# Central Research Questions for Driver Take-Overs in SAE-Level 4 Automated Driving

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**Summary:** Research on take-overs in SAE-Level 4 automated driving is crucial for ensuring safety during the utilization of these driving functions, as take-overs may still occur, e.g., when certain traffic situations require it. Central questions revolve around the vehicle system's decision procedure in these situations to request the human to take over and possible alternatives. The decision bases on the required take-over time in dependence of the current non-driving related activity and the time left until the system boundary is reached. The presented models *HoMoTo* and *SAM* are tools to support this decision and to enhance safety during the take-over process.

**Key Words:** Driver Take-Over, HoMoTo, Operational Design Domain, Situation Awareness Manager, Take-Over Time.

# 1 Motivation

Automated Driving in SAE-Level 4 (SAE-L4) [1] allows the driver to completely and continuously turn away from the driving task. Since the system always guarantees a safe state, by definition, take-overs by humans are not required unless the driver requests it. This means that the driver can even leave the driver's seat unoccupied or can sleep.

The automated driving functions of SAE-L4 will initially be restricted to Operational Design Domains (ODD) which are very limited at first and will be expanded later on, as SAE-Level 3 driving functions are today [2]. This means that take-overs occur as well in automated driving SAE-L4 before leaving the ODD. However, these take-over requests (TOR) can be predicted based on the navigation system for a long time. Further, take-overs may still occur within the ODD, e.g., in case of a system failure or a situation, which cannot be managed through the system. This includes defects of vehicle sensors or special weather situations that unexpectedly restrict the function of the vehicle. Further, in accident situations with massive route restrictions and congestion within the ODD, take-overs are reasonable as these may lead to massive delays.

In this case, in contrast to SAE-L3 function scope, the vehicle system *offers* the driver the

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option to take over (Take-Over Offer, TOO) or brings the vehicle into a safe state alternatively (e.g., stops on the hard shoulder; Minimal Risk Maneuver, MRM).

Then, this information should be communicated to other vehicles early (hazard warning lights, Vehicle-to-Vehicle communication (V2V)), as the vehicle may become a dangerous obstacle to traffic. If necessary, the vehicle must react accordingly after the take-over has not taken place. For example, if the driver is no longer fit to drive, an emergency call may have to be made. If the driver is fit to drive again and the manual drive is continued, it must be communicated (V2V) and signalized whether and when the journey will be continued manually.

Traffic jams and MRM that occur within the ODD can lead to massive deviations from the planned route and time of arrival at the destination as described above (see Figure 1, dark blue driving line). If the system could anticipate these situations earlier, the driver could have enough time to take over and steer the vehicle along an alternative route with less delay to the journey time, e.g., leaving the highway (see Figure 1, light blue driving line). After the detection of an uncertain situation or of traffic jam, a comparison by the vehicle system between the time until the driver is ready to drive again and the remaining time until the automated driving functions end on the alternative route is crucial here. Given the example above, the prediction of the take-over procedure of the driver, especially of take-over time until the driver is fully fit to drive again, is a significant factor for the success and safety of SAE-Level 4 driving functions as well. In future, automotive developers and manufacturers will have to deal with this safety-critical process when designing each vehicle interior variant and further developing driving functions. This issue leads to some central questions, which must be clarified before the market launch of SAE-Level 4 automated driving functions.

# 2 HoMoTo and Situation Awareness Manager (SAM)

After the offer (or the request, in SAE-L3) of the vehicle to take over the vehicle control, depending on the activity the driver performed during the passive drive (Non-Driving Related Activity, NDRA), the driver must execute more or less complex cognitive and physical action steps to restore driver readiness. The type, the amount, the variation and perhaps the order of the steps, the duration of each single step and of the whole take-over process depend on many situational factors. The human machine interaction of the driver with the interior elements during this transition process in digital and physical manner takes a completely new meaning in this context.

*Hand over, Move over, Take over* (*HoMoTo*) [3] is a model to describe the transition process of both, the driver and the vehicle interior, from an automated driving state while doing an NDRA back to manual driving. The *HoMoTo* model was developed by the Institute for Engineering Design and Industrial Design (University of Stuttgart) and aims to derive various possible take-over scenarios in a standardized procedure and as certifiable standard. This standard aims to ease OEMs to predict possible take-over procedures and the minimal take-over time (TOT) required, to estimate the human machine interaction and to derive design recommendations for the interior of SAE-Level 3

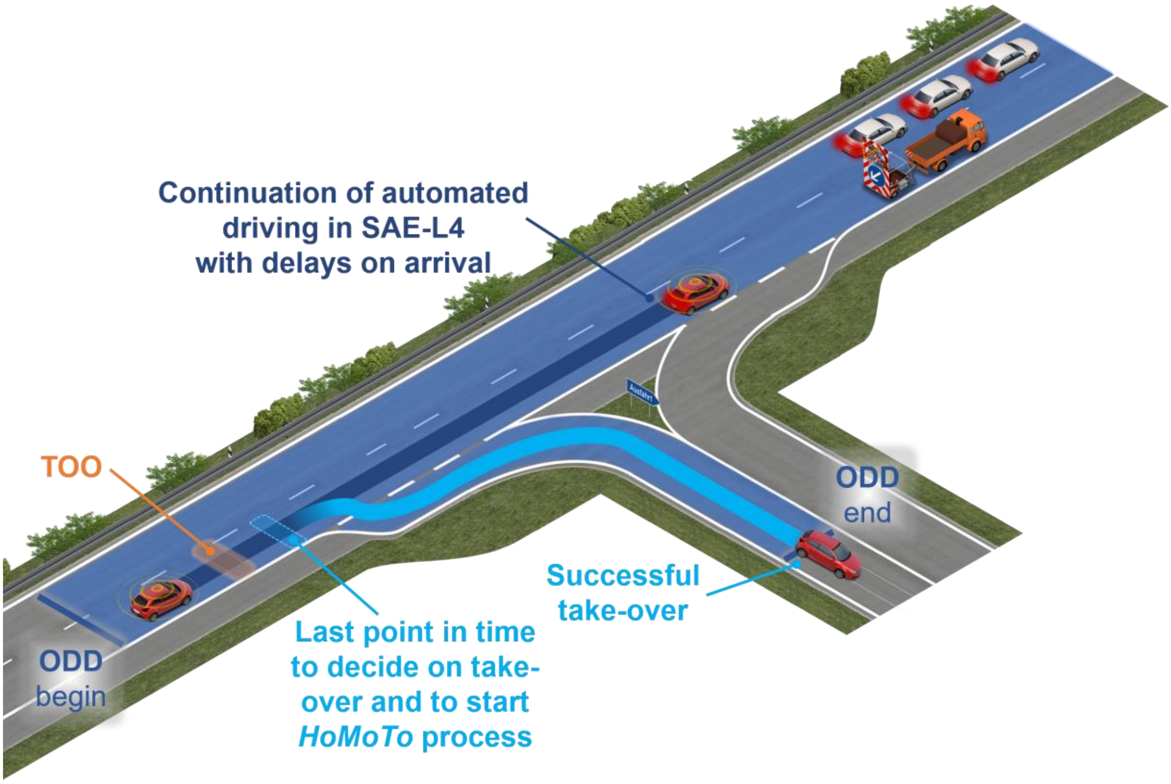


Figure 1: Example for TOO in SAE-L4 in case of traffic jam.

and 4 vehicles on the basis of this. *HoMoTo* is a tool to structure the whole transition process by dividing the whole phase into the three phases *Hand over, Move over* and *Take over*. These three phases may run sequentially or in parallel. Within the *Hand Over* phase the driver stows items used for the NDRA, like smartphone and/or book, and picks up objects needed for driving, like glasses. Preparing the driver's workplace, like turning the seat into driving direction and adjusting the seat back, is assigned to the *Move Over* phase. [3, 4]

The actual take-over of the driving task takes place within the third phase, *Take Over*. For this, the driver must first gain the necessary situational awareness (SA) of the current traffic situation around the vehicle and of the vehicle state itself during cognitive adaptation. The restoration of the SA is a relevant prerequisite for the safe take-over and is not a singular step. Rather, the recovery of SA begins with the TOR or TOO and continues during manual driving, with the greatest increase occurring during Phase 3, *Take Over* [5]. According to [6], situational awareness comprises a) perception of the environment, b) comprehension and c) prediction of the future state of the environment. Gaps in SA or deviations from what is actually happening in traffic around the ego vehicle can easily lead to a dangerous situation. Figure 2 depicts the control loop between driver, vehicle and environment and shows the importance of bringing the driver back in the loop before driving.

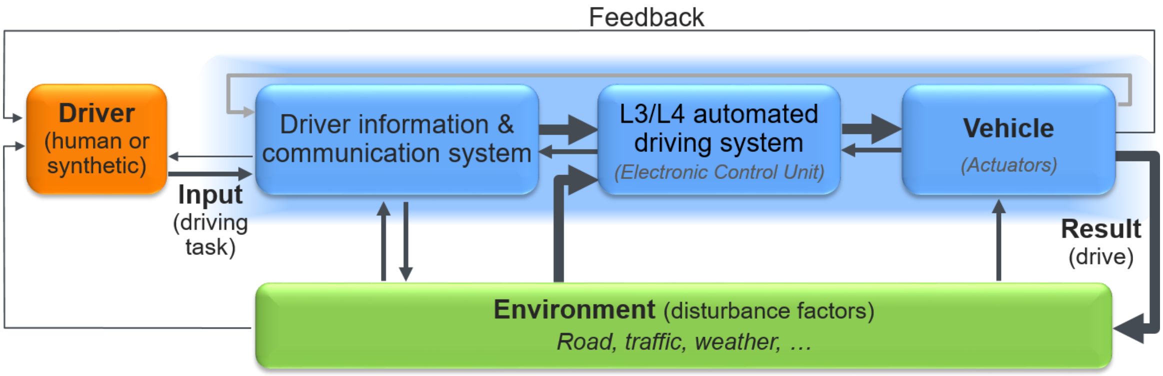


Figure 2: Control loop of driver-vehicle-environment.

Due to the extended range of functions in SAE-L4, NDRAs with increasing complexity and intensity, like working or watching movies, will be permitted. As immersion and the physical distance to the driving task increases, so does the mental distance from the driving task [5]. The diversity, the amount, the variation and the duration of the action steps increase as well. In addition, especially in this situation, the risk potential of a driving error can be greatly increased for some time after the take-over due to information deficits. At the end of a more complex take-over process, the question arises as to the SA of the human driver required for the subsequent driving task.

For this purpose, Remlinger and Pomiersky [7] developed the *Situation Awareness Management* (*SAM*). The novel software function provides a method for determining the required SA of the human driver and helps to check, regain and increase SA. The aim of the tool is a context-adaptive, individual increase in human SA during a take-over process and an increase in functional system safety [5]. With the help of the *SAM*, the vehicle informs the driver about the current location (e.g., route, direction of travel, location, lane), the current speed, traffic density, weather, road conditions as well as about the current conditions around the ego vehicle, i.e., the type of other vehicles, their distance, relative speed and their intention and any upcoming obstacles and special hazards. The *SAM* system carries out a kind of reality check before actually handing over the driving task to the driver in order to record, evaluate and check the driver's acquired situational awareness. In order to check the driver's attention, the driver must correctly allocate clues of the surroundings. Vehicle control is handed over when the vehicle ensures sufficient SA of the human driver. However, due to the legally required override capability of the driver in accordance with the modified Vienna Convention, the driver can finally insist on taking over. With the help of the *SAM*, the car manufacturer can nevertheless document an increased duty of care and counter possible product liability claims in a documented manner, as the driver's lack of fitness has been recognised and reported back to him or her. See Figure 3 for the current approach in the vehicle HMI.

Figure 3: Example question of SAM in vehicle HMI [8].

# 3 Take-Over Time as Critical Factor

Take-overs are very critical and safety relevant but will be part of the use case of automated driving functions. With the admission of automated functions, OEMs must demonstrate and guarantee sufficient safety during this take-over procedure to users in terms of liability.
The norm ISO 21448 SOTIF (2022) [9] aims to ensure Safety of the Intended Functionality (SOTIF) of automated driving systems through the absence of unreasonable risk due to a hazard caused by functional insufficiencies. SOTIF addresses the specification and design phase, the verification and validation phase, as well as the operation phase in order to eliminate hazards or reduce risks. Specific conditions of a scenario including reasonably foreseeable misuse can trigger hazards SOTIF aims to eliminate. The scope of application includes all levels of driving automation.
In the future, performance characteristics between automated vehicles will be defined through how passengers can use their passive ride and which activities are allowed. OEMs will differentiate themselves from the competition through the approval of NDRAs. Applying the principle of SOTIF to take-overs, OEMs of automated vehicles need to consider possible take-overs scenarios just after NDRAs the customer demands in the same way as for automated driving scenarios. The *HoMoTo* model is a tool to define these scenarios at an early stage in the vehicle development process. On the basis of this, the OEM is able to decide, which NDRAs are allowed, to what extent it restricts the exercise of NDRAs and how misuse is defined and restricted.
In the context of the development of the *HoMoTo* model, it was possible to identify the potential for adapting methods of work science to the take-over procedure in order to gain findings regarding necessary steps and tasks during the transfer to the driving task and the required TOT. In general, basic motion elements for hand and arm movements can be adopted from the process language of Methods-Time Measurement (MTM), a

predetermined motion time system, which is primarily used in the production field [3]. In some explorative studies, the transfer of MTM basic motion elements to the physical tasks during take-over proved to be suitable, even though the elements cannot describe all body movements [3]. For example, the calculation of the take-over after *Reading a Book* using the MTM motion elements results in 93.2 TMUs, which are 3.35 s [3]. Although the methodology and approach of MTM could be applied, these concrete time values of MTM cannot be transferred to the take-over procedure, as the MTM method is optimized for the field of production ergonomics and for physical work steps of highly trained workers performing highly repetitive tasks. The actions and movements of the driver during the take-over procedure are not to be weighted as highly practiced activities in the sense of the MTM principle and are therefore subject to a higher uncertainty in the time calculation. Therefore, the time for single motion steps need to be adapted for take-over scenarios. In addition, individual anthropometric characteristics of persons have a greater influence on the execution of movements due to the limited space in the vehicle interior.

Further, [10] described the necessary steps and tasks of the driver during the take-over procedure after various NDRAs with the help of different levels of task description from field of work science. A cycle of typical tasks during the *Hand over, Move over, Take over* procedure after different NDRAs could be identified.

With the *HoMoTo* model, we provide a scenario-based format to predict the take-over procedure, including the calculation of the necessary TOT based on the current state of the driver and the NDRA. With the addition of *SAM*, OEMs can ensure a sufficient safety during take-overs.

Still, not only the specific situation inside the vehicle influences the decision of taking over and the take-over procedure. The available time budget given through the automated driving system depending on the actual traffic situation around the vehicle and the interpretation of the situation correlates strongly with the take-over decision inside the vehicle. An adequate coordination of driver and system decisions depending on the specific traffic situation and driver state is crucial for the safety of the take-over.

# 4 Open Research Questions and Discussion

The issue described above leads to some central questions, which must be clarified before the market launch of SAE-Level 4 automated driving functions.

According to *HoMoTo* and *SAM*, first time values of the transition process of the driver in different scenarios can be derived. In general, for a successful take-over,

*the time required for the take-over < the time until automated driving function ends*.

Alternatively, the road infrastructure requires buffer spaces for stopping.

In a scenario that an uncertain situation or a traffic jam within the ODD is foreseen, decisions based on the options of an alternative route, the time left until the border of the ODD of the alternative route is reached and the TOT required have to be made, whereby minimum times are always assumed within *HoMoTo*.

Open research questions to discuss are:

- Which (vehicle) parameters do influence the *HoMoTo* transition of the driver?
- Which steps of the transition of the driver are influenced most?

Based on this, it has to be evaluated,

- how far in advance can the vehicle system predict an uncertain situation or traffic jam?

This must be compared with,

- how far does the ODD extend when leaving the intended route (e.g., motorway exit and access route)?
- How much time is given to the driver for *Hand over, Move over, Take over*?
- How much time is given for *SAM*?
- How long is *SAM* active?
- How long is the maximum time available for Level 4 take-overs?
- How hard should an automated vehicle brake to which target speed to gain time?
- And, does the alternative route provide a wider range of the ODD?

Depending on this, discussion is needed about,

- how much and which information outside the field of view but inside the ODD is necessary to make a decision about the take-over?
- How do decisions of the vehicle system provide the time values required for *HoMoTo* and *SAM*?

Take-overs are multi-layered decisions und must be made in the context of the driver's TOT and environmental conditions, such as distance to the unmanageable situation or to the traffic jam, alternative options on the route (e.g., exits on the motorway) and distance to this, the time budget if an alternative route is taken, current speed, and complexity of the take-over situation.

# 5 Outlook

The described research potential is currently partly part of the publicly funded research project called SALSA (Smarte, Adaptive und Lernbare Systeme für Alle, project start in July 2024). Focus in SALSA is the sleeping and waking up situation of the driver in SAE-L4 automated vehicles. The project aims to investigate the take-over situation, e.g., regarding TOT, take-over quality and the perceived comfort during the take-over procedure, in dependence of the body posture and seat adjustments to promote sleep.

To further elaborate the described *HoMoTo* model, the Institute of Engineering Design and Industrial Design (University of Stuttgart) is currently preparing a project draft and is forming a consortium from science and industry. The aim of the project idea is to develop a dynamic simulation and validation of individually describable take-over scenarios in (highly) automated vehicles with regard to human feasibility and a possible risk of injury in the event of an accident. For this purpose, the take-over procedure from an NDRA to the take-over of vehicle driving is digitally simulated and evaluated in terms of feasibility. This allows a large number and variety of situations, human postures and movements during an NDRA and during taking over to be analyzed automatically.

In order to describe human posture, movements and movement sequences in the vehicle interior digitally, a description language to transfer physical take-over steps correctly into the simulation world is necessary and is one of the project goals. To do so, the take-over procedure with single action steps and tasks needs to be converted into a suitable description format and form of documentation. The description format is used to clearly describe a human posture and movement for adopting a subsequent posture for the purpose of documenting and transmitting information about this physical state. The approach taken here is that of a modular format. The aim is also to achieve maximum compatibility of this description format with already established and partially standardized software and simulation procedures in development tools for automated driving functions (ASAM OpenX standards). The NDRA states and take-over scenarios can then be digitally analyzed in the ergonomics simulation in the RAMSIS 3D human model. A special challenge will be the coupling with anthropometric as well as cognitive human models. This is necessary for a consistent computer simulation of all driver and passenger scenarios in the vehicle interior.

In addition, the initiation of an accident with a pre-crash and crash phase is simulated during the take-over based on the respective occupant status and evaluated using injury criteria. The developments are based on measurements of test persons and are validated in practical software demonstrators. Due to the high scaling and transfer potential of the process, it will be used to further support the development of future mobility solutions and thus strengthen the mobility industry in the long term. Concrete work objectives are the simulation and evaluation of the driver state during NDRAs, the simulation and evaluation of the procedure for the occupant to take over the vehicle and the development of a description format for take-over scenarios, among others.

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