Cooperative Approach to Overcome Automation Effects During the Transition Phase of Conditional Automated Vehicles

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Abstract: One of the safety critical problems for conditional automated vehicles appears during the transition phase. Whenever the system is about to reach its boundaries the take-over request triggers the transition of the driving task to the driver. This transition is often designed by simply switching off the automation. Therefore, this paper proposes to design the transition phase cooperatively in order to establish a higher driving performance throughout the whole process. Further, recommendations for a proper cooperative transition phase are given.

Key words: cooperation, conditional automation, take-over, transition

1 Introduction

The indispensable technological progress affects todays series vehicles and emerges space for innovations. As it can be seen on the future projects of many original equipment manufacturers (OEMs), e.g. Audi [1], BMW [5, 16], Daimler [8], etc., this development is used as a chance to improve driver assistance systems which strides towards automated driving. On this path, the drivers' role is changing and raises new questions to human factor engineers [6, p. 687]. Between these two extremes, i.e manual and automated driving or in other words: full driving task and no driving task at all, the human driver cannot be fully excluded. There is still the need for a driver to monitor the environment up to a certain level entailing known problems with automated systems from the aviation sector, such as loss of skill, higher workload, loss of situation awareness, etc. [10, 19]. To classify the tasks in vehicles with increasing automation the Society of Automotive Engineers defined different levels of automated driving [17]. Current series vehicles are already capable of assisted driving which corresponds to the levels 1 and 2. Therefore, the focus on research is on the upper levels and especially the level 3 systems, which is further referred to as conditional automated driving (CAD). At this level, the driver is allowed to perform non-driving related tasks but is still the fallback level of performance if the automated system is unable to handle the situation. The driver needs a certain time budget to take over the driving task which is initiated by a take-over request (TOR) and restricted by the capability of the automated system and its sensors to assess the present situation. Within this short period of time the driver has to safely resume control and perform a maneuver that the automated system was not able to. Because of the named

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automation effects the goal is to ensure a good take-over performance. Therefore, this paper proposes a different approach to design the transition phase compared to common studies in this field.

2 Transition process

Whenever a level 3 automated vehicle is about to reach its system boundaries, a TOR is triggered to transfer the driving task to the driver. Figure 1 shows a schematic course of the driving performance during this transition process. Percentage values are only qualitative and represent a drive which obeys the traffic rules and without mistakes that could lead to an accident (100 %) and no driving performance at all (0 %). The automation ideally performs the driving task with 100% efficiency until the TOR is triggered. At this point, the transition of the driving task is often designed as a simple switch as shown in Figure 2. So either the automation or the driver is performing which is why the driving performance of the automation is reduced to 0% at the TOR. But concentrating mainly on secondary tasks and not being responsible to monitor the environment decouples the human from the control loop, also known as the out-of-the-loop performance problem [11]. These automation effects do not form a reliable basis to take over with high driving task performance and accordingly the starting point of the driver is marked very low in Figure 1. The further course to regain 100% efficiency is unknown and depending on the drivers individual characteristics and state, wherefore the end could be reached either before or after the system boundary.

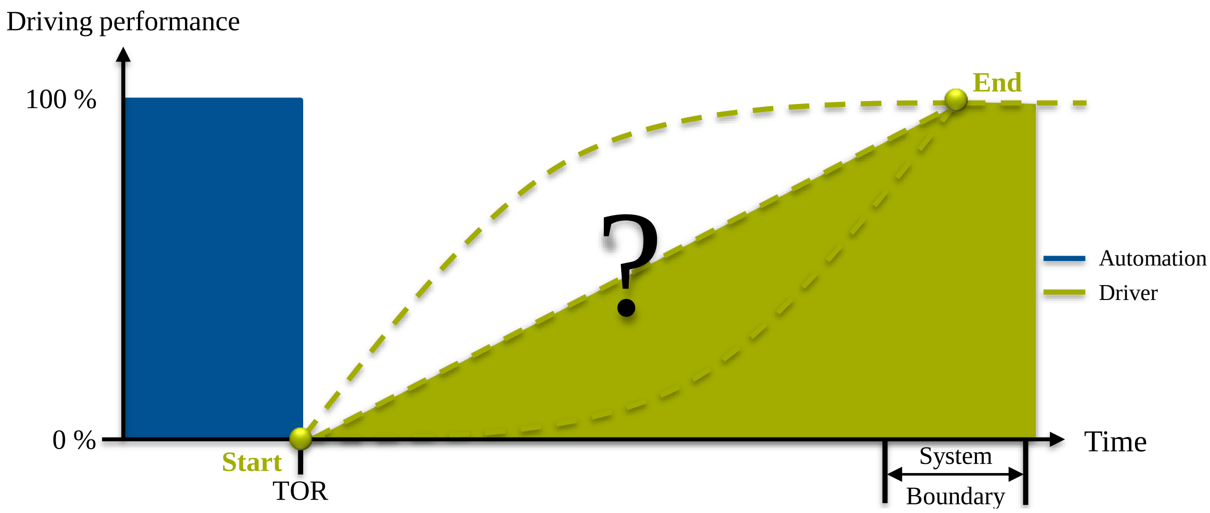

Figure 1: Schematic course of the driving performance during the transition process

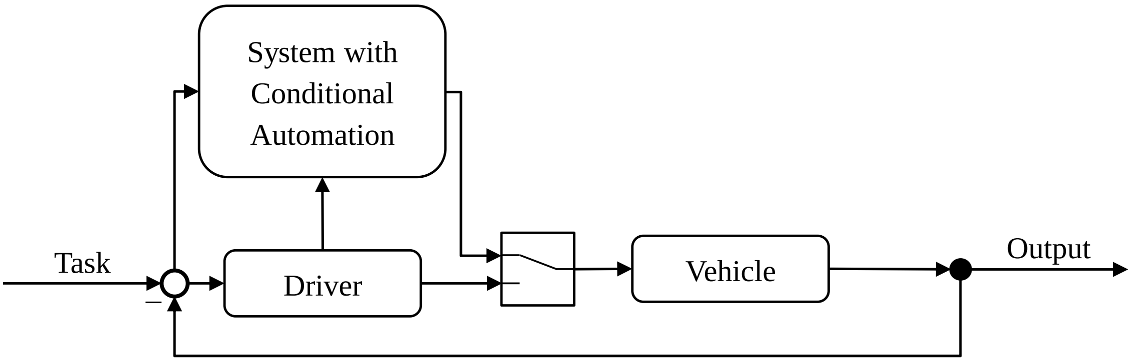

Figure 2: Block diagram of a drive with assistance systems. Adapted from Kienle [14]

The block diagram as shown in Figure 2 is not suitable for the transition phase because of the critical situation that comes along with a TOR. Figure 1 shows the resulting course of the driving performance because of the applied method of a switch. Yet, the drivers course provides great potential to reach 100% of driving performance. Therefore, this paper proposes a different approach of the driving task allocation for critical situations such as the take-over (see Fig. 3). In more specific terms, the idea is to replace the switch in critical situations by a summing point where both, the automation and the driver, act together towards the common goal (or in other words: cooperate) of safe take-over. Before and after a TOR the transition of the driving task can be designed by a simple switch since the criticality in those situations is lower and the driver does not necessarily need additional support. The ideal course of the driving task performance after this adjustment is given in Figure 4. The transition process is classified in two phases, the transition phase (TP) 1 and 2, divided by the hands on steering wheel time. The general approach to establish 100% driving performance for the whole process is addressed during the TP 1 only by the automated system since the driver is obviously not intervening in the driving task yet. After having the hands on the steering wheel, i.e. TP 2, the automation is supporting the driver, e.g. by assisting the maneuver decision and execution.

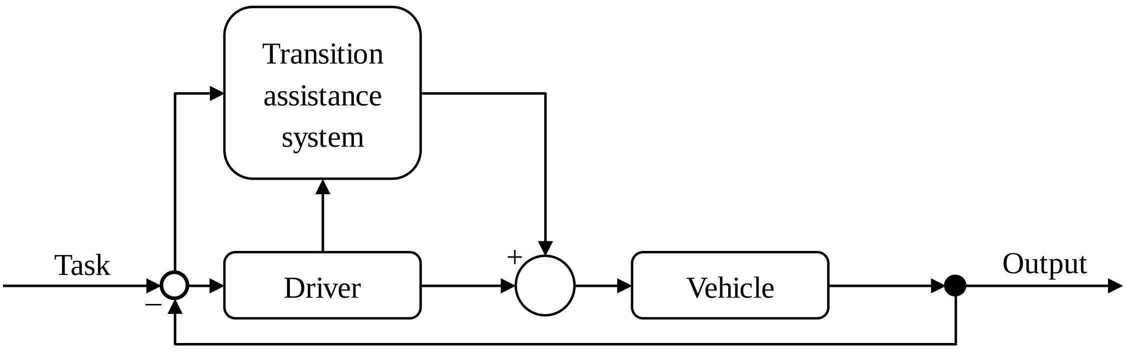

Figure 3: Block diagram of the cooperative transition phase

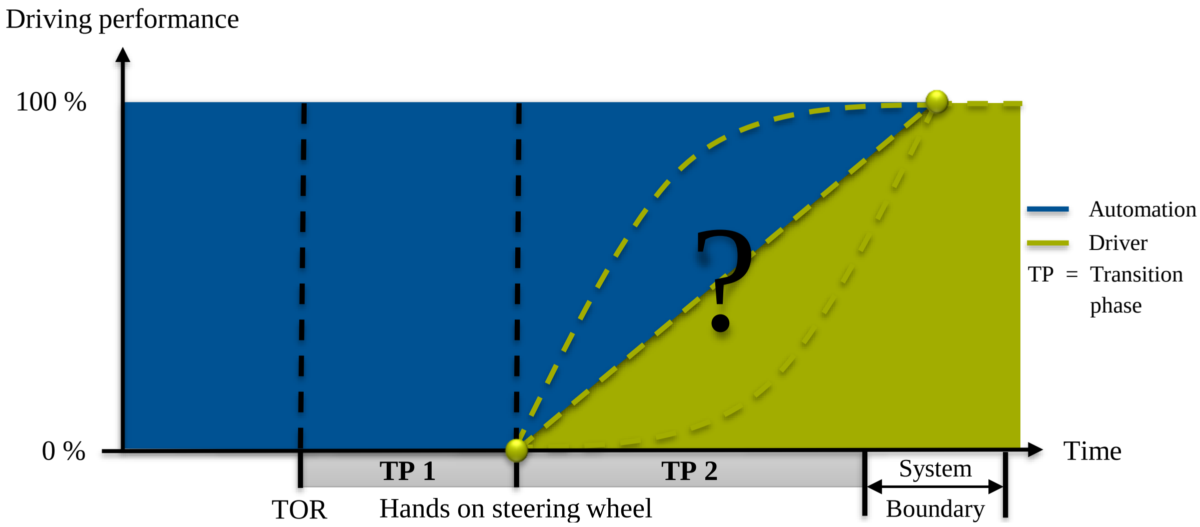

Figure 4: New approach applied on the schematic course of the driving performance during the transition process

3 Cooperative transition

3.1 General definition of cooperation

Before proceeding with redesigning the transition phase via cooperation between driver and automated system it is essential to define the term itself. Different application fields may have distinct views on cooperation. Yet, a domain independent definition was formulated by Hoc [13] as follows:

Two agents are in a cooperative situation if they meet two minimal conditions.
(1) Each one strives towards goals and can interfere with the other on goals, resources, procedures, etc.
(2) Each one tries to manage the interference to facilitate the individual activities and/or the common task when it exists.
The symmetric nature of this definition can be only partly satisfied.

Agents in this case can be two or more human or artificial agents [13]. In other fields such as the human-robot interaction the interaction is classified by four criteria, i.e. *working time*, *workspace*, *aim* and *contact* [18]. Here it is called *Coexistence* if the human and robot share the resources *working time* and *workspace* but they do not inevitably have to have the same *aim*. In turn, if the *aims* are matching it is classified as *Cooperation* and if additionally a direct contact is present it is characterized as *Collaboration* [18]. However, during the proposed transition phase from CAD to manual driving with the automated system actively supporting the driver the difficulty becomes clear. This support occurs by accessing the same resources as the driver and although it should strive towards the same goal of a safe take-over, the drivers expectation of it can be fairly different. This is why the aim of both sides do not have to match. Hence, this process of the automated system and human driver solving the critical situation of a take-over is labeled as *Cooperation*.

3.2 Designing the transition process with cooperation

The idea of designing systems where humans interact with automation in a cooperative manner is not new. Especially during the recent years with increasing interest in automated vehicles, questions arose about the way to do so adequately in the automotive sector. It is important to underline here that this paper is focusing on the cooperation during the transition process (see chapter 2) and not for the whole drive. An example for the latter is the project *H-Mode* which was funded by the German Research Foundation (DFG) [2]. Various recommendations to design cooperative systems can be found in literature, e.g. Flemisch et al. [12] named four cornerstones for cooperative control situations, i.e. *ability*, *authority*, *control* and *responsibility*. Biester [4, p. 11] gives an overview of the 15 most important characteristics of cooperation in human-automobile interaction. Considering that during cooperative situations the automated system and driver are handling the situation together, the automation can or should be seen as a team player. Therefore, Walch et al. [20] suggests four basic requirements for driver and automated system that have to be fulfilled in order to become an effective team player, i.e. *Mutual predictability*, *Directability*, *Shared situation representation* and *Calibrated trust in automation* [20, p. 7]. Further aspects to consider can be found in Klein et al. [15] and Christoffersen and Woods [7]. Bengler et al. [3] structured the most important aspects of cooperation for human-machine interaction and summarized it under the term of *Layers of cooperation*, i.e. *Intention*, *Mode of cooperation*, *Allocation*, *Interface* and *Contact*. These layers are considered as "requirements for successful cooperation" [3, p. 6]

All of the mentioned recommendations were considered for the approach of designing a cooperative transition process. Nevertheless, only those who are important for the transition process are given in the following together with recommendations to implement them. Since many of them are overlapping in their meaning similar ones were summarized as one.

Intention *or* **(Mutual) Predictability.** For intention inference it is necessary to determine on which level the cooperative activity is happening. Hoc [13] differentiated between *action*, *plan* and *meta* levels which can be allocated respectively to the three levels of driving task by Donges [9]: *stabilization*, *guidance* and *navigation*. In the transition phase the main encountered and most important level for intention inference and mutual predictability is the *plan* level because of an upcoming maneuver, wherefore a *shared guidance* system needs to be designed. Because of a time critical event, the intention inference needs to only consider the plan level contrary to the recommendation from Bengler et al. [3] to regard all three. In general, the automated system should execute its intention in TP 2, when the driver has at least the hands on the steering wheel. Therefore, the TP 1, right after the driver receives the TOR, is suitable to communicate the intention of both agents. A confirmation channel for the driver, e.g. through the human machine interface (HMI), is required and recommended [3].

Shared situation representation *or* **Common knowledge base.** The situation representation for both, human and machine, has not mandatory to be the same due to many reasons, e.g. perception of information because of different sensory systems, distinct information processing, etc. [20]. This aspect gets especially important when the driver needs to understand and predict the automated systems actions. Hence, whenever the system communicates its intention it should also communicate its view on the current situation in order to avoid confusion.

Authority *or* **Allocation of tasks & responsibilities.** Per definition of the automation level 3 by SAE [17] the driver has to take over the driving task in case of a TOR. To be in accordance with this, the drivers' input should always have the highest priority during the TP.

Control *or* **Directability.** The concept of *Control* [12] and *Directability* [7, 15, 20] share the idea that the controlling entity has the ability to shape the course of events. During a cooperative TP, which is solely a time and safety critical situation, both control entities will perform an action. Thus, the driver should be able to control or direct the actions of the automated system. The other way round, i.e. the automation overruling the drivers' input, has to be avoided due to the higher authority of the driver (see "Authority *or* Allocation of tasks & responsibilities").

Interface. The interface has to be designed in a way that a continuous communication is established which is recommended to be multi-modal [3, 4].

Contact. Since the TOR is a time critical situation and a contact is not only desired but crucial the interaction has to be ideally developed at vehicle control devices that are required to handle the situation, e.g. the steering wheel and pedals.

4 Conclusion and future research

Most authors developed their concepts and definitions for a cooperation between a human/driver and a technical system/vehicle for continuous interaction. Yet the proposed interaction in this paper aims at transferring the system's capabilities, including full knowledge about the situation and full control over all resources necessary for the driving task, to the human driver. This poses the question, if existing definitions, i.e. mode of cooperation, need additional stages that focus on the transition between the existing ones. Evaluation of the proposed transition phases will have to deal with the major influence of time on the cooperation. As time is limited, some processes, like negotiations about the system's influence on a control element, might be skipped, leading to the question of how the system's automatic retreat should be designed. It is also yet unknown, whether or not drivers are even willing to share the driving task in such a critical situation. Finally, subjective measurements of driver acceptance should not be neglected as they are crucial for the future implementation of cooperative transitions.

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