Influences of Instructions about Operations on the Evaluation of the Driver Take-Over Task in Cockpits of Highly-Automated Vehicles

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Keywords: Automated Driving, Automation, Driver Take-Over Task, Driving Simulator, Human-Machine Interaction, Human-Technology Interaction, Interface Design, Instructions, Operations, Take-Over Request, Test Method, Test Design.

Abstract: This paper works towards the development of a technologically independent framework to help render human-centered examinations of the driver take-over task present in highly-automated vehicles comparable. Based on available literature, the state-of-the-art and best-practices for driver take-over task examinations are analyzed and discussed. It turned out, that the scope of the studies' documentation, their level of detail as well as their wording differs significantly among themselves with respect to the instructions which were given to the test persons. Besides the stimulus materials made available to the test persons during the examinations, boundary conditions for the solution space of the task execution are defined by the instructions about operations provided. Therefore, the focus of this paper lies on the structural analysis of such instructions, suitable for a human-centered examination of the driver take-over task. By defining new demands for their documentation and enhancing comparability between future studies, this paper aims on holistically improving the robustness and validity of findings about human-performance in the field of automated vehicles.

1 INTRODUCTION

As long as automated driving systems, which are capable of redundantly handling an unlimited operational design domain (SAE International, 2018), are not available in series, partial automation with regard to the driving task will determine the market of advanced driver assistance systems. Per definition, these systems incorporate at least one transition between the driver and the automated system and vice-versa per drive. Therefore, understanding the human-technology interaction in automated vehicles is a major focus of research in the automotive industry.

The driver take-over task represents the procedure during which the responsibility of controlling the vehicle is transferred between the automated system and the driver. Various studies exist, which determine the driver take-over task or the driver's response to a driver take-over request (TOR) issued by the automated system, respectively.

To evaluate human-technology interaction in cockpits of highly-automated vehicles, driving simulators are a widely used tool, both in research and the automotive industry.

In order to obtain more generic, reliable and robust statements about the human-technology interaction after a take-over request, results obtained from various driving simulator studies can be compared. Although the available studies share the same overall subject, they differ with respect to their test setups, methods and designs, leaving the question to what extent the results of these studies can be rendered comparable.

Therefore, the present paper aims at working towards a comprehensive and comparable framework to support the execution of driver simulator studies in the field of partially automated driving systems by providing an overview about test methods and designs for the evaluation of human-technology interaction in cockpits of highly-automated vehicles.

2 RELATED WORK

This paper builds upon the description of a generic test setup suitable for the examination of the driver take-over task following on from (Hackman, 1969; Bubb et al., 2015; Winner et al., 2015; Schnöll, 2020). Its analytical foundation and development have been described in detail in (Schnöll, 2020). In the following, the building blocks of the framework are pre-

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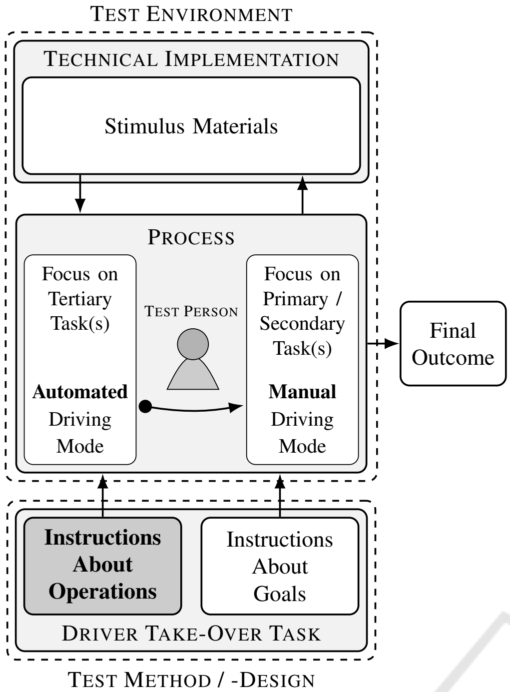

Figure 1: Illustration of a generic test setup suitable for the examination of the driver take-over task following on from (Hackman, 1969; Bubb et al., 2015; Winner et al., 2015; Schnöll, 2020).

sented.

Figure 1 shows a generic test setup suitable for the examination of the driver take-over task (Schnöll, 2020), following on from (Hackman, 1969; Bubb et al., 2015; Winner et al., 2015). A subset of terms used in Figure 1 originate from and are compatible with the 'framework for analyzing the effect of tasks' introduced by (Hackman, 1969). The aspect of decomposing the driving task into primary, secondary and tertiary tasks, known as the 'hierarchy of the driving task', is based on (Winner et al., 2015; Bubb et al., 2015).

2.1 Test Setup

As illustrated in Figure 1, a generic test setup consists of a test environment, a test method and design as well as a final outcome.

Test Environment. The test environment itself is defined by a technical implementation, which provides stimulus materials to the test person executing a process. Some stimulus materials provided to the test person are subject to an active interaction, e.g. a brake request, while others are at most influenced implicitly, like e.g. information regarding surrounding traffic participants or other road users.

Table 1: Categories for test environments being used to examine driver behavior in a partially automated driving system (Schnöll, 2020).

Test Environments	
Exemplary arranged in descending order based on available stimulus materials	
Categories	
1	Vehicle on public roads / test track
2	Dynamic driving simulator with screen projection (VR CAVE)
3	Dynamic driving simulator with VR headset
4	Static vehicle with screen simulation
5	Static simulation with screen projection (VR CAVE)
6	Static simulation with multiple displays
7	Static simulation with VR headset
8	Static screen simulation with a minimal input device set

In the present case, the process corresponds to the test person performing the driver take-over task, acquiring control over the vehicle from the automated system, which results in a transition from the automated to the manual driving mode. Since in full automation mode, the complete responsibility is considered to be on system side, test persons can focus on tertiary tasks, like i.e. the interaction with the vehicle's entertainment system, which are not connected to the actual driving task itself.

Process. The process is influenced by personal factors (Hackman, 1969), which can be categorized into stable and variable characteristics (Bundesanstalt für Straßenwesen, 2012). Variable characteristics are subject to frequent change, e.g. emotions, whereas stable characteristics remain unchanged over a longer period of time, as e.g. the driver's age (Bundesanstalt für Straßenwesen, 2012).

Categorization of Test Environments. Table 1 lists categories for test environments being used to examine driver behavior in a partially automated driving system. The categories are exemplary arranged in descending order based on available stimulus material. In case of a vehicle on public roads or a test track (1), the whole stimulus material is entirely available to the test person, whereas with a static screen simulation with a minimal input device set (8), it is tailored to a minimum.

By conducting studies in test environments such as ② - ⑧, stimulus materials are implicitly and explicitly tailored by the selection of the test environment and the provision of certain stimulus materials during the examination, as defined by the designer of the study. All stimulus materials, which are tailored during the design phase of the study, have a more or less significant influence on the test person's process execution.

Therefore, test environments have to be chosen purposefully in order to avoid unwanted side- and cross-effects as well as influences on the overall result of the study attributed to the test setup. Due to economic and resource-related boundary conditions, only a minority of studies can be performed in vehicles (cf. ①). When making use of test environments subject to tailoring of stimulus materials, potential consequences of the tailoring should be critically examined and discussed along with the results of the study.

Final Outcome. After having iterated through the process and having created one or more trial outcomes, as described by (Hackman, 1969), the final outcome represents the final result of the process execution of the test person.

Test Method / -Design. As illustrated in Figure 1, besides the test environment, a test setup incorporates the test method and -design, which is closely related to the research question of the respective study. The test method and -design consist of instructions about operations as well as instructions about goals (Hackman, 1969), which are communicated to the test person before the start of the respective test run. This way, boundary conditions and meta-information are given to the test person defining the solution space for the execution of the process.

The *instructions about operations* contain details on *how* the process shall be executed by the test person, whereas the *instructions about goals* carry information about *what* the test person's action shall result in to fulfill the work task under examination. Comparing the instructions about goals to the final outcome represents the performance of each individual test person.

3 RESEARCH QUESTION, DESIGN AND METHOD

Having analytically defined the generic structure (cf. Figure 1) and categorized the technical implementation of test setups used in literature, instructions given to the test persons in studies available in literature have to be investigated to be able to make a statement about their comparability.

3.1 Research Question

Independent of the different technical implementations of test environments used in literature, another dimension towards comparability of the respective studies is to examine the instructions about operations which are given to the test persons about to perform a driver take-over task. Hence, the research question in scope is: How can instructions about operations given to test persons in studies examining the driver take-over task be compared?

After analyzing and comparing the different instruction sets given in literature, a generic set of task groups for the definition of instructions about operations shall be derived in order to give a foundation for a generic framework supporting comparability of future studies dealing with human-technology interaction in cockpits of highly-automated vehicles.

3.2 Research Design & Method

To answer the research question, various publications investigating human performance in and interaction with automated driving systems using driving simulators have been reviewed and compared to obtain an understanding about their commonalities and differences as well as best-practices in test methods and -designs.

Representative statements have been collected and compiled into an overview which contains examples about instructions about operations with regard to the driver take-over task from literature. Based on the findings from this analytical research, technologically independent instructions about operations for the driver take-over task have been structurally derived based on the methodological approach of the Hierarchical Task Analysis (HTA), as described by (Diaper and Stanton, 2003).

4 RESEARCH RESULTS

To obtain an overview about practices in research, available literature has been analyzed and compared regarding the instructions about operations which are communicated to the test persons in the respective studies. The analysis focused on instructions that relate to the overall interaction with the test environment as well as the driver take-over task itself. Out-side the scope of this analysis were instructions with relation to non-driving-related tasks (NDRT).

In the first part of this section, findings from the literature analysis are presented. These are followed by a section introducing a methodical approach for the definition of instructions about operations which can act as a baseline for the documentation of future studies related but not limited to the driver take-over task. Furthermore, the results obtained from the presented work are connected and contextualized to the illustration of a generic test setup suitable for the examination of the driver take-over task (cf. Figure 1), which has been introduced before.

The results from the literature analysis are structured into three sections: engagement and disengagement criteria for automation, the influence of instructions given to test persons during the studies and their potential effects on the considered between-subjects factors as well as determinant statements which are related to personal interpretation. The sections mentioned above represent comparison criteria for instructions about operation given to test persons in studies examining the driver take-over task.

4.1 Engagement & Disengagement Criteria

Table 2 gives an overview of engagement and disengagement criteria for automation in driver take-over task examinations. Whereas it is a best-practice in literature to engage and disengage automation by pressing a button on the steering wheel (cf. Table 2), it is rather unusual that the simulator itself gives the command for engaging the automation as with (Mok et al., 2015).

Gas & Brake Intervention. Typically, the disengagement of the automation system because of a driver intervention is caused through a steering or braking action performed by the driver (cf. Table 2). It is noticeable, that a gas pedal interaction is widely not taken into account, although it is a driver interaction which could avoid collisions in some scenarios, i.e. when a vehicle is approaching from the rear with a high differential velocity.

In contrast to that, disengaging automation based on the brake pedal actuation is very common in literature and could be observed in a variety of studies (Jamson et al., 2013; Louw et al., 2015; Petermeijer et al., 2017; Capallera et al., 2019). However, not all studies contained information on the exact pedal travel threshold which has been utilized. Typical values for the pedal travel threshold found in literature range between 10% (Gold et al., 2013; Zeeb et al., 2016) and 20% (Petermeijer et al., 2017).

Steering Intervention. A steering intervention usually is triggered when turning the steering wheel by a certain angle. According values found in literature range between $2..3^{\circ}$ (cf. Table 2).

Other measured quantities triggering a steering intervention are less frequently taken into account in literature. In the studies analyzed, (Zeeb et al., 2016) considered the absolute steering wheel angle velocity and acceleration as a criterion for a driver intervention. Moreover, (Petermeijer et al., 2017) set a threshold for disengaging automation depending on the ego vehicle's deviation from the center of the current lane, thus measuring the steering intervention indirectly while observing the steering behavior over a certain time period.

4.2 Instructions About Operations

Between-Subjects Factors. The analysis of available studies examining the driver take-over task has shown, that the level of detail the overall communication between the test person and the researcher is documented with varies significantly across the studies.

Some authors explicitly mention written instructions used for briefing (Gold et al., 2016; Neuhuber et al., 2020) whereas typically, the communication with the test person has been described on a more generic level. In such cases, a deeper evaluation of the influences, the communication between the researcher and the test person has on their task execution turns out to be difficult. In addition to that, based on the information gained from the literature only, it is hard to estimate if the communication with the test persons has been informal during the studies or if a potential formalization was not documented in the publication itself.

However, if a publication lacks a detailed description of the way instructions have been provided to the test persons, consequential effects on the results of the respective study cannot be determined. This applies in particular when utilizing between-subjects factors, which are commonly used for validation to statistically increase the robustness of findings and achieve a more general validity of the research result.

Personal Interpretation. If the boundary conditions for executing the driver take-over task are not specified precisely, the task execution process can be subject to an unintended and unexpected personal interpretation. However, this may also be implemented

Table 2: Engagement and disengagement criteria for automation in driver take-over task examinations.

Engagement & Disengagement Criteria	
Pressing a button on the steering wheel engages and disengages automation	(Jamson et al., 2013; Louw et al., 2015; Mok et al., 2015; Zeeb et al., 2016; Petermeijer et al., 2017)
Automation shall be enabled after a command from the simulator is delivered	(Mok et al., 2015)
Steering Intervention, if:	
Steering wheel is turned more than 2°	(Gold et al., 2013; Louw et al., 2015)
Steering wheel is moved by more than 3° from its current position	(Jamson et al., 2013)
Absolute steering wheel angle velocity is larger than 0.075 °/s	(Zeeb et al., 2016)
Absolute steering wheel angle acceleration is larger than 5 $°/s^2$	(Zeeb et al., 2016)
Steering, so that the deviation from lane centre is greater than approx. 0.5m	(Petermeijer et al., 2017)
Brake Intervention, if:	
Brake pedal is pressed	(Jamson et al., 2013; Louw et al., 2015; Petermeijer et al., 2017; Capallera et al., 2019)
Brake pedal travel is greater than 10%	(Gold et al., 2013; Zeeb et al., 2016)
Brake pedal travel is greater than 25%	(Petermeijer et al., 2017)

consciously in studies, i.e. in case such aspects are coupled to the research question in scope of the examination. Nonwithstanding this, it is notable, that some publications dealing with the driver take-over task leave room for the personal interpretation of the work tasks by the test person. When describing the interaction with the automation system, various terms subject to personal interpretation can be found.

Exemplary, (Jamson et al., 2013; Eriksson et al., 2017; Banks et al., 2018; Capallera et al., 2019) report instructions to the test persons which refer to their subjective perception of *comfort*. (Jamson et al., 2013; Banks et al., 2018) mention, that the test persons could use the automated driving system on a *voluntary* basis, whereas (Jamson et al., 2013; Eriksson et al., 2017; Capallera et al., 2019) relate to the subjective feeling of *safety* or the test person's *appropriate* reaction to a driver take-over request or the execution of non-driving-related tasks respectively.

Hierarchical Task Analysis (HTA). As mentioned before, the instructions about operations provide boundary conditions under which the driver take-over task shall be performed by the test person.

In order to converge towards a generic and holistic instruction set to achieve comparability over different driver take-over task examinations, the influence of instructions subject to personal interpretation must be minimized. An initial but important step in this direction is the compilation of a technologically independent set of work tasks the driver take-over task is composed of. Therefore, a structured analysis of the respective tasks is required.

(Diaper and Stanton, 2003) give an overview about established methods to model tasks and compare their syntactic and semantic differences. Following (Diaper and Stanton, 2003), the Hierarchical Task Analysis (HTA) approach can be used to investigate human performance 'within complex, goal-directed control systems' featuring human-technology interaction, which matches a highly-automated vehicle in traffic. Hence, to generically define instructions about operations suitable for the driver take-over task and the underlying human-technology interaction, a Hierarchical Task Analysis (HTA) has been performed. The findings of this analysis are discussed in the following.

Driver Take-Over Task. Table 3 illustrates the results of the Hierarchical Task Analysis (HTA) as the generic specification for the instructions about operations suitable for the driver take-over task. The notation used is based on the one defined for the Hierarchical Task Analysis (HTA) by (Diaper and Stanton, 2003). This particularly applies to the execution con-

Table 3: Specification for human-centered instructions about operations for the driver take-over task based on a Hierarchical Task Analysis (HTA) as described by (Diaper and Stanton, 2003).

	Driver Take-Over Task *Instructions About Operations*	
	Description	**Condition(s)**
	Supervise the vehicle status by monitoring the human-machine interface components in the cockpit	IF a take-over request (TOR), initiated by the system, has been detected: > 1
1	**Examine** and understand the situation:	1.1 + 1.2 + 1.3 + 1.4 + 1.5 > 2
1.1	Current position with respect to the next waypoint	
1.2	Static environment	
1.3	Dynamic environment	
1.4	Road and its course	
1.5	Traffic situation	
2	**Plan** the intended driving maneuver path:	2.1 + 2.2 > 2.3 > 2.4 > 3
2.1	Define drivable space	
2.2	Predict dynamics, movements and behavioral reactions of other traffic participants	
2.3	Evaluate potential driving strategies based on 2.1 and 2.2	
2.4	Define driving strategy to be performed	
3	**Prepare** the driver take-over maneuver:	3.1 + 3.2 > 4
3.1	Bring hands into the position required for manually controlling the vehicle	
3.2	Bring feet into the position required for manually controlling the vehicle	
4	**Perform** the driver take-over maneuver:	4.1
4.1	**Interact** with the vehicle by applying appropriate control signals (e.g. gas / brake / steering) in order to execute the driving strategy defined in 2.4	

ditions listed in the second column of Table 3.

A plus-sign indicates, that the respective tasks associated with it have to be completed before the next consecutive task group, which is represented by a one-digit number, can be performed. A special characteristic of this notification is that the conjoined tasks can be completed in an arbitrary order, which reflects the highly-subjective way in which different test persons may fulfill a given work task. Once a task group is completed, the subsequent one follows until the whole driver take-over task is completed.

The first row of Table 3 is an exception to the above since it describes the ongoing, permanent action of the test person *supervising* the vehicle status by monitoring the human-machine interface components in the cockpit. The actual driver take-over task is started IF a driver take-over request (TOR), initiated by the automation system, has been detected by the driver.

In this case, the driver initially has to *examine* and understand the traffic situation the vehicle is in 1. In order to gain awareness and an understanding about the surrounding situation, the current position with respect to the next waypoint, the static and dynamic environment as well as the road and the traffic situation have to be understood (cf. 1.1 - 1.5). Among others, the sequence these subordinate tasks are performed in, can depend on stable or variable personal characteristics, like the individual feeling of safety or comfort (cf. (Bundesanstalt für Straßenwesen, 2012; Schnöll, 2020)).

After having examined and understood the surrounding situation, the intended driving maneuver path can be *planned* 2. To do so, the drivable space around the ego vehicle has to be defined 2.1 and dynamics, movements and behavioral reactions of other traffic participants have to be predicted 2.2 . After having gained information about the static and dynamic environment as well as the dynamics of the surrounding traffic participants, potential driving strategies can be evaluated 2.3 and defined 2.4 based on this.

With a driving strategy defined, the driver take-over maneuver can be *prepared* 3 by bringing hands and feet into the position required for manually controlling the vehicle 3.1 + 3.2 . Having prepared for the driver take-over, the maneuver can be *performed* 4 by *interacting* with the vehicle 4.1 by applying appropriate control signals in order to execute the driving strategy defined in 2.4.

Figure 2 illustrates the results obtained from performing the Hierarchical Task Analysis (HTA) for the driver take-over task (cf. Table 3) as an extension of the generic test setup presented in Figure 1. As illustrated in Figure 2, the instructions about operations for the driver take-over task can be generically described by the 6 consecutive task groups *supervise*, *examine*, *plan*, *prepare*, *perform* and *interact*.

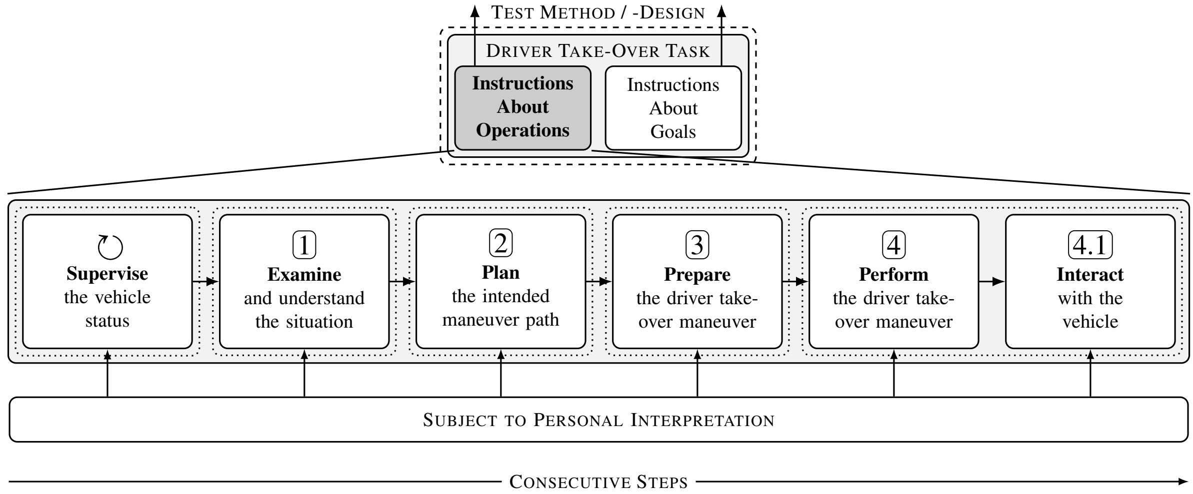

Figure 2: Instructions about operations suitable for the examination of the driver take-over task (cf. Figure 1; Table 3) following on from (Hackman, 1969; Bubb et al., 2015; Winner et al., 2015; Schnöll, 2020).

As shown in Table 3, some lower-level tasks inside the respective task groups are non-sequenced, as indicated by the plus-sign associated to them. The order of the task completion is determined by the test person's personal factors, whereas the whole process of performing the driver take-over task itself is subject to the test person's personal interpretation.

5 CRITICAL ANALYSIS

The presented approach aims to be suitable for the description of various driving tasks. However, in general, these are influenced by varying stimulus materials, surrounding conditions and personal factors, leading to many permutations. Therefore, the presented tables, figures, lists and examples do not claim to be exhaustive.

The performed literature analysis should be regarded as an indication for state-of-the-art and best-practices used in this research field and makes no claim to completeness. It is intended to help draw conclusions as to which aspects of the documentation of the research results should be given special attention. The compilation of the instructions about operations has been achieved through analytical research based on a Hierarchical Task Analysis (HTA). Depending on the research question in scope of the respective examination, other groupings or levels of detail are possible when following the presented method. Moreover, the human-machine interface design as well as the technical implementation of the test environment's cockpit are expected to influence the overall cooperation between the test person and the automation system, which should be considered when planning test runs.

6 CONCLUSIONS

6.1 Summary

This paper works towards the development of a technologically independent framework to help render human-centered examinations of the driver take-over task present in highly-automated vehicles comparable. It introduces and discusses a framework which pursues the idea of generically describing instructions about operations suitable for the driver take-over task. This can be achieved by formalizing human-centered instructions about operations necessary for the driver take-over task on one hand, as well as their communication to the test persons on the other. The presented framework supports a common baseline for upcoming human-centered studies conducted in the field of highly-automated vehicles and follows on from a novel description of a test setup for the driver take-over task.

Based on available literature, the state-of-the-art and best-practices for examinations dealing with the driver take-over task have been analyzed and discussed. It turned out, that the scope of the analyzed studies' documentation, their level of detail as well as their wording differs significantly among themselves with respect to the instructions which were given to the test persons.

The analysis utilizing the presented framework has shown, that the instructions about operations for the driver take-over task consist of subsequent, generic tasks groups, which can be further assessed based on the research question in scope. The applicability for the driver take-over task has been exemplary demonstrated by having subdivided the generic task groups further. The presented method can be tailored or extended to meet the specific requirements of the respective research questions, thus making it suitable for a technologically independent usage in various test setups.

6.2 Discussion

When following the presented methodology, researchers should consciously and attentively document instructions about operations provided to the test persons to avoid unintended, implicit side effects on the study itself. This is especially relevant for test environments making use of abstracted vehicles, like driving simulators of various types, since their technical implementation goes by with an explicit or implicit tailoring of stimulus material provided to the test person.

To maintain comparability regarding the between-subjects factors within the own study as well as render the study comparable with others, researchers should minimize the potential for subjective interpretation of their given instructions by the test persons. Therefore, a structural analysis of the task under examination is required, which can be performed by following the framework presented in this paper.

In general, to achieve comparability within the own study, the test execution should be formalized by using a reproducible way of providing the instructions about operations to each test person. In order to enable comparability with other studies, as well as generate transparency over potential unintended side effects, it is recommended to devote special attention to the detailed documentation of the instructions about operations.

In addition to that, the validity and robustness of the obtained results can be increased by formalizing the interaction with the test persons, e.g. by utilizing written instructions and reduce communication to an absolute necessity. The difficulty with this is to find a balance between the formalization of the communication without making the test persons feeling uncomfortable or treated impolitely, which can have an impact on the results of the examination, respectively.

It is recommended to investigate if a gas pedal interaction causing the ego vehicle to accelerate could be a valid way to solve the driver take-over task in the respective scenario. Providing access to this additional stimulus material can lead to a better understanding of driver take-over maneuvers in different scenarios. Furthermore, inconvenience with the automation system, i.e. by subjectively driving *too slow*, can be qualitatively measured and assessed as a beneficial side effect.

6.3 Outlook

In a subsequent analysis, the test method and -design of studies investigating the driver take-over task has to be examined further to gain a holistic understanding of the research results obtained in this field. Therefore, the introduced methodology should be implemented in existing and upcoming studies to verify its suitability. Aspects worthwhile to investigate could be meta-goals and objectives the test persons shall achieve as well as the correlation between typical research questions and technical implementations of test setups the respective studies are conducted in. Additionally, the applicability of the technologically independent approach presented could be verified by conducting a study based on the methodologies introduced in this work.

Furthermore, deviating performances of test persons within the presented task groups could be mapped to established models of human error functions. Understanding the origin of the individual behavior of each test person contributes to the successful design of future human-machine interfaces for the driver take-over task.

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