Situation Awareness Management for Driver Take Over from Level 4

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Abstract. The market launch of series-produced vehicles with the first functions of conditional automation according to SAE Level 3 by automobile manufacturers is imminent. For years, research has been conducted worldwide into the requirements placed on drivers when they are called upon by the vehicle to take over the driving task from the vehicle again (Take Over Request, TOR). In the next higher Level of automation, Level 4, the human driver will no longer be permanently required as a fallback Level, which represents a major step toward the fully autonomous mobility of the day after tomorrow. Accordingly, the vehicle's occupants will be able to devote themselves to other activities (non-driving-related activities, NDRA) during the automated journey, leaving the driver's seat unoccupied. Over a longer introductory phase, the use of Level 4 functions will remain restricted to routes of manageable complexity, i.e. highways and their feeder routes. If a TOR to Level 2 is made in Level 4, for example to be able to drive manually on a detour route beyond the freeway, a significantly more extensive transfer procedure will be required than in Level 3. At the end of a more elaborate take-over process, there is the question of the required situational awareness of the human driver. A novel software function to increase and verify this situation awareness is presented in this paper.

Keywords: Automated driving · Autonomous driving · Take over request · TOR · Non-driving-related activities · NDRA · Hand over – move over – take over, · HoMoTo · Situation awareness · SAM

1 Introduction

Developments in vehicle technology under the heading of "automated driving" are opening up many new opportunities for vehicle occupants to engage in non-driving-related activities (NDRA) in the vehicle interior. However, this also results in more complicated handover processes during the necessary change from passive autonomous driving to active person-controlled driving. Some systems designed by car manufacturers facilitate the handover process, but do not accompany the cognitive change between the passive passenger role and the active driver role. The complexity

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of the handover is partly due to the cognitive and emotional impact of the previous NDRA on the driver. In another part, the type and degree of the automation function play a major role.

2 Basics of automated driving

2.1 Level of automated driving

Autonomous driving is fundamentally defined by the independent execution of driving tasks by the vehicle [1]. According to SAE, the automation levels are divided into six levels in ascending order, from heteronomous (Level 0) to fully autonomous (Level 5) [2].

Level 1 and 2 functions represent driver assistance functions that must be constantly monitored despite their supportive function. The driver has full responsibility. In Level 3, vehicle control is autonomous after activation depending on the situation, for example in defined driving conditions such as slow-moving traffic. As a result, the driver must continue to at least monitor the vehicle control over significant sections of the journey and must otherwise expect the control to be taken over at any time. Likewise, non-driving activities are only possible to a limited extent during automated driving in Level 3. In Level 4, on the other hand, the driving task can be completely handed over to the vehicle under certain conditions and constraints. In suitable application cases, the destination can be reached completely independently by the vehicle without requiring intervention by the driver. If the vehicle's area of application can be completely covered by automated driving, the permanent installation of a steering wheel is not absolutely necessary. The type of activities permitted for the occupants is more varied in the area of Level 4 driving than in Level 3. Significantly more complex tasks can be performed while the system is driving. [2]

In Level 5, the vehicle is basically capable of reaching any destination autonomously and without driver intervention, regardless of boundary conditions. All vehicle occupants are now exclusively passengers in the vehicle. [2] It is possible that the achievement of automation Level 5 is pure utopia, since it does not seem possible to cover all the routes that exist today in a rule-compliant manner. Thus, the approved routes for automated driving will presumably be restricted by the vehicle manufacturer or operator and thus the driving function will not correspond to SAE Level 5.

2.2 Non-Driving-Related Activities

Especially in Level 4, Non-Driving-Related Activities (NDRA) offer a new and extended type of activities for all occupants while driving. For example, reading, sleeping, or working on a laptop are only a small excerpt of the possible NDRA. It should be noted that the NDRA depends on the user context and can therefore vary greatly, especially in Level 4. With increasing complexity of the NDRA, the immersion and therefore the mental distance from the driving task can vary considerably. [4]

2.3 Hand Over – Move Over – Take Over

During an NDRA, the inactive driver may be requested to take over the vehicle in order to manually drive the vehicle to SAE Level 2 or lower after the takeover. In Level 3, the handover of the driving task can be made by a Take Over Request (TOR) from the vehicle to the driver. The take over period is between 7 and 15 s from Level 3, according to the current state. [3, 9]

A take over request from Level 4 is currently barely discussed because it is not required by definition in Level 4. Nevertheless, it makes sense in certain circumstances, such as congestion avoidance on non-Level 4 routes. As described by Schäffer et.al., the TOR is followed first and foremost by actions of the occupant to return to the driver task. [9]

These actions can be subdivided into the following steps (see Fig. 1):

1. NDRA/highly automated driving
2. *Take Over Request*
3. Termination of the NDRA
4. Stowing and depositing objects
5. Taking and preparation of the driver's workplace
6. Recover situation awareness (SA)
7. *Take over the driving of the vehicle*
8. Manual driving activity in Level 2

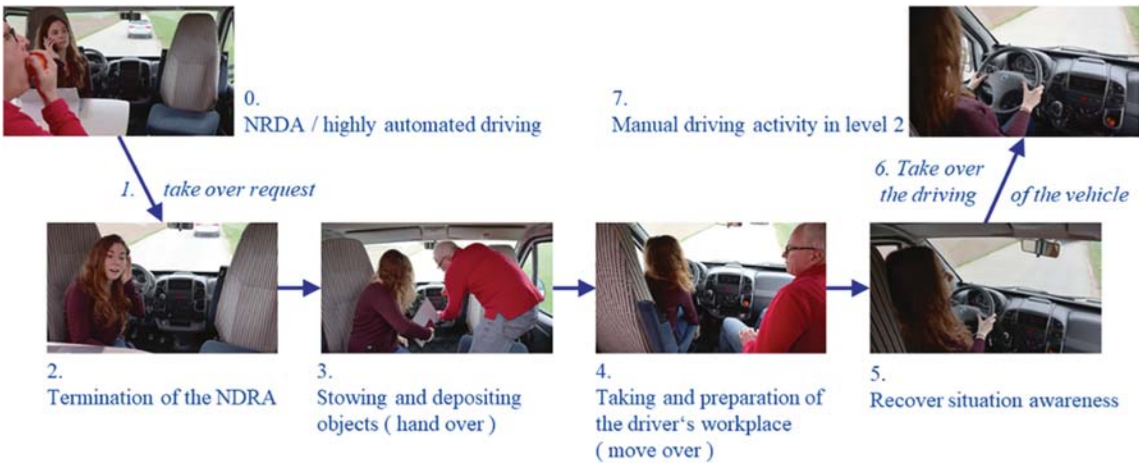

Fig. 1. Demonstration of the take over process from an NDRA in a passenger car

This process is subsumed by Schäffer et.al. under the term HoMoTo (Hand over – Move Over – Take over). The action steps will not be strictly sequential for a skilled driver, but will flow smoothly into each other. [9]

2.4 Legal Aspects of Switching the Responsible Vehicle Driver

The transition from hetoronomous to autonomous driving and back again to heteronomous driving results in a change of the responsible vehicle control. The question of liability for automated driving has not yet been clarified comprehensively and in detail, as this is a responsibility of the legal regulations of the individual states with regard to the approval of automated driving, which has only been carried out in isolated cases and in part and will still take several years. Nevertheless, it can already be seen today that in the phases of automated driving, responsibility and thus liability in the event of accidents will shift away from the driver and onto the automobile manufacturer or operator, depending on who is responsible for the respective officially approved software-based driving function. In situations where the human takes the lead to control the vehicle primarily manually, there would again be a shift in liability back to the driver. However, the handover/takeover phases represent a gray area in the transfer of liability, because it is currently not clear whether the responsibility for possible accident consequences between manual and automated vehicle control can even be initially clearly and sharply delineated. The degree to which the driver is willing to take over the vehicle is also an important issue. [6]

During automated driving, the driver may be disengaged (physically and mentally) from the current driving situation, the current traffic situation, and the perception of the environment due to NDRA. Thus, an issue regarding situation awareness may arise during driver takeover to Level 2. [7]

2.5 Recovery of Situation Awareness

A crucial step of HoMoTo is the restoration of Situation Awareness. The term situation awareness describes a person's awareness of his or her actual environmental conditions. It is well known that a longer lasting interruption of the environmental awareness can lead to an increasing deviation of the Situation Awareness from reality when the environmental conditions change. This can make spontaneous appropriate response to the environment very difficult. Analyses of various aviation and maritime accidents following malfunctions of autopilot systems illustrate that taking control after prolonged passivity of pilots or shipmasters can lead to spontaneous overload due to a lack of situation awareness. [12]

Situation Awareness Recovery (Step 5 in the HoMoTo process) is not a singular step. Instead, the restoration of SA begins as early as the TOR and the termination of the NDRA and continues into the actual manual driving activity in Level 2. Within this continuous stepping of SA, the largest increase in SA occurs in Step 5.

Depending on the complexity and intensity of the NDRA as well as the subsequent driving task, the potential danger of a driving error due to information deficits can thus be greatly increased for some time after the takeover. Even a few minutes after the takeover, a misbehavior on the road can still be measured [7]. Reduced situation awareness can be triggered on the one hand by the complexities. The complexity level of the activity can be measured at different levels. Thus, it can be assumed that an attitude that deviates from the driver's position, leads to a stronger situational distancing. This is due, on the one hand, to the additional task of resuming the driver's position and, on the other hand, to the mentally stronger distancing due to the deviating posture. Another physical influence is the degree of physical relaxation from which the driver is called. Thus, regaining physical and mental activation after sleeping is more difficult than after a short look out of the window. [13]

The psychological readiness to control driving is divided into two levels, emotional and cognitive (see Fig. 2). The emotional level does not directly affect driving ability in the form of poor perception, but plays out on a meta level that can lead the driver to an emotionally exuberant driving style due to watching an action movie beforehand, for example. The cognitive level, on the other hand, determines the conscious perception of the situation. This is indispensable for a clear spatial and temporal assessment and evaluation of a traffic situation.

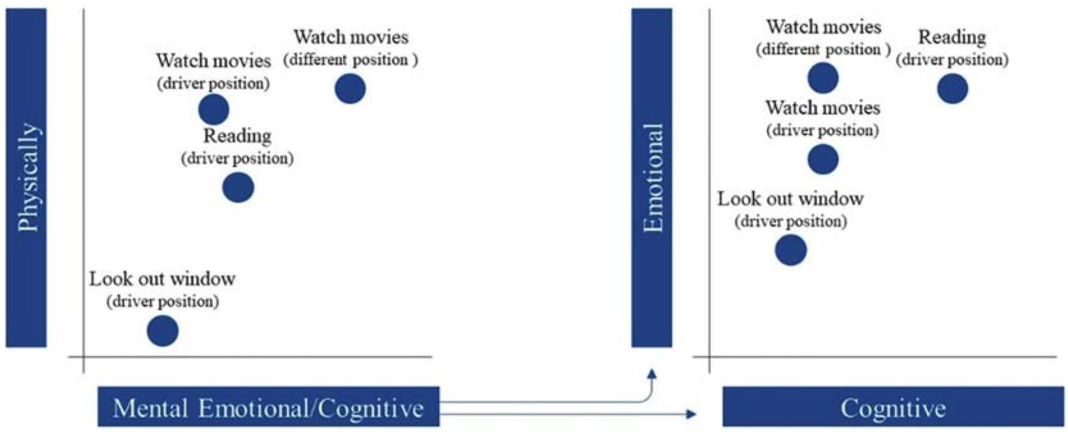

Fig. 2. Hypothetical classification of NDRA activities

The respective SAE Level of the automated journey also implies significant differences in the sequence of the driver handover and the subsequent driving process. If it is a Level 3 ride, the driver is forced to take over the driving task or else risk an emergency stop on the shoulder of the roadway. Although the scope and extent of NDRA activities in Level 3 will be less than in Level 4, a possible strong situational distancing is still to be expected. There is also a great deal of mental pressure on the driver, as the driving task shouldn't be declined in order to avoid stopping and possibly obstructing following traffic.

In Level 4, similar situations could appear under unfavorable circumstances, which additionally show a higher complexity of the NDRA. However, in Level 4 it can be assumed that the vehicle will spontaneously request takeovers only to enable serious changes in the course of the trip. This could be, for example, the time-saving bypassing of a traffic jam via a non-automated alternative route (see Fig. 3). In such a scenario, the driver has the option of taking over manual control, since refusing the driving task would result in longer driving time in the traffic jam.

This example shows that sensible and partly spontaneous driver takeover requests will also occur in Level 4. In such a situation, similar to Level 3, an expectation is placed on the driver that the control should be taken over.

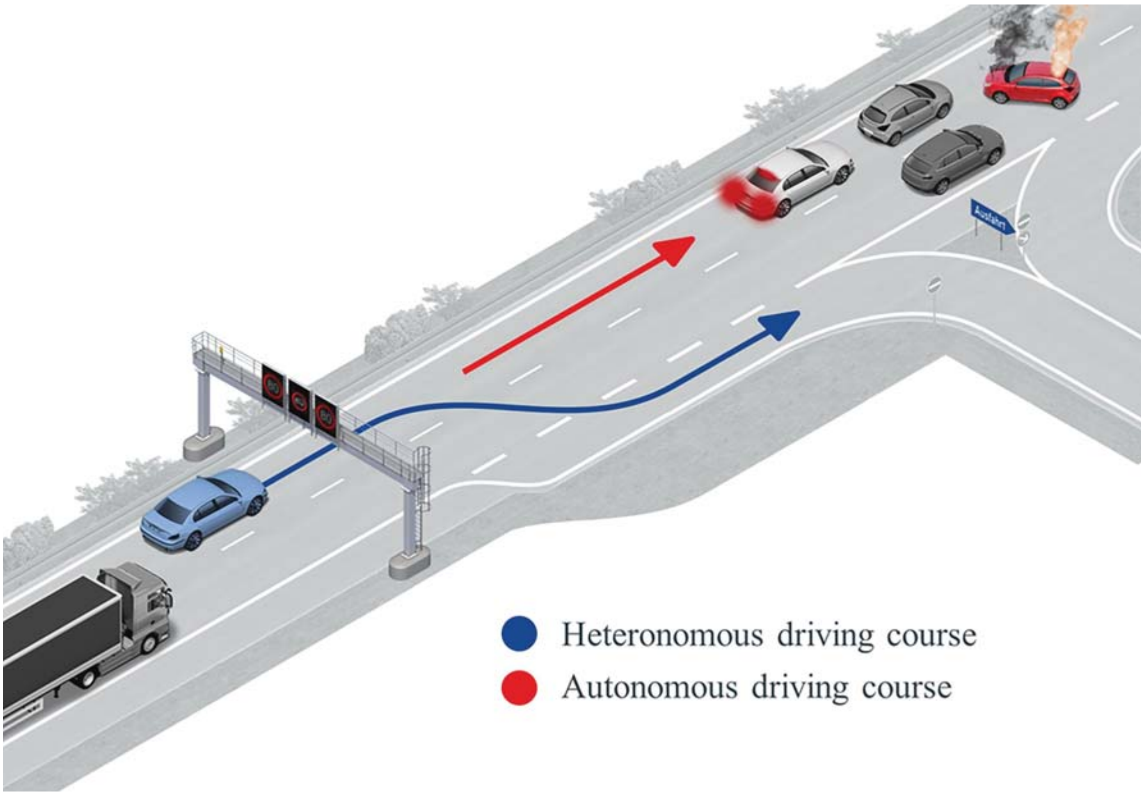

Fig. 3. Illustration of an example driver handover situation from L4 to L2. The blue arrow shows an alternative, non-automated route that promises a faster arrival time

The difference to Level 3 is the necessity of a much earlier recognition and request of the driver takeover. This is because a driver takeover from Level 4 will be much more time-consuming.

3 Existing Systems in the Context of the Handover of the Driving Task

A literature and patent search has already identified several technical solutions for supporting the driver takeover process. The various support approaches address different phases of the transfer process.

The composition begins with a system that tests the driver's readiness to take over after Level 2. In Emery Charles Gulash's patent specification, acoustic patterns collected from the driver determine whether or not the driver is ready to take over. [8]

Other systems that monitor and check the driver and his or her suitability to drive, such as Brian Mark Fields' paternalistic system, are triggered by, for example, heart rate, skin conductivity or voice modulation, and can assign or deny the driver a fitness to drive. To this end, these systems sometimes include various HMI elements that can alert the driver to possible inattention. [8, 14]

Although some of the driving skills to be recovered are checked and active warnings are issued in the event of inattention, the systems do not include the cognitive recovery of driving skills by pointing out road characteristics relevant to driving, for example.

The system of Kaustubh already tries to meet this problem. It aims at not directly switching off the automation systems in order not to hand over the complete responsibility directly to the driver. A gradual handover should support the state into manual driving. [10]

According to their descriptions, various systems that ease the handover process do not refer to situational feedback before the actual driving task, but merely provide a supporting effect during the driving activity that has already been taken over. For example, Abbink and Mulder show a split steering system in which the vehicle can guide the driver by slightly oversteering without completely handing over the driving task. [11]

Another system by Brian Mark Fields is designed to monitor the driver and detect whether distraction is present during driving. The detection can be done using different physiological parameters as indicators. If a distraction is present, the vehicle can initiate relief actions or a warning to avoid distracting the driver. [14]

The systems described are mainly dealing with the handover itself, but not with the recovery of the driver's situation awareness. The patent by Fields explicitly discusses driver monitoring and readiness. However, when driver readiness is not present but a handover becomes necessary, only warning signals are provided, but no environmental information for the driver. Similar approaches are shown in the other systems.

However, due to the situational distancing of the driver by NDRA in Level 3 and 4 explained above, an abrupt return of the driver to the current driving and traffic situation of the passenger car is inevitable. Driving-relevant information such as current location, road type, traffic volume, weather […] must be transmitted to the driver before the driving task is handed over. The process previously described in the "HoMoTo process" shows a sub-process in point "5. Recover situation awareness (SA)", which is to establish the situational awareness of the driver before the existing systems. The process of situation awareness is an indispensable requirement for the safe transfer to Level 2. Thus, a kind of system alignment between the information perceived by the driver and clouded by NDRA and the cognitive state of the vehicle should take place. In the interaction between vehicle and driver, it should also be checked whether the driver has received the transmitted cognitive state without any gaps. This state could be recorded and evaluated through a check by the vehicle. In addition to regaining situation awareness and thus increasing safety for the occupants, this process can also fulfill a decisive function in the transition of responsibility for vehicle manufacturers and drivers.

4 Situational Awareness Management – Approach to Optimized Driver Handover

To minimize the driver handover risks described above, a new Situation Awareness Management (SAM) system is designed by Remlinger and Pomiersky to assist the driver in regaining the situation awareness required for the driving task. The SAM system represents a new software function in the vehicle that serves to provide the information required by the driver about the vehicle and the surrounding situation and to communicate this information to him in a way that is easy to understand. The driver, who has become a passenger of the vehicle during the automated journey, is to be guided quickly and mentally into the context of the driving task with the help of the SAM after the takeover request. Thus, the driver is mentally prepared for the Level 2 drive.

We must be aware that the driving situation from which the vehicle hands over responsibility to the driver from Level 4 has a completely different quality than in the case of a takeover from Level 3. While in the case of TOR in Level 3 the vehicle is close to the end of its operational capabilities and therefore has to call the driver for help. In Level 4 it currently has everything under control and only hands over to the driver due to a strategic decision change. Thus, it knows all the necessary information that is relevant for a calm and controlled transfer of responsibility of the control. The information to be transferred to the driver corresponds to a scheme that is comparable to the transfer of information from one employee to another during a shift change in responsible activities.

Thus, the vehicle informs the driver about the current location (start-finish, route, direction of travel, locality, lane), also about the current speed, traffic density, time of day and weather and the road condition. Then the driver is informed about the acute conditions around his vehicle, i.e. type of other vehicles and their distance, relative speed and, if applicable, intention in front, behind and beside his own vehicle. It is crucial that the transmission of this information is well understood and is as fully grasped and internalized by the driver as possible in order to truly achieve situational awareness with high immersion. [5]

This situational retrieval of environmental perception can take place with the aid of various HMI elements in the vehicle. For example, visual, auditory or haptic signals, or a combination of these, can be used to transmit information about the surrounding situation. It should not be forgotten that this information transfer takes place before the actual takeover, but relatively complex physical preparations must also be made beforehand. After the NDRA has been terminated, objects may have to be stowed and the driver’s position assumed in accordance with the HoMoTo process (see Fig. 1).

The driver's perception can also be specifically directed to upcoming obstacles and special risks. This can be, for example, a car that is in the blind spot or a sharp curve that is only imminent after the handover (see Fig. 4). On the basis of the vehicle's information networking, the transmission of information to the driver can also include information looking ahead into the future.

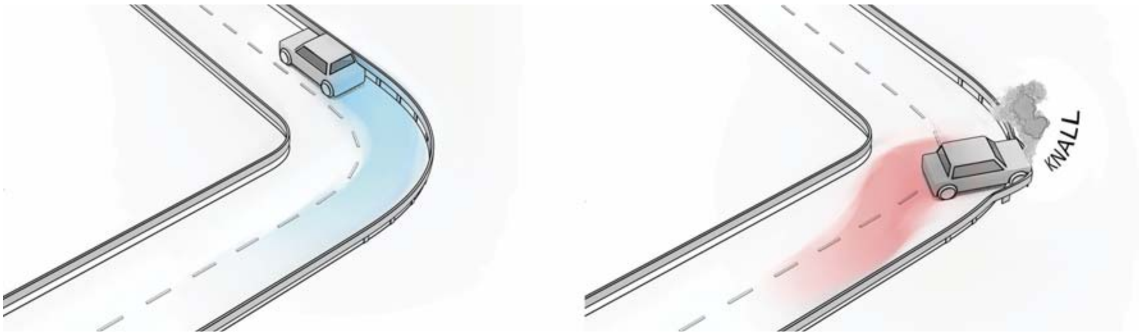

Fig. 4. Presentation of the unexpected course of the road, in connection with the lack of situational awareness of the driver on the right side

In order to use this information transfer effectively in terms of driving safety, the vehicle can now perform a kind of reality check before handing over the driving task to the driver in order to check his or her acquired situational awareness.

The vehicle can observe the driver's behavior during the transmission of information and use his behavior and reactions to conclude whether the transmitted information is being absorbed. Similar to how a human in conversation detects whether the person across from them is listening and following instructions, the vehicle’s HMI would do the same with the driver. Just knowing that listening and understanding is being controlled will lead to higher attention. This should result in the driver absorbing the traffic-relevant information and consciously dealing with it. When conveying information, particular care should be taken to ensure that the content is not unnecessarily detailed and that the sequence does not follow an expected pattern, so as not to provoke a superficial standard reaction from the driver. The sequence should help the driver to focus more on the driving event and the associated risks.

The communication and interaction can be placed on all HMI modalities and thus be registered across different medialities. If the driver's state is not clearly ascertainable, certain information can also be retransmitted if the handover time permits, in order to reactivate the driver. In the case of a final determination of a lack of situation awareness, the driver can be advised not to take over the vehicle or, if necessary, the vehicle can even be rejected. In Level 4, the vehicle would be able to continue its journey independently at this point. From a Level 3 drive, it would be brought to a stop in a safe position accordingly.

In this way, a vehicle manufacturer introduces an additional safety function into the vehicle. However, due to the legally required override capability by the driver according to the modified Vienna Convention, the driver can finally insist on a take-over. In this way, however, the car manufacturer can document an increased duty of care and counter possible product liability claims in a documented manner, since the driver’s lack of fitness has been recognized and reported back to him. The detailed concept with several solution approaches for such a Situation Awareness Management System is documented in detail in a patent application. [8]

Such system can be combined in the vehicle with other known functions in which the driver is checked by various sensors for his physical readiness or fitness, such as increased fatigue or an unfit driving position.

The benefits of cognitive recovery of situation awareness are evident on several levels.

In terms of safety, improved and more complete situation awareness recovery is expected to result in fewer errors in vehicle control after the handover. In addition to increased self protection, there is also added protection for other road users. Furthermore, it is expected that a feeling of safety and support is additionally conveyed to the vehicle driver, giving him or her increased self-confidence and satisfaction in terms of driving comfort. At the same time, an appropriate sense of responsibility is also demanded of the driver. Overall, a high-quality implementation of such system in the vehicle can create mutual trust between the automobile manufacturer, user and traffic authority for the challenging handover-takeover situation in automated driving.

5 Outlook

NDRA-dependent cognition states are to be recorded more precisely. From this, information about the NDRA-dependent return phase in the traffic situation can be derived and corresponding handover times can be recommended.

Likewise, it has to be examined in more detail which spatial and perceptual bias in the driver is caused by NDRA. Which driving-relevant data are overshadowed by preceding actions for a longer period of time and therefore have to be brought closer to the driver. Furthermore, it has to be investigated which mechanisms and systems for situation awareness can be used to generate a fast and accurate perception in the driver. The interaction between driver and vehicle is significantly driven by the development of suitable HMI. Like the HMI, the transmission of information must be developed and resulting comprehension and driver's reaction have to be experimentally tested and analysed.

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