AN ASSISTED DRIVER MODEL. TOWARDS DEVELOPING DRIVER ASSISTANCE SYSTEMS BY ALLOCATING SUPPORT DEPENDENT ON DRIVING SITUATIONS.

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ABSTRACT: Partially automated driving is expected to increase traffic efficiency. However, automation causes human factors concerns. One concern is the reduced operability during transitions between automation level, e.g. when failures occur. These concerns ask for a more justifiable implementation of automation for automobile appliances. As a first step towards applicable solutions for driver support, we developed the assisted driver model. The attempt with this model was to answer: what driving situations are in need for what kind of support? The influence of different levels of automation on task performance, were used to define 7 recommended support types relevant for driver assistance. For the allocation of recommended support types to distinguished driving situations we then considered the prerequisites to provide good operability in terms of the avoidance of errors and familiarity with driving circumstances. An assessment of adaptive cruise control showed the model's potential to help developing advanced driver assistance systems whilst anticipating concerns associated with the appliance of partial automation.

1 INTRODUCTION

Driver assistance is expected to offer an important contribution to solving mobility problems, because assisting the driver has the potential to increase traffic flow and reduce accidents [1-3]. Initiatives with regard to partially automated driving endorse these expectations, e.g. the Save Road Trains (SARTRE) project [4] and the Grand Cooperative Driving Challenge (GCDC) [5]. Nonetheless, the development of driver assistance systems is most of the times based on what is technologically possible, not necessarily on what drivers are in need for [6]. As a consequence, today's systems are with varying degree successful in enhancing comfort and safety for individual drivers, but less successful in offering traffic improvements on a larger scale [7]. In addition, applying partially automated driving to increase traffic efficiency will also cause new problems, among which is the introduction of transitions between different levels of automation associated with different driving situations. The reason for these transitions is that the diversity of the driving task makes it unlikely that one type of automation will be applicable for all situations. Therefore, appropriate transitions need to be accounted for when developing partially automated driving. Furthermore, there are many concerns related to partial automation. Most of these concerns can be summarized by out-of-the-loop performance problems. These problems basically mean that a user (the operator) is partially placed remote from the control loop and a consequence is that the operator's awareness of the situation or system's status may be reduced. This causes serious problems, especially when system errors, malfunction or breakdowns occur, resulting in slower reaction times [8], misunderstanding what corrective actions need to be taken and manual skill decay [9].

The relevance to optimize traffic efficiency and the expressed concerns ask for improvements upon the design process and scope of driver assistance. However, specific solutions how to implement automation and how to overcome unwanted implications, are not readily available [10]. As an attempt to create solutions for applying partial automation, the present paper introduces an assisted driver model, which recommends driving support dependent on driving situations. This attempt needs to be considered as a first step to go from a descriptive model to a more prescriptive model for the design of driver assistance which contributes to traffic efficiency by applying partial automation. The aim of the assisted driver model is also to define appropriate transitions between different levels of automation. However, the generation of the model is the main scope of the current research.

This paper will therefore answer the following questions: (a) What driving situations can be distinguished? (b) What support types should be distinguished? and (c) How can the support types be allocated to the driving situations? After answering these questions, the assisted driver model will be unfolded. As an example of the model's practical applicability when designing new driving assistance, suggestions for improving an existing driving assistance system, adaptive cruise control, will be given before concluding this research.

2 WHAT DRIVING SITUATIONS CAN BE DISTINGUISHED?

The driving task is often analysed in terms of three different performance levels distinguished by Rasmussen [12]. Although Rasmussen's model is a general model for task performance, it also fits well to the driving task [13], [14]. The three levels that Rasmussen distinguishes are the knowledge-based, rule-based and skill-based level.

Differences between the levels relate to the involved mental effort. At the highest knowledge-based level, human behaviour is goal-controlled and represents a more advanced level of reasoning.

This is the level at which people develop new ways of problem solving. Performance at knowledge-based level is therefore applied in novel situations or at new locations.

It requires considerable attention and effort and is therefore demanding. Rule-based behaviour is characterised by the use of rules and procedures to select a course of actions in a familiar situation.

The rules can be acquired through experience or can be based upon prior instructions (training). When driving, rule-based behaviour involves interpreting everyday situations and applying rules and regulations that fit that situation. Once a rule is chosen the actions are carried out in a rather automatic fashion. At the lowest skill-based level, highly practiced tasks are carried out.

This level represents a type of behaviour that requires very little attention, without consciously controlling a task. Actions are performed in an automated manner.

Rasmussen considers the amount of mental effort needed to execute a task and therewith addresses a dependency on individual differences in task performance. As a consequence, it is not possible to take a subtask (steering, shifting gear, braking, etc.) and exclusively fit it to one single level. ('Shifting gear', as an example, is at skill-based level for an experience driver, but at knowledge-based level for novice drivers.)

Apart from individual differences in task performance (e.g. experience), also differences in familiarity with the involved task situations influence performance. An experienced driver will for example pass a familiar crossing while performing at rule-based level, but needs knowledge-based performance at a poorly laid out intersection in a foreign city. These dependencies on perceived familiarity with traffic situations can be made more explicit by relating Rasmussen's task performance model to Michon's generic hierarchy of the driving task.

Michon [15] proposed that the driving task could be structured at three levels. These levels are: the strategic, tactical and operational level. At the strategic level drivers prepare their journey; this concerns general trip planning, choice of route, transportation mode, time, etc. At the tactical level drivers exercise manoeuvring control, allowing to negotiate the directly prevailing traffic circumstances, like crossing an intersection or avoiding obstacles. Here, drivers are mostly concerned with interacting with other traffic and the road system. The operational level involves the elementary tasks that have to be performed to be able to manoeuvre the vehicle, mostly performed automatically and unconsciously (e.g. steering, using pedals or changing gears). Executing a tactical or operational task always facilitates achieving the goals of a task on a superordinated level.

Figure 1 relates Rasmussen's task performance model with Michon's driving task hierarchy. Differences in familiarity with situations or environments which are essential to execute the involved tasks influence the performance levels. For strategic driving tasks this involves familiarity with travelling routes, for tactical tasks familiarity with traffic situations and for operational tasks it involves familiarity with the vehicle design. Therefore, combining Michon's taxonomy of the driving task to Rasmussen's model for task performing resulted in a desired model that relates driving situations to individual differences in driving experience and familiarity with driving situations. In general the performance level is higher when a task involves rather low levels of familiarity.

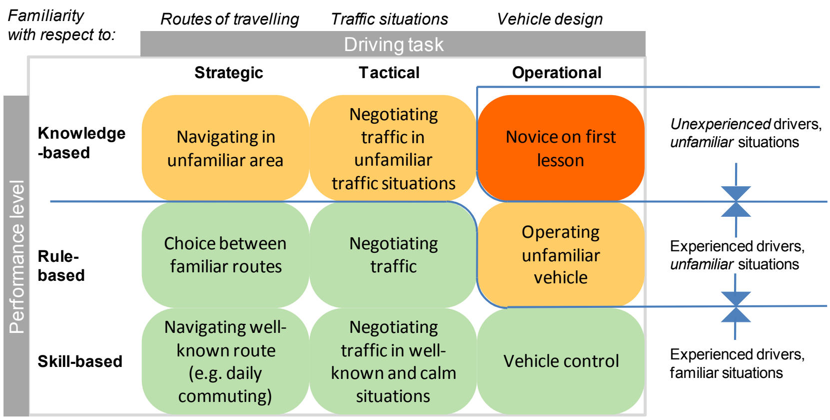

Fig.1. Driving situations. (Examples are adapted from Hale [16].)

3 WHAT SUPPORT TYPES SHOULD BE DISTINGUISHED?

The previous matrix (fig. 1) defined driving situations based on the relation between performance level and familiarity with the environment in which a driving task is being performed.

To apply appropriate support to driving situations, we would preferably relate the matrix to an existing taxonomy of driving support types. Although such a specific taxonomy does not exist, it is possible to use a generic taxonomy: Levels of Automation (LOA), developed by Endsley & Kaber [11].

Levels of Automation considers 10 scales of intermediate support levels offered by partial automation of a task.

This taxonomy is suitable for defining driving support types, because the 10 levels cover most of the theoretically possible intermediate levels of automation.

Besides, LOA's aim is to facilitate appropriate system function allocations between human and computer controllers keeping both involved in the control loop –and this offers an important contribution to avoidance of out-of-the-loop performance problems as indicated in the introduction.

To be able to relate our taxonomy of driving support to driving situations, we first need to explain the LOA taxonomy, upon which our support types are being based.

3.1 Levels of Automation (LOA)

Levels of Automation (LOA) considers human and/or computer allocation to the following functions of the control loop: (a) Monitoring: Scanning displays or the system's environment to perceive information regarding system status and/or the ability to perform tasks, (b) Generating: Formulating options or strategies to achieve tasks, (c) Selecting: Deciding on a particular option or strategy, and (d)

Implementing: Carrying out the chosen option.

Table 1 gives an overview how the Levels of Automation divide human and/or computer execution of a task over the different functions. Because it is difficult for either the human or machine to perform any task without directly monitoring either the state of the system or inputs from the other, functions are sometimes allocated to both human and computer.

Table 1. LOA Taxonomy (Endsley & Kaber [11])

	FUNCTIONS			
LEVEL OF AUTOMATION (LOA)	MONITORING	GENERATING	SELECTING	IMPLEMENTING
1. Manual Control	Human	Human	Human	Human
2. Action Support	Human/Computer	Human	Human	Human/Computer
3. Batch Processing	Human/Computer	Human	Human	Computer
4. Shared Control	Human/Computer	Human/Computer	Human	Human/Computer
5. Decision Support	Human/Computer	Human/Computer	Human	Computer
6. Blended Decision Making	Human/Computer	Human/Computer	Human/Computer	Computer
7. Rigid System	Human/Computer	Computer	Human	Computer
8. Automated Decision Making	Human/Computer	Human/Computer	Computer	Computer
9. Supervisory Control	Human/Computer	Computer	Computer	Computer
10. Full Automation	Computer	Computer	Computer	Computer

3.2 Effects of LOA on human/system performance

The different levels of automation as defined within the LOA taxonomy (table 1) have been tested with respect to human/ system performance [11]. The results of the test provide an indication of the relevant task aspects that may influence the effectiveness of a human/machine system. Hence, the results will be considered for further application for the desired assisted driver model and will therefore be summarized here.

Overall operator/system functioning proved to be best for LOA's involving partial automation of the implementation aspect of a task, as is the case with action support (level 2) and batch processing (level 3).

With regard to option-generation, purely human generation of options (action support (level 2) and batch processing (level 3)) performed far better than joint human-computer generation of options (levels 4, 5, 6 and 8). Purely computer generation of options (rigid system (level 7), supervisory control (level 9) and full automation (level 10)) also performed slightly better than joint human-computer option-generation, but not as good as with the purely human generation of options.

The fact that the joint human-machine generation of options produced worse performance than generation by either the human or machine component alone is in agreement with previous research [17-20].

This low performance can be explained by distraction and doubts that humans encounter during joint human-computer selection of options. The results advocate that option-generation should be performed by either the human or the machine.

With respect to performance after automation failure, recovery time is significantly greater during batch processing (level 3) and automated decision making (level 8). Recovery time was lowest for action support (level 2).

Because batch processing (level 3) differed only from action support (level 2) upon the implementation role, which involved joint human-computer interaction for action support and purely computer interaction for batch processing, this result indicates that operator ability to recover from automation failures substantially improves with partially automation requiring some operator interaction in the implementation role.

Based on the results, three recommendations can be made with respect to desired levels of automation for the supported driver model:

(a) Operator performance is generally most improved by physical implementation assistance,

(b) joint human-computer generation of options need to be avoided; human generation of option is best, computer based option-generation is second best,

and

(c) the human must remain involved in the implementation part of a task to avoid decrease in operator performance during transitions to manual control.

3.3 Proposed taxonomy of support types for driver assistance

To apply appropriate support to driving situations, we required a taxonomy of driving support types. After adapting Endsley & Kaber's taxonomy of automation levels (LOA), this paragraph presents a first attempt to provide the desired taxonomy of driving support types. Compared to LOA the levels have been adapted and reduced to seven levels relevant for driver assistance. This alteration is based on the following considerations:

Firstly, to be able to select options it is desirable to be involved in Generating as well.

Secondly, due to the complexity of driving situations and the responsibility of the driver, a situation in which the human only executes the implementation-role and all other task steps are being automated, is not desirable.

Thirdly, complete automation of the implementation role is also not desirable, because this causes decrease in operator performance during transitions to manual control. Using these considerations to reflect upon the existing Levels of Automation resulted in the following 7 levels (see also table 2) of our proposed taxonomy of driving support types:

1) Augmenting: Both human and machine monitor the present situation. The machine especially supports acquiring sensory information. An examples is night vision.

2) Advising: The machine supports by generating options, the human however

selects. The selected option might be another option than generated by the machine. Examples: Attention Assist (advises to take a break) or Lane Change Assist.

3) Warning: The machine temporarily generates and selects an option which, according to the machine, is mandatory to perform. Examples: Lane Departure Warning (warns for accidentally departing a lane) or frontal collision warning.

4) Intervention: The machine temporarily generates, selects and executes an option which, according to the machine, is mandatory to perform at that moment.

5) Decision Support: By combining Action Support (see next level) and Advising, the human is being supported in terms of allowing full dedication to the selection-role.

6) Action Support: The implementation part is being supported. E.g.: powered steering.

7) Full Automation: The computer carries out all action. All Automated Guided Vehicles (AGVs) belong to this category. Strictly speaking, this type goes beyond support as there is no human performance involved at all.

Table 2. Support types

	FUNCTIONS			
SUPPORT TYPES	MONITORING	GENERATING	SELECTING	IMPLEMENTING
1. Augmenting	Human/Computer	Human	Human	Human
2. Advising	Human/Computer	Human/Computer	Human	Human
3. Warning	Human/Computer	Computer	Computer	Human
4. Intervention	Human/Computer	Computer	Computer	Computer
5. Decision Support	Human/Computer	Human/Computer	Human	Human/Computer
6. Action Support	Human	Human	Human	Human/Computer
7. Full Automation	Computer	Computer	Computer	Computer

4 HOW CAN THE SUPPORT TYPES BE ALLOCATED TO DRIVING SITUATIONS?

In the previous section we identified generally applicable support types for driver assistance. The matrix in figure 1 defined driving situations based on the relation between performance level and familiarity with the environment in which a driving task is being performed. The scope of this paper is to recommend which of the acknowledged support types should be applied within what driving situation. Therefore this section answers the question: "How can the acknowledged support types be allocated to the driving situations?"

For the allocation of support to different driving situations we consider the prerequisites to provide good operation of a task with respect to the involved performance level and driving task type. For the performance levels these prerequisites involve the avoidance of errors. For the different driving task types, the prerequisites involve the ability to properly manage these tasks. First, the contribution to avoid errors dependent on performance level [21], [22] will be explained.

Knowledge-based performance depends heavily upon the performer's fundamental knowledge, diagnosis, and analysis skills. As a consequence, errors on this level are mainly caused by inaccurate knowledge or applying an inaccurate mental model, therefore support in terms of Advising and Decision Support is appropriate. At this level, Augmenting is also recommended, because it facilitates acquiring accurate information. A knowledge-based task is demanding, which might cause task overload. Furthermore, the task is most severely impaired by adding another (sub)task [23,24]. Therefore, Action Support is also recommended to support tasks at knowledge-based level, because it avoids errors by reducing or automating subtasks.

Rule-based performance is characterized by a strong top-down control: A situation triggers choice of a particular schemata and then actions are applied according to this scheme.

Therefore, misinterpretation-errors are the main risk for deteriorated performance at this level. Appropriate support is Augmenting, because then especially the monitoring part is being supported.

Moreover, the top-down control can be so strong that it does not allow the bottom-up input of other signals to reach the necessary attention of the operator [22]. Then, appropriate support is Warning. Also Augmentation can avoid that relevant signals are being blocked. Problems at the rule-based level may as well occur if people lack knowledge about the rule that should be applied, or apply the wrong rule. Support in terms of advising could then be beneficial. However, one needs to be careful with applying advise, because it might cause distraction or confusion [11]. Moreover, rule-based behaviour is often involved in tasks which require direct responses. In many cases advising is then not practically applicable.

Skill-based performance requires very little attention, because those tasks are highly trained and show almost automatic task performance.

Although automatic performance does have its advantages (response is fast and does not require many attentional resources), the presentation of information that triggers automatic responses can be so strong, that all other information will be ignored. Mistakes typically occur during exceptional situations when drivers fail to identify changed information, causing the execution of a false routine [22].

An example is keeping lane based on old road markings, when the road layout is actually be diverted in a new situation. To avoid ignorance of relevant information, support in terms of Warning and Intervention is recommendable. As the execution of routines might cause inattention, Action Support is also appropriate at this level.

Now the contribution to avoid errors dependent on performance level have been explained, the text below will explain what prerequisites are required to properly manage driving tasks. Hence, we consider familiarity with the environment and circumstances associated with driving tasks.

- For execution of strategic tasks especially familiarity with, and correct interpretation of the road infrastructure is important. Therefore support in terms of monitoring and option generating is most beneficial, which are offered by Augmenting and Advising.

- For tactical tasks familiarity with and correct perception of traffic situations are of extreme importance. Support types which facilitate monitoring and avoiding mistakes when selecting options are therefore most recommendable; e.g. Augmenting, Warning, Intervention and Decision Support. Also Action Support is appropriate, because it allows more dedication to the selection role by supporting the implementation role.
- For correct execution of operational tasks especially familiarity with the vehicle behaviour is important. Support in terms of Warning and Intervention may avoid problems due to driver's inexperience with vehicle behaviour. Support in terms of automation of subtasks (as with Action Support and Full Automation) are also recommended if this support is provided at all instances, because it then reduces the subtasks the human is involved in and allows to become more familiar with remaining subtasks.

5 PROPOSED ASSISTED DRIVER MODEL

The previous section explained how support types relevant for driver assistance can be allocated to driving situations. This resulted in recommended support conditions per performance level and per driving task. Figure 2 combines the recommended support types by selecting which support types fit both conditions and therewith visualizes the desired assisted driver model.

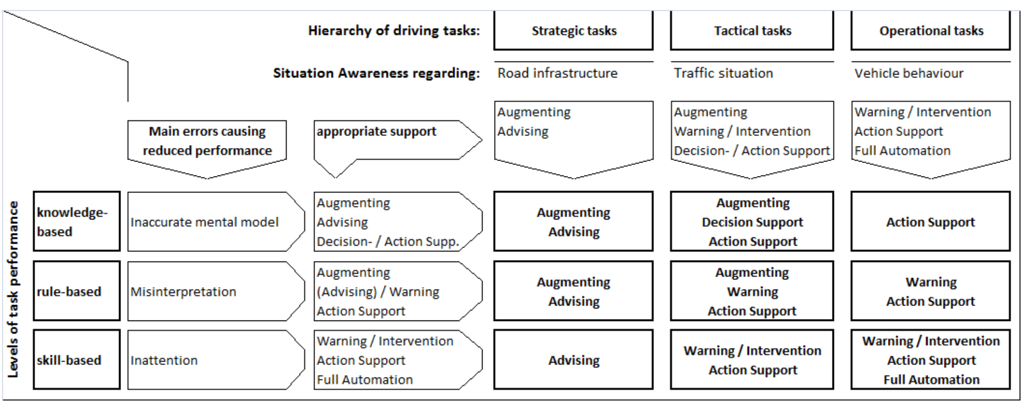

Fig.2. Assisted driver model showing preferred support types dependent on driving task situation and performance level

In figure 2 we see that support with regard to the implementation part is dominantly being recommended for tactical and operational tasks executed at rule- or skill-based level. Within these conditions, action support is generally most recommendable, because then the human remains involved in task execution and preserves situation awareness, which allows better reaction times after failures or unexpected events. Providing support related to mental processes, like option generating or selecting, might temporarily increase the required level of task performance. Drivers can only achieve such high level of task performance by skipping less important subtasks or by adapting their driving behavior [25].

Support in terms of option generation or selecting (like Decision Support) is therefore not recommended in situations where such adaptive responses are not possible, e.g. in situations dominated by tactical driving tasks operated at skill- or rule-based level. In general, advising must be considered very carefully as it might cause worse performance due to doubts or confusion.

Advising is therefore restricted to those situations which allow more intensive mental consideration, as is generally the case for strategic tasks. (Advising is therefore also the recommended support type for strategic tasks at skill-based level, although the schematic does not provide a match for this combination.)

6 EVALUATING ACC WITH THE ASSISTED DRIVER MODEL

The attempt of the assisted driver model is to facilitate the design of driver assistance by recommending support types for new applications of partially automated driving. As an example of the model's practical applicability, this sec¬tion suggests improvements to an existing partially automated system; adaptive cruise control.

Adaptive Cruise Control (ACC) supports two subtasks: maintaining a certain speed and keeping distance. To assess this assistance function we first review how both subtasks relate to the recommended support types assuming that these tasks are executed by a person with average driving experience.

For an average driver, the subtask to maintain speed is an operational task executed at skill-based level. During heavy traffic, drivers consider to keep distances which are long enough to avoid collision, but short enough to avoid other drivers continuously merging in front. As it is within such dense traffic for which ACC offers advantages, we consider keeping distance a tactical task. Experienced drivers execute this task with skill-based performance. For both conditions the model recommends warning, intervention or action support, among which especially action support is most appropriate. When we then look at the support offered by ACC, we see that this support is not in line with the assisted driver model. With ACC, before mentioned subtasks are being replaced by setting predefined speed and headway. For prevalent systems these settings involve selection of the right options which are represented in an abstract manner, requiring mental effort to translate the abstract representation of headway to its practical meaning. Evaluating and refining the settings also require adjustments over time. Therefore the subtasks involved with operating ACC are considered tactical tasks at knowledge-based level.

Basically, we see that the support offered by ACC places the driver remotely from the implementation part, which might cause slower reaction times and reduced situation awareness. (problems, which are indeed being reported [7].) In general, support should ensure that new subtasks are as much as possible being performed at skill- and rule-based level, because drivers then behave more homogenously and predictably [26]. Also on this note, ACC does not offer recommended support. Furthermore, most ACC systems do not automate keeping distance under all circumstances. The driver could be required to intervene by braking during high deceleration rates. Because the driver is then suddenly made responsible for the implementation part, without prior involvement, this could be a possible threat. Action support offering human involvement in the implementation would therefore be the most appropriate support type, allowing better performance during error recovery. In praxis this could be realised by implementing pedals with force feedback. When ACC is activated, the brake and acceleration pedals would continue to move or offer resistance to indicated the system's adaption in speed and distance in accordance with traffic situations. This would mean a more active involvement of the driver and allow better reactions when transitions to manual control are necessary. The suggested solution is in agreement with experimental research on force feedback [27]. Although the current example only involved ACC, the model allows also improvements to other applications, as shown for example with an assessment of Semi-Automated Parallel Parking [26].

7 CONCLUSIONS AND DISCUSSION

The attempt with the assisted driver model presented in this paper was to answer from a human-centred perspective, the question: what driving situations are in need for what kind of support? This attempt needs to be considered as a first step to go from a descriptive model to a more prescriptive model for recommendation of support types when developing new assistance systems with partially automated driving. For our research, Levels of Automation (LOA) [11] turned out to be an appropriate descriptive model, because it describes most of the theoretically possible intermediate levels of automation. From the development of our desired prescriptive model, the following findings can be concluded:

- 7 recommended support types relevant for driver assistance have been distinguished.
- For the translation of general automation levels to recommended support types, the following considerations turned out to be relevant: (a) Operator performance is generally most improved by physical implementation assistance, (b) joint human-computer generation of options need to be avoided, because it might cause confusion or doubts, and (c) the human must remain involved in the implementation part of a task to avoid decrease in operator performance during transitions to manual control.
- Relevant driving situations were distinguished by relating Michon's taxonomy of the driving task to Rasmussen's model for task performing and reflect also individual differences, i.e. driver experience and familiarity with traffic situations.
- For the allocation of recommended support types to the distinguished driving situations we considered the prerequisites to provide good operability in terms of the avoidance of errors and familiarity with the

driving circumstances. The recommended support conditions per performance level and per driving task were then combined by selecting which support types fit both conditions.

The result of this research is an assisted driver model that recommends support types dependent on driving situations. The proposed model is applicable for the development of improved application of partially automated driving, as has been shown with an assessment of adaptive cruise control. Based on this assessment problems could be avoided by allowing human involvement in the implementation of the subtasks to maintain speed and keep distance, instead of placing the driver remotely from these tasks (as is the case with prevalent systems). Action support (e.g. force feedback on the pedals) is therefore the recommended support type and this is in agreement with other research [27]. In this respect the model successfully shows the potential to improve driver assistance systems whilst anticipating concerns associated with the appliance of partial automation.

However, the scope of the assisted driver model goes beyond improvement to existing systems. Ultimately, the model is intended to facilitate the design of new systems for partially automated driving whilst incorporating sound transitions between different levels of automation. For this broader scope the recommendation of support types should account for more influencing factors than the avoidance of errors and familiarity with driving situations alone. One important aspect will be giving and taking back responsibility. It is hypothesized that retrieving responsibility improves when the operator remains involved in the implementation part. For error recovery, this is being confirmed by Endsley's test results (see section 3.2.). Therefore this kind of support is also likely to provide good operability when transitions take place from higher levels to intermediate levels of automation. Moreover, we presume that consistency in support types between a transition from one driving situation to another and between the same situations in the opposite direction, will also be important. Furthermore, when transitions are involved, we should also look at the commonly recommended support types within each driving situation. When the model shows several similar support types, the influence of these support types on operability after transition could probably help to make a more precise recommendation. Obviously, experiments with simulated driving tasks based on before mentioned hypotheses are required to further explore the influence of transitions between driving situations and between automation levels on operability. Finally, it is also desirable that the model will take timing aspects into consideration (i.e. duration and recurrence of a task), because timing aspects influence workload and should therefore be related to the choice of support types too. Preferably, further development of the model will account for before mentioned aspects and allow a more refined recommendation of support types when developing new assistance systems with partially automated driving.

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