed combination of assessment aspects provides reliable outcomes, i.e. that they do not contradict each other. This validation is the second aim of our study. Moreover, an applicable framework should have predictive value: the measurement aspects defined should demonstrate a discriminant capacity regarding the effectiveness of the assessed interface-support. The latter will be evaluated by pilot-testing exemplary interface solutions within our proposed framework. Assessing the predictive value of the framework constitutes the third aim of our study. That is, the interface solutions discussed in this study serve as a means to evaluate the framework - the development of optimised solutions was not, at this stage, a goal in itself.

As such, this study aims to answer three questions:

- What assessment aspects should be included in the framework?
- How reliable are the measurements applied for the assessment aspects of the framework?
- Is the proposed framework effective in predicting the level of support offered by interfaces?

In answering these questions, we first, in Section 2, identify relevant aspects for assessment and introduce the framework's basic concept. Then, potential measures for the identified assessment aspects are reviewed in Section 3. Section 4 explains the methodology chosen to test the proposed framework, and Section 5 presents the results of the tests. These results are then discussed in Section 6 in terms of what they mean with respect to the framework's reliability as well as the framework's effectiveness in identifying adequate interface-support for partially automated driving. Finally, Section 7 draws conclusions with respect to the framework's merits when it comes to developing interface solutions for drivers of partially automated vehicles.

2. Concept of framework

2.1. Assessment aspects within the framework

Supervisory control is strongly related to a driver's understanding of how the system reacts to difficult situations in combination with knowledge and understanding of the required human (re)actions (Jamson et al., 2013; Jin and Kaber, 2009). As such, assessments of supervisory control should especially address cognitive performance, an aspect well covered by the psychological construct ‘Situation Awareness’ (Endsley, 1995). Intervention tasks, on the other hand, are strongly related to operational capabilities in terms of performing fast and accurate countermeasures and undertaking adequate and timely actions to resolve a critical situation (Merat et al., 2014). Consequently, intervention assessments should especially address task performance. Moreover, both aspects are complementary: even with correct understanding, adequate control could fail (Summala, 2005). In addition to cognitive performance and task performance, a framework should also assess perceived comfort since raising comfort is, in general, an important goal in the development of Advanced Driver Assistance Systems (ADAS) (Bengler et al., 2014). Further, partial automation creates ambiguity between comfort and safety: although driving control is taken away from the human operator (the driver), the human driver should retain final responsibility for safe driving (Bainbridge, 1983). Consequently, success in partially automated driving will to a considerable extent depend on whether carrying out supervisory control (including occasional intervention) will be less effort than the non-automated driving task itself. Given that we focus on assessing the interface support itself, the framework is not intended to assess network improvements or *system* acceptance. To summarise the above arguments, the assessment aspects within our framework will focus on:

a) Increased situation awareness;
b) Driver's performance in critical situations;
c) Acceptance of the offered support.

2.2. Scope of the framework

Drawing on an earlier publication (Van den Beukel and Van der Voort, 2015), this paragraph briefly describes the framework's further qualities:

a) The framework allows comparison, early in the design process, between levels and types of support in order to distinguish the relative appropriateness of interface solutions.
b) The framework can be applied in driving simulator experiments. This is desirable because: (1) real-world prototype testing is difficult early within a development process; (2) controlled environments are preferable for testing reliability and reproducibility; and (3) it is too dangerous to test some of the traffic situations that are critical to partial automation in real-life circumstances.
c) The framework can assess drivers' interactions with partially automated driving systems. Scenarios that represent cooperation between automation and a driver's supervisory and intervening tasks are an inherent part of it.

2.3. Simulated traffic scenarios within the framework

Appropriate scenarios were identified in a previous study (Van den Beukel and Van der Voort, 2015) and can be divided into two categories: (1) ‘hazardous’ scenarios requiring extra attention, but not intervention, from the driver; and (2) ‘critical’ scenarios where drivers need to intervene to avoid an accident. In line with currently available systems, our scenarios focus on vehicle automation within congested traffic. On a somewhat arbitrary basis, we imposed a speed threshold, such that automation would only be available below 50 km/h. Fig. 1 represents the scenarios that were selected to embody different levels of required understanding and ability to resolve a situation (Van den Beukel and Van der Voort, 2015). The previous study showed that the three ‘critical’ scenarios all required significantly more effort from the driver than the hazardous scenarios. Further, it was concluded that the six scenarios are representative of supervisory and intervention tasks as introduced by partially automated driving systems and, therefore, these scenarios will be used in the current study.

3. Measurement methods

This section defines the measures and measurement techniques that will be applied to our identified assessment aspects: (a) gained situation awareness; (b) driver's performance in critical situations; and (c) acceptance of the offered operational support.

3.1. Measurement of Situation Awareness (SA)

Endsley (1995) defines SA in terms of three levels: “(1) the