SimuVal - a knowledge base for valid driving simulation

Driving simulators are being used increasingly as part of the vehicle research. In this regard, the validity of a driving simulator represents a necessary condition in order to facilitate the transfer of the results to reality. The Institute of Ergonomics (Institut für Arbeitswissenschaft, IAD) of Technische Universität Darmstadt addressed this topic of validation of driving simulators, as part of a two-year DFG project. The findings of the project are summarized below.

1. Motivation:

The use of driving simulators as a study environment for driving tests has become a common practice. This is mainly due to the fact that the influence of disturbance variables can be controlled in a driving simulator [1] and a secure testing environment is ensured for the subjects [2]. Nevertheless, a simulated test environment has certain disadvantages too. Driving simulators can never reflect the reality to 100% [3]. To examine if the results obtained in a driving simulator are all the same transferable to reality, it is necessary to validate the driving simulator. The aspects of validity can be differentiated into two [4] & [5], namely into physical and behavioural correspondence. Physical correspondence describes the differences in the physical characteristics and the external form between the driving simulator and the real vehicle, whereas the behavioural correspondence refers to the balancing of the driver behaviour in simulated and real investigation environment and is assumed to be present, provided that no statistically significant difference exists [6].

2. Benchmarks for selected design parameters

There is a range of different driving simulators, which are different with regard to their design parameters. The "equipment quality" contributes directly to the physical validity (among others [7]). In the literature, there are benchmarks for each of the parameters which are presented as excerpts in the following.

What is particularly important is the visual perception. The horizontal viewing angle (field of view, in short FOV) affects visual perception significantly. According to [8] an angle of 50° horizontally is acceptable as the minimum FOV; however, depending on the driving situation, a FOV of 180° may be advisable [9]. For a correct perception of speed, at least 120° is required [10]. The vertical FOV plays a lesser role; in this respect, [8] considers 40° to be adequate [9]. The physical validity of a driving simulator, besides the visual, inter alia, is also influenced by the proprioceptive perception. For driving simulators, there are several possibilities of simulating motion, such as hexapod, rail system, turntable, and vibration actuators. A 100% representation of acceleration in a driving simulator is usually not possible; therefore, it is reduced by a scaling factor. For lateral movements, according to [11], a value of 0.5 to 1.0 and for longitudinal movements the order of less than 0.05 is possible.

The benchmarks presented provide design suggestions for a physically valid driving simulation. The driver behaviour related correspondence is not necessarily achieved by the fact that the components of a driving simulator indicate a high quality and therefore physical reality. In the research, derivation of design recommendations from a driving simulation valid for driver behaviour is mostly yet to be achieved.

3. Validity of driver behaviour as a research field

At the Institute of Ergonomics of Technische Universität Darmstadt, the question of validity of driver behaviour in driving simulators has been explored in detail. Besides study of the literature, the DFG funded project titled " Bestimmung und Quantifizierung von Gestaltungsmerkmalen einer realitätsnahen Fahrsimulation " included the implementation of new series of investigations in the

field and in the simulator as well as ultimately derivation of essential design recommendations for a valid[1]
driving simulation.

The analysis of reference literature shows that are already some studies which are dedicated to the validation of driving simulators (Overviews in [2], [12]). The research efforts to date, however, raise critical points that are essential for further investigation (elaboration in [13]). Validation studies lack a clean methodology and presentation of results. So as to exclude the influence of individual performance requirements, it is important to have recourse to different series of experiments on identical group of subjects; however, this is still absent. In addition, there is often a lack of a complete presentation of the results, together with important statistical test values. Due to this fact, it is hardly possible to compare the findings of different studies. Also, there is a gap with regard to the objectives of the investigations considered in the validation studies. Thus, only two studies are known [13] that examined the suitability of driving simulators as a study environment for functional analysis of driver assistance systems. However, this question turns out to be important if particularly for such study objectives mostly experiments are conducted in simulated environment. Also the validation of driving simulators for night driving has rarely been conducted, although under such adverse visibility conditions high accident rates prevail which accordingly results in a need for research.

As part of the DFG project, corresponding driving tests were conducted in the field and in the static IAD driving simulator (180° FOV horizontally, sound simulation, force feedback). It is found that partially valid results can be achieved [14] with a driving simulator of this equipment in investigations under night vision conditions. When testing critical braking manoeuvres with active brake intervention, however, a static driving simulator has its limitations [15] due to lack of vestibular feedback. In this regard, an acoustic feedback could create a more realistic impression and provide essential stimuli for the perception of the acceleration forces.

Also a systemic study of the influence of independent variables on the validity remained until now largely incomplete. [13] provide an overview of the main influencing factors: task-related and environment-related stress factors and individual conditions of performance. In a study, mostly a specific driving simulator is examined with regard to validity. What remains disregarded is the fact that the individual design components of a driving simulator as well as the investigation scenario have an impact on the results. Accordingly, a study was conducted at IAD, which examined the influence of motion simulation and the FOV horizontally with respect to validity. For this purpose, the dynamic driving simulator belonging to the Fraunhofer IGD (Darmstadt) was used. The test section consisted of city, highway and rural road passages. In the literature there are already few studies that explore the influence of FOV horizontally or also of motion simulation (among others [10], [16]) in more detail. However, a comprehensive study that considers systematically varied both design parameters and also a wide range of validity parameters in various scenarios, is not available till now. Mostly seen was a significant influence of design parameters on the subjective perception of reality of the subjects. The results of the objective characteristics of this study are integrated into the software tool described later and elaborated there systematically.

4. Model development

From the previous observation, it is not clear how the design parameters affect the driver behaviour and thus the validity depending on a scenario. This will be explained in more detail in the following.

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[1] In the following, the term validity refers to, unless explicitly contradicted, the driver behavior related correspondence between real und simulated environment of investigation.

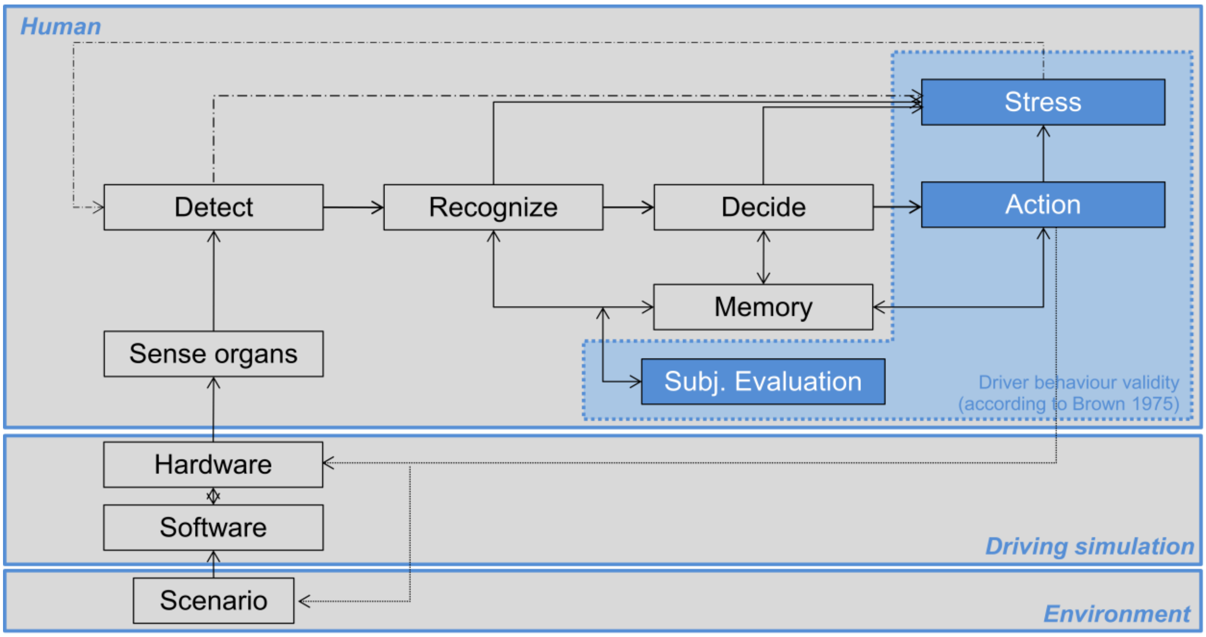

Figure 1: Relationships of effect between independent and dependent variables of the driver behaviour validity (solid arrows = short-term effect; dotted arrows = long-term effect).

Figure 1 shows a model-based analysis of the interdependency between the independent variables of scenario and hardware/software and the dependent variables of action, stress and subjective evaluation. According to the methodology of [17], the validation of a simulator involves a comparison this same dependent variables in the field and in the simulator. The aim of the model is to explain the relationship between dependent and independent variables based on the information processing of humans. The scenario of a driving test series goes down as an environmental variable in the man-machine interaction; it is modelled in the simulator software. The hardware design parameters of the driving simulator pass on this scenario information, for example, about the imaging medium to the human. The human receives the stimuli through his senses and processes them. According to [18] the information processing can be divided into steps of detection, recognition, decision and action. In the processing of information, there is a balancing with the sensory memory as well as the short – and long-term memory [19]. In this, there is also a comparison of the stimuli presented in the simulator with reality. This closeness to reality of the simulated environment as perceived by the subject acts indirectly on his decision and action and thus on the validity. This validity aspect can also be referred to as fidelity of a driving simulator [20] and, according to [7], in analogy to driving behavioural validity. At the end of information processing is the action of man. It is directly related to stress [21]. In the area of action as well as in the area of stress, there are various validity parameters that allow a comparison of driver behaviour between the field and the driving simulator and provide evidence for the driver behaviour validity. In addition to action, also the other phases of information processing act on the stress a [22] & [1] because they "demand a workload" from the human. The detection leads, on a long-term basis, to a stress in the form of a fatigue effect, since it only involves the direct reception of stimuli by sense organs and does not result in memory balancing or processing. The phases of cognition and decision-making, however, act quickly on the stress. There is also a backlash of the stress on the phase of detection [1], since a high stress affects the stimulus perception negatively seen from a long-term point of view. Besides the human-related effect of action on the stress, there is also a backlash of action on the environment (scenario) as well as the driving simulation itself (hardware). Therefore, the subject can defuse the dangerous situation, for example, by pressing the brake pedal (hardware) in case of a critical rear-end collision and thus influence the scenario.

As is evident in this model, the design parameters of the driving simulator (hardware / software) as well as the scenario selection will influence the validity. Therefore, it is important to adapt the design of a driving simulator and its components to the respective target of investigation.

5. The software tool "SimuVal"

The software tool "SimuVal" was developed at the IAD to provide assistance to researchers in the configuration of a driving simulator, so that it is optimally suitable for the respective target of investigation. Since the optimal form of the design parameters depends on the considered characteristic values as well as the investigation scenario, a guide in the classical sense was out of the question. In order to meet this complexity, the systematized findings were combined into a software tool.

The software tool[2] was developed in C++. The tool offers the possibility to systematically look for study results concerning driver behaviour validity through a graphical user interface, to add new entries or modify existing ones (Figure 2).

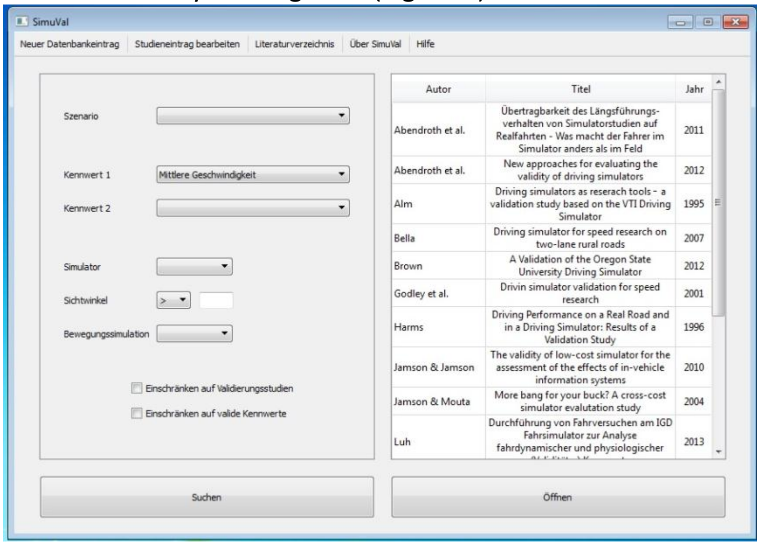

Figure 2: Screenshot of the software tool

6. Summary

In summary, it can be said that the DFG project at IAD has delivered a comprehensive insight into the question of the validity of driver behaviour validity, systematized previous study results in this context, revealed key factors affecting the driver behaviour validity and quantified their effect on a number of validation characteristics in the context of a comprehensive study. The results from our own trials as well as from the literature are systematically processed in the software tool "SimuVal" according to the influencing factors and shown graphically to the user.

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