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Takeover at Level 3 Automated Driving

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Author Christian Müller-Tomfelde, Visteon

Abstract

For the upcoming generations of vehicles with level 3 automation the situation for drivers and automakers changes dramatically in various aspects. First, drivers will experience a new freedom, that they do not need to have their hands on the steering wheel all the times and do not need to monitor the surroundings constantly like before. Furthermore, they are allowed to pursue so called non-driving related tasks (NDRT) or activities such as reading, eating etc. However, certain constrains are imposed on drivers at level 3 automation: they need to stay perceptive to notifications from the automated driving system and they need to be prepared to take over control of the vehicle without undue delay. Second, drivers will become monitored to determine their status and ability to take over the manual dynamic driving task. Also it will become important to detect potential miss use of drivers such as sleeping or leaving the driver seat, while being driven automatically at level 3. Third, automakers not only need to develop new technology that goes beyond that of traditional vehicles, like high-performance computers and sophisticated software. With the advent of automated driving systems the carmakers also can become liable according to German law even after selling the car when the vehicle is in automated drive mode and not under control of the driver.

This article will shed some light on the takeover process at level 3 automation against the backdrop of the new German transport law. The driver's transition back to manual drive is decomposed in sub tasks to clarify the matter for the discussion and a possible location for managing the takeover in the architecture of the automated driving system becomes suggested. Then we identify a fundamental dilemma between safety and comfort when realizing the takeover management with the driver monitoring technology for level 3. To cope with the dilemma, i.e., to mitigate negative impacts on safety while maintain high acceptance and comfort of the system at the same time, we propose a dedicated human machine interface strategy. Finally the position and function of the takeover management unit in the automated driving system gets described and key characteristics highlighted.

Overview Take0ver at Level 3 Automation

The safe and convenient takeover of the driving task by the driver is the key element for the introduction of Level 3 Automation on highway in the next years. Not only had the German legislation to be changed according to the amendments to the Vienna Convention from 1968 but also means and devices need to be in place to guarantee appropriate transition times from automation to manual driving. Driver monitoring technologies as we know it for drowsiness detection is likely to be extended to that periods where the driver pursues so called non-driving related tasks or activities during automation. These tasks/ activities are not any more side-tasks or secondary tasks while driving but rather allowed activities such as email reading on the smartphone, eating, etc. which is the instant benefit to drivers. To pave the way for a common understanding we complied a synopsis of the takeover based on the timeline around the change from automated driving at level 3 to manual dynamic driving at level 2.

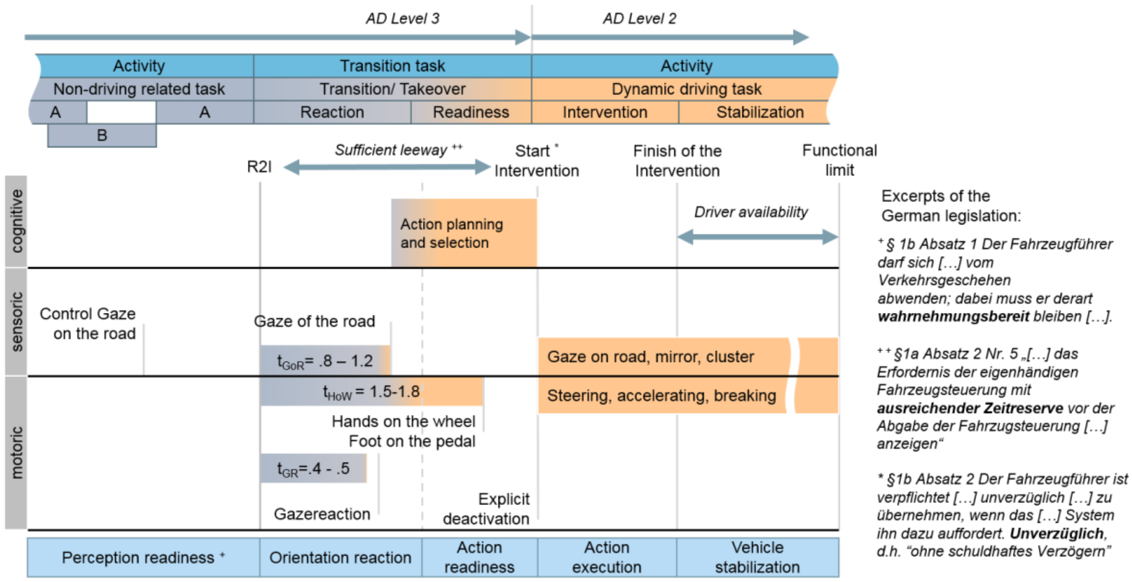

Figure 1 A Synopsis of the takeover at level 3 automation. While the driver pursue non-driving related activates a request to intervene (R2I) is issued when the driving system detects a functional limit. Drivers need to give up their activities immediately without due delay and become ready to drive manually. In standard situations enough leeway needs to be provided to allow for a safe and comfortable take over.

We suggest a three-tier representation of the activity sequence, where a middle activity, the transition represents the driver's task of transitioning from non-driving related tasks (left) to the manual driving task (right). Here, we focus on standard situation where an upcoming foreseeable functional limit of the automated driving system such as end of highway ride, or adverse weather conditions requires the driver to take over the driving task. We decompose the tasks of the drivers before and after the Request to intervene (R2I). The discrete representation of strictly sequential tasks may not hold in naturalistic driving situations because of the more transient nature of human task switching. However, the presented decomposition bears the potential to foster the mutual understanding of all relevant groups participating in the development of realization of the takeover, such as function developer, HMI designer, ergonomist, and psychologists, amongst others. Also, the discussion and in depth considerations about the role of driver monitoring technologies for the takeover reveals a dilemma when it comes to the realization of the management of the takeover: With driver monitoring technologies such as head tracking, gaze detection and even more advances, e.g., posture detection, the prediction for the time drivers will need for the transition improves in quality. This may lead to shorter predicted transition times than those of the cumulated 95% of drivers would require and, at the same time, to a higher system acceptance since users get more adequately requested to take over and therefore can spend more time on their non-driving related activities. However the chance of incomplete or unsuccessful transitions to manual driving, i.e., too late intervention, increases in cases of unexpected events that were not apparent when the time budget for the takeover was planned in the first place. In essence, the safety of the takeover becomes compromised while the user acceptance may increases when monitoring the driver's state influences the planning of the takeover and the request to intervene in particular. Once the request is issued, the driver needs to give up the current activity to become ready to drive manual, usually starting to perform an intervention or maneuver. Not to mention that the driver needs to be receptive any time of during the automation being in the situation to see or hear the R2I. The driving situation and functional limit that led to the takeover stipulate the actions the driver needs to perform, while the transition task follows some simple patterns on the way establishing the readiness for driving manually after the automation. Usually the driver's first reaction to the request to intervene is turning the head and eyes towards the road. This happens on average within half a second but can last in some case up to several seconds. Following or in parallel to this reaction drivers puts back their hands on the wheel after approx. 1.5 seconds. In case of a non-driving related activity prior to the request that involves the hands such as reading email on a tablet or eating, the hand-on-wheel time is extended since the artifact needs to be put away before.

The HMI of the Takeover

Automated driving at level 3 and higher reorders the role of the driver and the automated driving system. Before the driver was controlling the vehicle at any time and was constantly within the loop prone to do not anything else but driving. Automated driving is a disruptive technology in the way that drivers become a passengers and the vehicle don't need a driver to reach the destination at all times. The former symbiosis of driver and vehicle becomes revolutionized into cooperating partners each doing what they can do best. This means also that new concepts for the human-vehicle-interaction for automated driving systems need to be developed. However before reaching these aspects, the current and urgent problem to solve resides in the safe transition from automated back to manual drive, i.e., from level 3 back to level 2. The driver pursuing a non-driving related task needs to be always perceptive to notifications of the driving system and ultimately the request to take over control of the vehicle. On the other side the automated driving system needs to yield enough temporal leeway to drivers to safely transition from their current activity to the manual dynamic driving task. Driver monitoring technology bears the potential to deliver a significant step forward but also comes with a dilemma when trading safety and acceptance of the takeover management, as mentioned above. Here a diligent Human-Machine-Interaction (HMI) design can help to mitigate the dilemma of the takeover management. We suggest a HMI request cascade with rising urgency that offers to drivers the opportunity to return to the manual driving task at their convenience and peace, rather than sending out a single request with the one and only last opportunity to react.

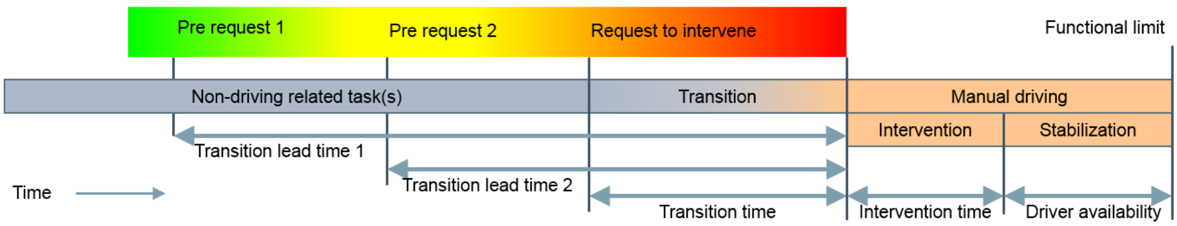

Figure 2 In case of a standard a functional limit an HMI cascade of 2 pre-requests with rising priorities develops over time. While the order in sequence of the cascade remains the same, the temporal organization may change due to unexpected events after the initial detection of the functional limit. The HMI cascade is deigned to mitigate the dilemma when monitoring the driver status to increase system acceptance and maintains safe operation for standard takeover situations.

The pre-requests of the cascade substantiate the safety of the takeover since the functional limit of the driving system gets notified to drivers with more than enough leeway to transition to manual driving. On the other side the system acceptance is kept high due to the rising levels of pre-requests priorities. This concept also exhibits several other benefits next to the mitigation of the dilemma of the takeover management. First, the driver can choose a point in time for taking over that suits his situation. Rather than being triggered, the takeover can happen self-paced. Second, even when an unexpected event after the first pre-request shrinks down the overall time budget of the takeover, the request cascade remains the same, except the timing. Thirdly, pre-requests can get perceived also by other passengers and who can actively contribute in getting the driver back into the dynamic driving task.

Takeover management unit

Automated driving at level 3 and higher reorders the role of the driver and the automated driving system. The driving system need to signalize the takeover to the driver who is occupied with a non-driving activity with an appropriate leeway. Therefore, driver monitoring technologies need to be deployed to fuse the data and information about the driving situation outside the vehicle with the driver's state inside the vehicle. Transitioning from level 3 back to level 2, so called, assisted driving, requires a new system component for managing the takeover. The component remains dormant in automated drive mode until a functional limit appears. Once a limit, such as an end of the highway travel, adverse weather conditions ahead, etc. is detected by the automated driving system, the takeover becomes planned by the management unit. The result of the planning needs to be updated with every new fused data sample that arrives at the management unit.

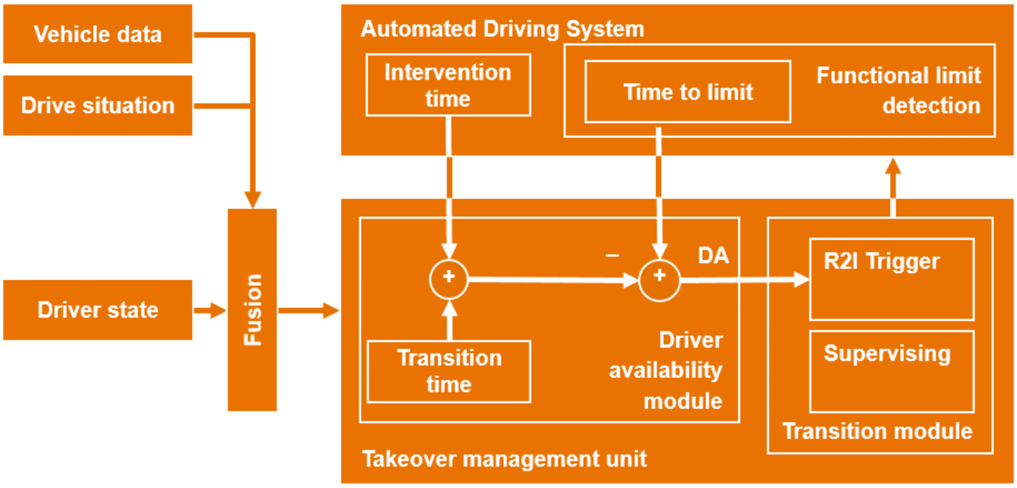

Figure 3 The takeover management resided next to the automated driving system and complements its functionalities to become a complete level 3 system. Here not only the driving situation needs to be assessed constantly but also the driver's status in order to provide appropriate leeway when it comes to a standard functional limit. The model of the takeover process needs to be updated constantly with the incoming data in order to manage the takeover safe and in an acceptable manner.

For example, the predicted time to the functional limit might change, the traffic situation could deteriorate and would require more transition time of the driver, etc. all these changes impact of the result of the takeover planning. In other words, the takeover management unit needs to render a dynamic model about the so called driver availability, the key factor in the takeover process. The main equation is:

$$DA = TTC - (Transition\ time\ + Intervention\ time)$$

Where TTC refers to the so call time-to-collision, the time to the functional limit and DA stands for Driver availably. The TTC and the intervention time gets estimated by the automated driving system, while the transition time becomes estimated based on the driver's state and driving situation. When DA is greater zero, it is anticipated that the driver could transition and intervene before the functional limit is reached. When the driver availability becomes negative the situation is beyond control and a minimal risk condition is reached. Either all level 2 assisted functions should hold or a fully automated minimal risk maneuver gets initiated. It is important to understand that the DA needs to be determined every time when one of the elements of the input changes to increase the quality of the prediction. The takeover management unit needs to become a part of the automated driving system at level 3 and higher and its position and safety standards need to be defined accordingly.

References

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