TECHNICAL REPORT

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# Road vehicles — Human performance and state in the context of automated driving —

## Part 1: Common underlying concepts

*Véhicules routiers — État et performance humaine dans le contexte de la conduite automatisée —*

*Partie 1: Concepts fondamentaux*



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# Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 39, *Ergonomics*.

This second edition cancels and replaces the first edition (ISO/TR 21959-1:2018), which has been technically revised. The main changes compared to the previous edition are as follows:

— editorial modifications to the format of the figures;

— corrections of the references to clause numbers (Clause 7 is now Clause 8);

— corrections to redundant descriptions.

A list of all parts in the ISO 21959 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.



 

# Introduction

Although automation technology is advancing at a very fast pace, the majority of automated driving levels (as defined by SAE) still require a human to fulfil specific remaining (driving related) tasks while being in automated driving mode. The basic requirements with respect to the driver strongly depend on the level of automation and are subject to human factors research all over the world. The SAE standards SAE J3016[70] [71] and SAE J3114[72] have already introduced working definitions of key concepts in this field. This document puts an emphasis on common underlying concepts of driver performance and state in the context of automated driving.

Driver performance includes driver's activities in transitions both from manual driving to automated driving and from automated to manual driving, as well as interaction behaviour while using the system. Driver state here means driver's internal conditions that may affect performance including knowledge of and attitudes toward driving automation systems.

Concepts on driver performances in transition from manual to automated driving and from automated to manual driving are described in Clause 5. Concepts on driver state related to the transition are described in Clause 6 and a specific concept "readiness/availability" that refers to driver state that predicts the intervention performance is described in Clause 7. Concepts for driver's experiences and attitudes that may affect driver performance and state in the context of automated driving are described in Clause 8.

# Road vehicles — Human performance and state in the context of automated driving —

## Part 1: Common underlying concepts



## 1 Scope

This document introduces basic common underlying concepts related to driver performance and state in the context of automated driving. The concepts in this document are applicable to all levels of automated driving functions that require a human/driver to be engaged or fallback-ready (SAE level 1, 2 and 3). It can also be used with levels that enable a driver to resume manual control of the vehicle (a compatible feature for SAE levels 1 to 5).

Common underlying concepts can be applicable for human factors assessment/evaluations using driving simulators, tests on restricted roadways (e.g. test tracks) or tests on public roads. The information applies to all vehicle categories.

This document contains a mixture of information where technical consensus supports such guidance, as well as discussion of those areas where further research is required to support technical consensus. These common underlying concepts can be also useful for product descriptions and owner manuals. The contents in this document are informative, rather than normative, in nature.

## 2 Normative references

There are no normative references in this document.

## 3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

## 4 Purpose

The purpose of this document is to provide common underlying concepts for human performance and state for the researchers and developers of driving automation systems (more specifically SAE levels 1–5) in order to facilitate the sharing of information and knowledge as these systems are developed and deployed.

This document does not provide design principles on how a human-machine interface (HMI) for automated driving should be designed or developed. However, common concepts and measures could be used during the development phase when different HMI designs are evaluated in terms of usability, user experience and safety.

It is not intended that anything in this document restricts or provides direction regarding the technology used to create these systems, or the underlying design of these system.

 

# 5 Human performance in the context of automated driving

## 5.1 General

Human performance has two aspects—behaviour being the means and its consequence being the end[16]. The focus on consequences, and hence on performance, is especially relevant for situations such as the transition processes from automated to manual control (level 0) and vice versa (see Figures 1 to 4). The following subclauses give an overview of possible measures for driver- and system-initiated transitions. For transitions between different automation levels (e.g. 4→2 or 3→1) within one vehicle appropriate measures can be selected or adapted according to the specific circumstances.

## 5.2 Transition from manual to automated driving

### 5.2.1 Transition process model

Figure 1 shows a process model for a prototypical transition from manual to automated control, either initiated by the driver or by the system.

EXAMPLE After entering the highway the driver is informed about the availability of a "highway pilot function"1). He/she decides to activate automation by a dedicated steering wheel button.



1) See: https://www.daimler.com/innovation/case/autonomous/highway-pilot-2.html, Hunger 2017. Highway pilot system is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

 

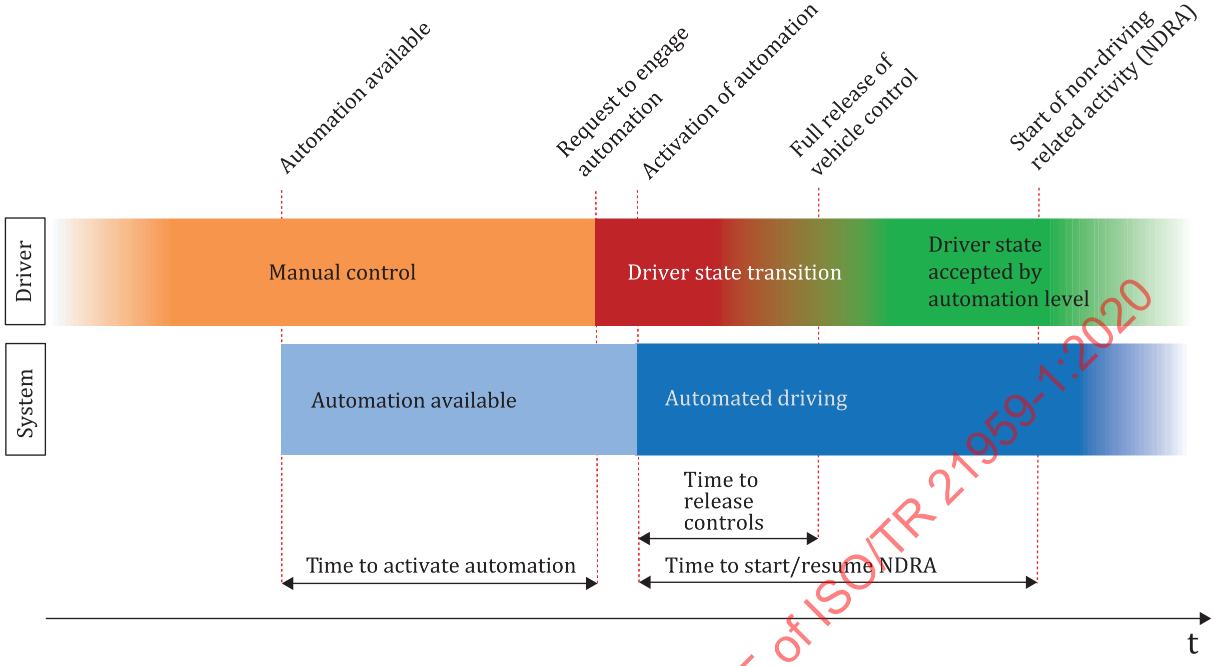


**Figure 1 — Driver/system-initiated transition from manual to automated driving (concepts are further specified in 5.2.2 and 5.2.3)**

### 5.2.2 Definition of related concepts

a) **Manual control**: Driving phase where a human driver is performing the dynamic driving task (DDT)—all of the real-time operational and tactical functions required to operate a vehicle in on-road traffic (see Reference [70] for the definition of level 0 automation). In cases where lower level automation features are already active, this phase can be regarded as including the remaining (manual) elements of the DDT required by the driving automation system. For example, driving with adaptive cruise control requires the driver to perform the lateral control (sub) task as well as the object and event detection and response (OEDR) subtask.

b) **Automation available**: If all operational conditions for a driving automation system are fulfilled the system is ready to be activated by either the user or the system. This system availability may be signalled to the user via the driver vehicle interface (e.g. screen, tones). However, even if an automation feature is available, the driver may have to judge whether activation is appropriate [taking into account the mechanical condition of the vehicle (not detected by the vehicle, e.g. broken suspension component)] This will be covered in a future planned document (ISO/SAE 22736).

c) **Request to engage automation**: Event usually initiated by the user through the driver-vehicle interface of the vehicle to activate the driving automation system. Apart from user-initiated transitions, system-initiated transitions from manual to automated control may also be possible, especially after the driver has temporarily overridden the automated mode by manual intervention. At the end of driver intervention, the system may automatically activate/resume from suspended to active mode. For example, in some automated steering control systems, after the driver has transitioned from automated to manual control by manual use of the steering wheel, when the driver is no longer moving the steering wheel, the system may automatically activate/resume from manual to automated steering control.

d) **Activation of automation**: Onset of the driving automation system activation. There may be a delay between requesting the activation and the activation itself either due to technical reasons or by intentionally introducing an activation process as an HMI design feature.



 

e) **Driver state transition** (manual to automated): Process where the driver is releasing control to the driving automation system. The transition includes physical aspects (releasing hands and feet from primary vehicle controls) as well as cognitive aspects (ensuring that automation has taken over successfully). The physical transition phase ends when the driver fully releases manual vehicle control (hands and feet do not have any action on longitudinal or lateral vehicle control). Behavioural markers for the end of the cognitive transition are less obvious.

f) **Automated driving**: Driving phase where a level 1 – level 5 (L1 – L5) system is performing specific aspects of the DDT.

g) **Acceptable driver state by automation level**: Driver state that is required or activity that is allowed by the driving automation system. The driver state may or may not be monitored by the driving automation system. Requirements on acceptable driver states are strongly dependent on the automation level. Sleep is commonly seen as not acceptable by L2/L3 features or physically leaving the driver's seat is not acceptable for L2/L3 features.

h) **Non-Driving Related Activity (NDRA)**: Any activity not related to the monitoring of the driving automation system and/or the current driving situation is called non-driving related activity. This can include activities that take up any of visual, auditory, visual-manual, auditory-manual, manual, or cognitive capabilities.

i) **Non-Driving Related Task (NDRT)**: Any activity related to a dedicated task that is different from the monitoring of the driving automation system and/or the current driving situation is called non-driving related task. An activity becomes a task when it has a specific goal, and the task can be made up of a series of activities leading up to this goal. A NDRT can also be called secondary task, but only as long as there is a primary task, in this case operating the vehicle. When driving is no longer the driver's primary task—such as during automated driving at SAE levels 3 and higher—the NDRT stops being a secondary task. Under such circumstances the NDRT itself can be regarded as the primary task.

#### 5.2.3 Measures for human performance in releasing control to automation

a) **Time to activate system**: It is the time interval between events "automation available" and "request to engage automation".

b) **Time to release controls**: It is the time interval between events "activation of automation" and "full release of vehicle control".

c) **Time to start/resume NDRA**: It is the time interval between events "activation of automation" and "start of NDRA".

d) **Method used to engage driving automation system**: It is the specification of required driver action to fully release control to driving automation system (e.g. double-pull of stalk at steering column or simultaneous activation of dedicated steering wheel controls).

### 5.3 Transition from automated to manual driving

Transitions from automated to manual driving, may have two different "sources". They may be system initiated or they may be driver initiated as is presented in the subclauses below.



 

### 5.3.1 Transition process models

Figure 2 shows the process model for a system-initiated transition from automated to manual vehicle control with definitions of relevant time periods. This transition model assumes the result of a fully stabilised vehicle.

EXAMPLE 1 While using a highway pilot system[2)] the function issues a request to intervene (RtI) due to an internal system error. After preparing for taking over manual vehicle control the driver deactivates the highway pilot function and switches to manual driving mode.

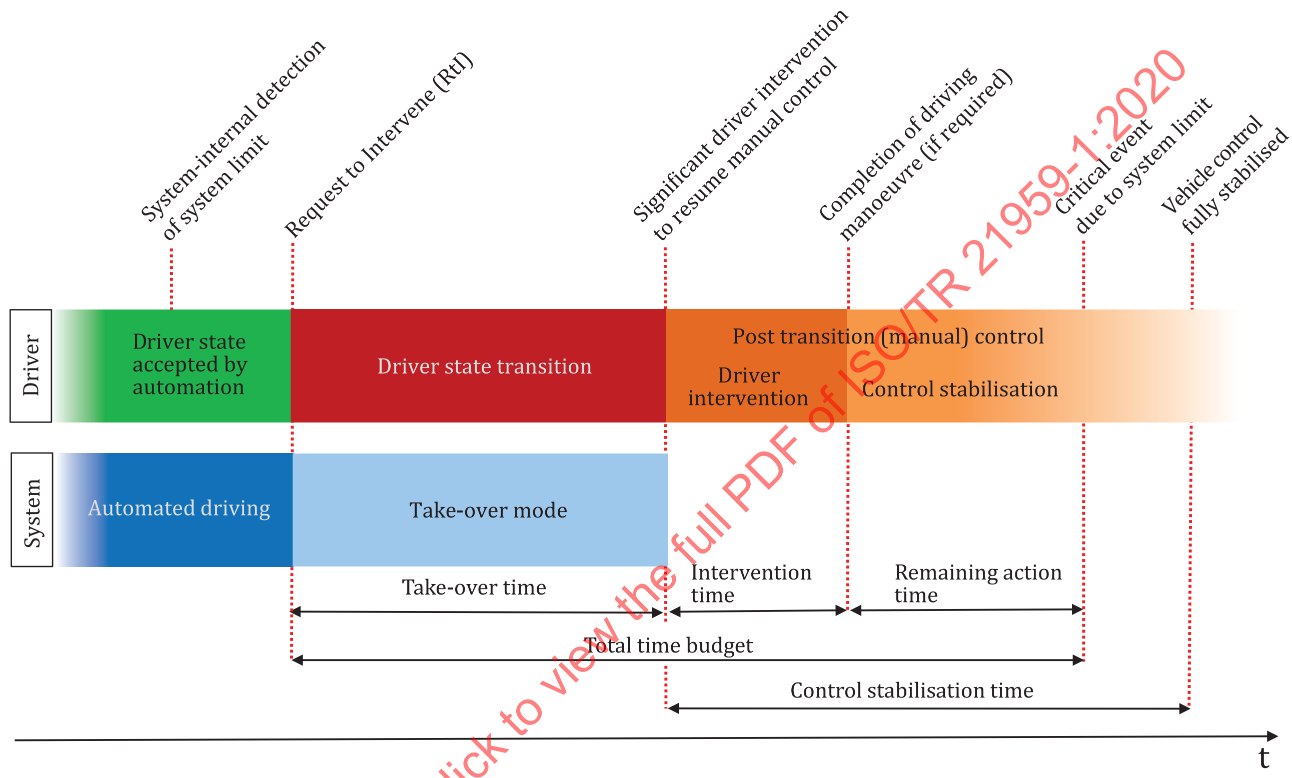


**Figure 2 — System-initiated transition from automated to manual driving (concepts are further specified in 5.3.2 and 5.3.3)**

In addition to system-initiated transitions, user-initiated transitions without a RtI are covered, as level 1 to level 3, and some level 4 or level 5 systems may be designed to be deactivated by the user at any point in time during full operation. There are two types of reasons for a user to deactivate the automation feature which are described below.

Figure 3 describes the process of regaining manual vehicle control due to the detection of system performance limitations (mandatory transition). In this case the L1/L2 driving automation system does not issue a RtI to the driver.

EXAMPLE 2 While using a L2 automation system in a construction zone the driver observes that the system is following invalid lane markings. He/she decides to immediately take-over control by manually overriding the lateral steering control (leading to manual driving mode).

2) See: https://www.daimler.com/innovation/case/autonomous/highway-pilot-2.html, Hunger 2017. Highway pilot system is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.



 

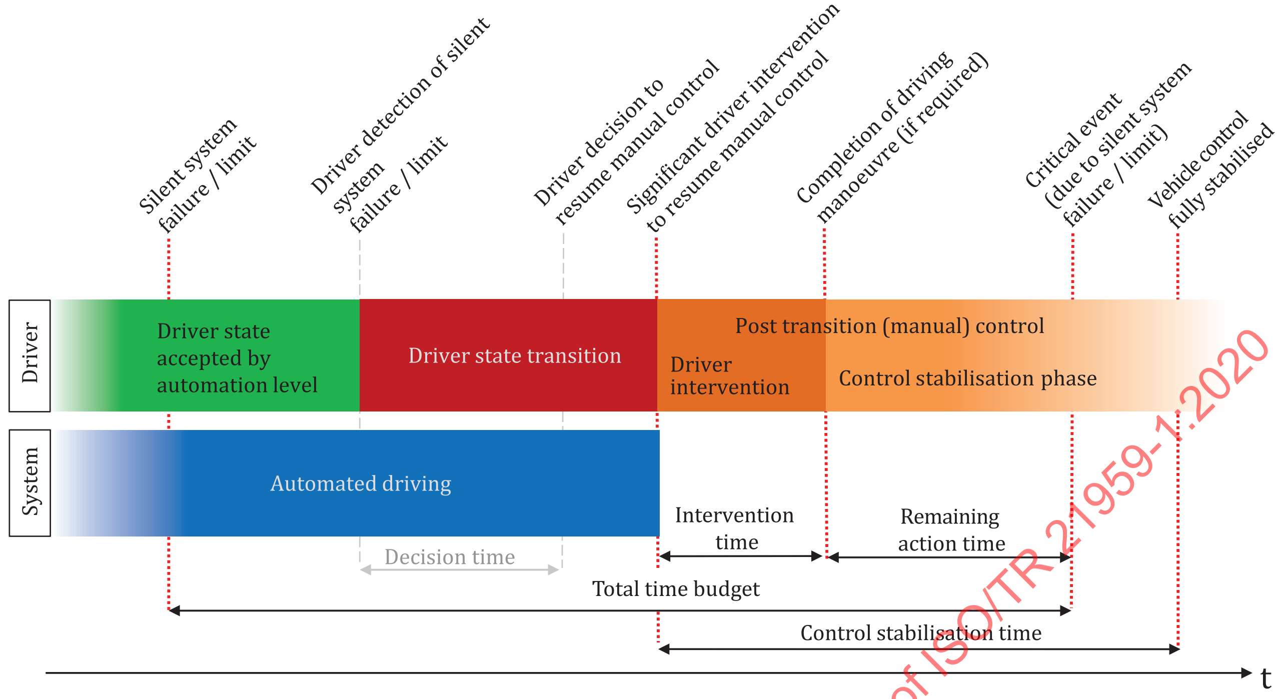


**Figure 3 — Mandatory human-initiated transition of automated to manual driving due to detection of system performance limits (concepts are further specified in 5.3.2 and 5.3.3)**

On the other hand, the driver may want to deactivate the driving automation system without detecting system performance limitations (optional limitations). For this case the transition process described above can be slightly adapted (see Figure 4).

EXAMPLE 3 While using a traffic jam pilot feature in heavy traffic on a city freeway, the driver deactivates all driving automation features using a designated control for that purpose and switches to manual driving in order to exit the freeway and find a faster route.

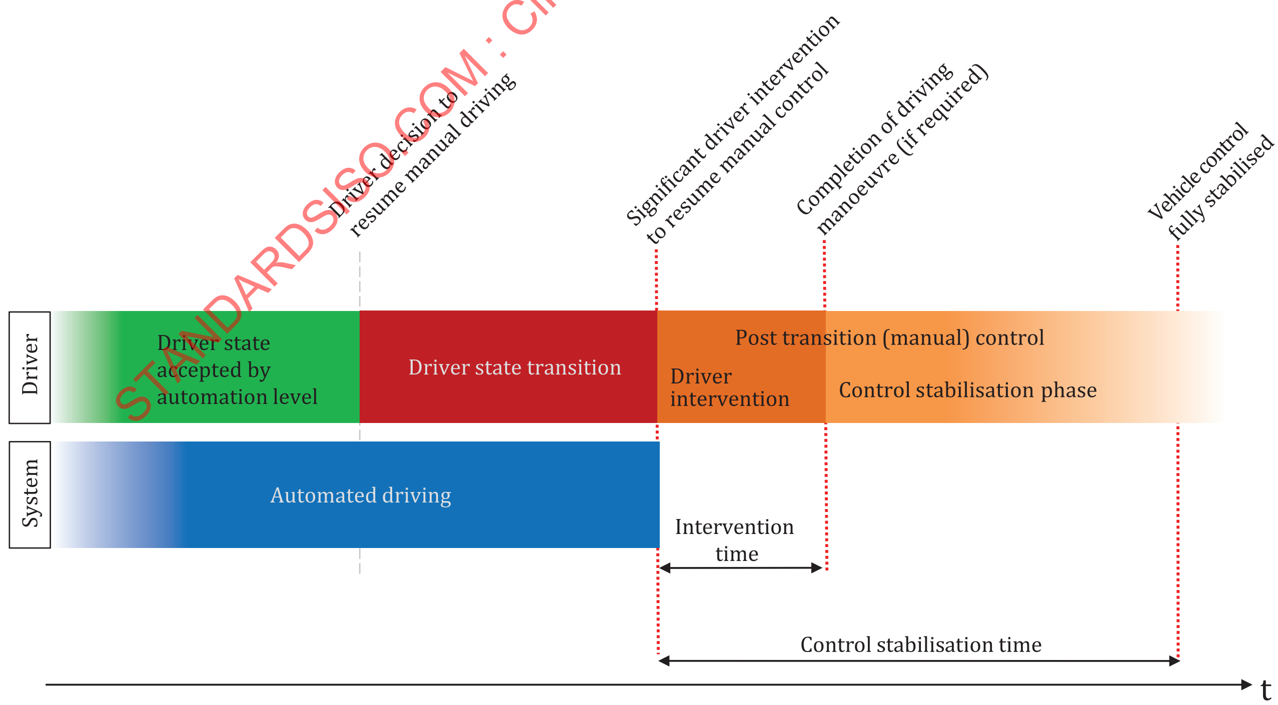


**Figure 4 — Optional human-initiated transition of automated to manual driving (without system performance limit; concepts are further specified in 5.3.2 and 5.3.3)**



 

### 5.3.2 Definition of related concepts

a) **Request to intervene** (RtI): Notification by a driving automation system to a driver/fallback-ready user indicating that he/she should take over vehicle control (perform all or parts of the DDT). According to the requirements of SAE level 3+ systems, all system related limits are recognized and appropriate driver requests to take-over control are triggered. The RtI time stamp is essential to analyse the subsequent transition process as it is regarded as the beginning of the driver state transition process. If a request to intervene is not issued by the driving automation system because of an automation-external vehicle failure (for example, flat tyre, broken steering system and so on), the (perceivable) failure signal can alternatively be used as a corresponding event. Drivers of level 2 automation may encounter (silent) system failures or performance limits which are not recognized and communicated by the driving automation system. In this case the driver may notice suspicious vehicle control due to a potential system limit which triggers the decision to regain manual control.

b) **Silent system failure and/or silent system limit**: System performance limitation of a driving automation system that is not recognized and communicated to the user. The performance limitation may be due to internal failure states or incorrect interpretation of the driving environment.

c) **Critical event due to system limit**: Situation that can be specified in time and space that the driving automation system cannot handle safely and that will occur in case the driver does not intervene. System limits are associated with different time budgets:

   — Long-term system limits (e.g. the planned transition of a highway pilot when reaching the exit) can be communicated well in advance to allow for a sufficient preparation. Driver performances with respect to early communication of long-term system limits are not within primary interest of this document.

   — Mid-term system limits (e.g. approaching a construction site that cannot be handled by the system) require the driver/fallback-ready user to take-over within a certain time budget. This type of system limit is central to the definition of SAE level 3 systems.

   — Short-term limits (e.g. due to sensor range) ask the driver for immediate take-over of the DDT. This type of system limit is central to the definition of SAE level 2 systems.

Although the majority of system limits will be detected and communicated via a RtI for higher automation levels, there may be system limits for level 2 systems without a RtI (see Figure 4).

d) **Take-over mode**: The concept refers to the system behaviour after a RtI has been issued. The remaining performance depends on the automation level and on the design of a particular system. Level 3-5 systems can be able to continue operation after issuing a RtI for a specified period of time. Depending on the type of system limit, system operation might be of degraded nature. Level 2 systems may be deactivated immediately after a RtI has been issued. The take-over mode may already contain measures to reach a minimal risk condition (such as a stopping manoeuvre). However, details on human performance aspects with respect to a minimal risk manoeuvre will be covered in a future, planned document (ISO/TR 21959-2[51]).

e) **Driver state transition** (automated to manual): Process of transforming the actual driver state (possibly determined by NDRA) to a target driver state suitable to effectively take-over manual control. This process can be analysed on a sensory, motoric and cognitive level. Relevant time markers within this phase are: interrupting/finishing a non-driving related task, start of visual reorientation, gaze on road centre, hands on wheel/feet on pedals, etc.

f) **Significant driver intervention:** Action initiated by the user of a driving automation system to request manual control over all or some parts of the DDT. The way manual control can be resumed by the user depends on the driving automation system design, but usually comprises significant driver intervention on primary vehicle controls and regular deactivation mechanisms (e.g. based on buttons or switches). The system reaction towards the driver intervention also depends on the particular design of the automation function. For higher-level automated driving systems (ADS) which remain active after a RtI, “significant driver intervention” corresponds to requesting system deactivation. The subsequent change of the system status may be immediate or delayed (e.g. in order to establish safe conditions for manual driving). SAE level 2 functions may deactivate vehicle control of some or all aspects of the DDT at the time of issuing the RtI. In this case driver intervention takes place in manual mode and typically corresponds to significant and relevant actions on primary vehicle controls.

g) **Post transition (manual) control:** A defined, extended time window to analyse the quality of manual control driving after a RtI has been issued. The post transition driving phase can be decomposed in the driver intervention itself and a control stabilisation phase.

h) **Completion of driving manoeuvre**: The kind of take-over action that is expected by the driver to successfully handle the system limit. The intervention depends on the demands of the take-over situation. Examples range from easy tasks such as bringing hands back on the steering wheel to follow the lane to more complex manoeuvres such as manual lane changes or brake manoeuvres, etc. Depending on the take-over situation it can be difficult to determine the exact end of the driver intervention as there is a gradual transition to the control stabilisation phase.

i) **Vehicle control fully stabilised**: After the immediate driver intervention phase, manual vehicle control performance can be below the average performance of an individual driver. The time period until vehicle control performance is fully re-established is referred to as “control stabilisation phase”.

### 5.3.3 Measures for human performance in regaining control from automation

#### 5.3.3.1 Type of driver intervention

The method for how a particular driving automation system can be overridden or deactivated can be fully specified. This includes describing thresholds for significant driver intervention on primary vehicle controls and/or how the system can be deactivated by dedicated controls.

Following is an overview of methods used to resume manual vehicle control (perform part or all of the DDT). Typical categories are:

— automation feature override or deactivation by brake intervention;

— automation feature override or deactivation by accelerating;

— automation feature override or deactivation by steering intervention;

— automation feature override or deactivation by dedicated controls (e.g. on/off switch); and

— other automation feature override or deactivation.

Overview of different sequences of driver intervention, for example 1st action (leading to manual mode), 2nd action, 3rd action (focus on start of action since actions may also be performed in parallel).

#### 5.3.3.2 Time-related performance measures

The time-based performance measures apply to the transition process depicted in Figures 2, 3 and 4. The described time periods can be further split up into sub-processes (similarly as is shown for driver take-over time) but also combined to define new time periods (e.g. driver take-over time + driver intervention time). For the sake of simplicity, no dedicated concepts are introduced for these derived measures. Intervention time combined with the previously mentioned term take-over time is also a relevant time-based metric.

a) **Take-over time**: Time interval between onset of RtI and user-initiated intervention or deactivation of an engaged automation function. This measure is central to human factors research on automated driving and has been used by many authors (e.g. References [17]; [6]; [66]). The transition process can be decomposed into further sub-processes (all starting with the RtI):

  — time to first driver reaction (e.g. interruption of non-driving related task);

  — time to start of visual re-orientation;



 

— time to visually fixate RtI message (if visual HMI is involved);

— time to visually fixate road centre (or other relevant aspects of the scenery);

— time to start to move (at least one) hand to wheel/feet to pedals;

— time to grasp wheel/touch pedals;

— time to start to operate relevant vehicle controls (e.g. blinker) or steering/pedal operation; and

— time to onset to override or deactivate an engaged automation feature by specified methods.

b) **System deactivation time**: Higher level automation functions may be deliberately designed to delay the transition to manual control under certain circumstances (e.g. in order to establish safe conditions for manual driving). This period of time (not mentioned in Figures 2 to 4) can be considered separately and is not part of the human-focused "take-over time".

c) **Decision time**: Time interval between detection of a silent system failure and the decision to disengage the automation feature (see Figure 3).

d) **Intervention time**: Time interval required by the driver to handle the imminent take-over situation by performing an appropriate driving manoeuvre. The requirements of the driver intervention vary from performing complex driving manoeuvres to simple tasks such as maintaining the current vehicle dynamics. In the latter case the driver intervention time could be very short or even be neglected. In any case clear behavioural or environmental markers is defined for the end of the required driver intervention. An example is shown in Reference [61]. Intervention time combined with the previously mentioned term take-over time is also a relevant time-based metric.

e) **Total time budget**: The time interval between the RtI and the system limit is defined as total time budget. It represents the maximum time window after a RtI for a successful resumption of manual control by the driver.

f) **Driving recovery time***:* Time required by the driver to recover driving with the appropriate reaction (according to the driving context) from the RtI warning. It is defined as take-over time in addition to the intervention time. Comparison between total time budget and driving recovery time is used to provide guidelines that take account of all the driver's reactions to ensure a successful manoeuvre.

g) **Remaining action time**: Time interval between a successfully finished driver intervention and the system limit. Computationally, it can be calculated as the difference between the total time budget and the sum of driver take-over time and driver intervention time. Gold, et al. (2013)[17] used a slightly modified variant of this measure, namely the remaining time to last intervention possibility at the time of intervention.

h) **Control stabilisation time**: Time duration it takes for an individual user to reach a similar or comparable quality level of manual driving performance as in ordinary level 0 driving by an average driver (reference condition). For downward transitions to levels >0, corresponding performance for this particular level can be used as reference behaviour. Longitudinal and lateral dimensions of vehicle control can be considered. An example is shown in Reference [30].

#### 5.3.3.3 Quality-related measures

Apart from describing the type and timeliness of user response it is essential to assess the quality of the driver intervention after the RtI. The interpretation of take-over quality measures will always depend on the (design of) take-over situation under investigation. For example, a driver reaction that is beneficial in one situation (e.g. swerving to avoid an accident) may be detrimental in another (e.g. swerving when there is neighbouring traffic). Accordingly, different investigations of take-over quality are always compared carefully and with extensive attention to detail. Furthermore, the described quality measures vary in external validity and sensitivity (usually following the relationship of increased validity—decreased sensitivity and vice versa). They can further be classified in terms of objective (e.g. behavioural and electrophysiological measures that do not depend on a person who measure) and subjective (e.g. self-reported base on the person's experience) measures.

a) **Safety-oriented, objective take-over quality measures**: A variety of measures are available and have been used to assess driving behaviour in take-over situations with respect to its safety effects on the individual itself and on other traffic participants. Examples of performance measures for assessing the safety-effects of a driver response to a RtI (e.g. used by References [17]; [38]; [6]; [66]; [45]; [58]) are:

   — share of test subjects being able to avoid collision with other traffic participants/prevent run off-road events;

   — description of collision severity;

   — omission of visual checks/mirror use;

   — operating errors (especially related to system deactivation);

   — maximum longitudinal/lateral acceleration values/frequency of strong or emergency braking (e.g. $-4\ m/s^2$/$-6\ m/s^2$);

   — minimum time to collision/minimum time on/to headway/frequency of "near misses" ($TTC_{min}$ <1 s/1,5 s); and

   — minimum time to lane crossing ($TLC_{min}$).

b) **Sensitivity-oriented, objective take-over quality measures**: As opposed to the safety-oriented measures that are relevant to the critical situation, other measures can be used to show potential mid- and long-term detrimental effects of having to regain manual control after an extended period of automated driving. The potential measures related to lateral and longitudinal control are:

   — Standard deviation (SD) of lateral position (e.g. References [45]; [42]);

   — SD of steering wheel angle (e.g. Reference [8]);

   — yaw rate error and SD of yaw rate error (e.g. Reference [10]);

   — metrics of distance to other vehicles or objects; and

   — metrics for longitudinal control quality, e.g. time headways, speed behaviour (e.g. considering speed limits).

The measures are recommended to be used on an individual level to compare baseline manual driving performance with post-transition performance.

c) **Expert-based assessment of take-over quality**: In order to assess the overall safety effects of a transition in a particular traffic situation, a combination of appropriate measures is taken into account as single measures may not be sufficient to differentiate safe and unsafe events (for a definition of safety-critical events see Reference [33]). Expert-based assessments of traffic situations have the potential to weigh and integrate different timing and quality parameters into a global controllability measure. This approach has also been recommended in the Response Code of Practice[54] in order to assess the controllability of driver assistance systems. In the context of automated driving, controllability can be defined as the driver's likelihood to safely cope with all possible driving situations occurring during normal use, at system limits or after system failures. Naujoks et al. (2017) [47] proposed a standardized rating scheme for controllability of transitions by trained raters that aggregates different aspects of the take-over situation to one global measure of driving performance based on video footage (see also References [27] and [26] for expert-based assessments of manual driving performance) which differentiates the following performance levels:

   — Rating "1": perfect performance (i.e., absence of imprecisions and errors);

   — Rating "2–3": imprecisions of vehicle control (e.g., imprecise lane keeping);

— Rating “4–6”: occurrence of driving errors (e.g., late or insufficient braking);

— Rating “7–9”: endangerments of oneself or other road users (e.g., near misses); and

— Rating “10”: collisions or loss of control.

d) **Subjective take-over quality measures**: Objective measures are ideally combined with subjective judgements of the intervention quality, either by the driver him/herself or by an external observer. Examples of judged aspects can be trust in coping with the situation, experience of being precise, and to what level the driver feels in control. A potential scale that can easily be adapted for this purpose is the “Scale for criticality assessment of driving and traffic scenarios”[48].



# 6 Human states in the context of automated driving

## 6.1 General

The scope of this clause is to introduce a basic structure for how to think about driver states in the context of automated driving. Rather than covering measures for all possible user states, the overview is intentionally limited to human states that are related to human performance in transition situations.

## 6.2 General concepts for mental state related to automated driving

The cognitive aspect of a human state in the context of automated driving primarily refers to the interpretation of the current driving situation with respect to perception, decision and response selection. It includes higher-level states such as situation and automation mode awareness (see Clause 8) during automated driving as well as in transition situations.

The process of perception, decision and response selection is influenced by the way in which attentional resources are allocated to the current tasks (e.g. Reference [64]) as well as by long-term, memory-based factors such as the mental model a human driver has developed for the system.

Knowledge (or assumptions) about the likelihood of system limits and the kind of possible transitions influence the speed with which a transition situation can be correctly interpreted. Similarly, system trust is considered as an influencing element on the cognitive driver state as it influences the way we think about and use automation (see Clause 8).

The cognitive state is also influenced by arousal level because total amount of attentional resource is considered to be influenced by arousal level. The following list describes exemplary impacts on the human’s cognitive state.

a) **Attention**: The element of cognitive functioning in which the mental resources are focused on a specific issue, object, or activity. Attention has been described as a function that accomplishes selection[65] and its main purpose is to facilitate perceptual processes[62][4][63]. Attention is also said to be a function that selects stimuli for further higher-level cognitive processing[5][1][7][4].

b) **Attentional resource**: Amount of attention applied to the target of attention. Physiological measures such as EFRP (Eye Fixation Related Potential) can be used to assess the amount of attentional resources applied to the road environment or to the non-driving related visual (also visual-manual) task[60]. Attentional resource is also called mental resource. Subsidiary task methods, such as the DTR (Detection Response Task[69]), are used to obtain behavioural measures to assess spare attentional resource. The Operation Span Test can also be used to assess spare attentional resource[59].

c) **(Task) demand**: Level of mental activities necessary to achieve the goal of a task. The human’s cognitive state during automated driving may be affected by the level of task demand requested by the current (potentially non-driving related) activity and the effort invested by the human. A wide range of measures have been proposed. Examples of subjective measures are the Rating Scale of Mental Effort[67], the NASA-TLX scale[22], and the Driving Activity Load Index (DALI) scale[28][50]. In automobile driving context, road structure (e.g. curve radius) and surrounding traffic (e.g. distance to an adjacent vehicle) are factors of the demand. It also depends on the driver behaviour task that a driver can select (e.g. target speed and target time to arrive the destination). The amount of mental resources of a person to perform the task depends on the task demand. Therefore, the demand can be estimated by workload measures. An example of a behavioural measure to assess the amount of demand level on the human is the standardized DRT[69] to quantify cognitive workload. Another example is the recent use of AttenD (Driver Attention System[44][29]) to measure the effect of multi-modal demand on driver attention[56][55].

## 6.3 Concepts corresponding to automation related driver states

The following concepts relate to driver states associated with monitoring the driving automation system or the driving environment (see transition process model in 5.2.1 and 5.2.3).

a) **Monitoring the driving environment**: The activities and/or automated routines that accomplish real-time roadway environmental object and event detection, recognition, classification, and response preparation (excluding actual response), as needed to operate a vehicle (SAE J3016[71] and SAE J3114[72]).

b) **Monitoring the driving automation system performance**: The activities and/or automated routines for evaluating whether the driving automation system is performing part or all of the DDT appropriately. (SAE J3016[71] and SAE J3114[72]) This is not limited to monitoring the HMI but also includes monitoring the environment to see if the system performs adequately for the circumstances.

c) **Object and Event Detection and Response (OEDR)**: The subtasks of the DDT that include monitoring the driving environment (detecting, recognizing, and classifying objects and events and preparing to respond as needed) and executing an appropriate response to such objects and events [i.e. as needed to complete the DDT and/or DDT fallback; (SAE J3016[71] and SAE J3114[72])].

d) **Receptivity**: An aspect of consciousness characterized by a person's ability to reliably and appropriately focus his/her attention in response to a stimulus (SAE J3016[71] and SAE J3114[72])

e) **Situation awareness**: A driver's understanding of the driving environment as it pertains to performance of DDT subtasks, including the driver's perception of the elements of the environment, the comprehension of their meaning, and the prediction of their near-future status[41][12] (SAE J3114[72])

   An example definition of situation awareness in the context of level 2 automated driving is the rate at which the driver anticipated the safety-critical event and the timing of regaining control of the manual driving task[42]. The situation awareness does not only refer to "knowing, what to do" but also includes time aspects of action planning "When do I have to do something?". Depending on how urgently a RtI is assessed in a given situation, take-over times are likely to vary accordingly.

   Situation awareness here focuses on situation awareness of road/traffic environment and does not include situation awareness of driving automation system (see "operating mode awareness" and "operating state awareness").

   SAGAT (Situation Awareness Global Assessment Technique) has been developed to assess level of situation awareness. SART (Situation Awareness Rating Technique[12]) can be applied to assess the anticipation of a safety-critical event. Other potential indicative measures are unusual short or long reaction times and/or subjective urgency ratings of the situation.

f) **Vigilance**: The ability to maintain attention and alertness over prolonged periods of time. In the context of driving automation, especially a level 2 system, drivers are required to maintain attention to road environment and system state. Since drivers are not required to operate any steering nor pedal operation, it may be difficult to maintain attention to driving environment, and, as a result, they may fail to detect RtI and silent failures.

PVT (Psychomotor Vigilance Task) has been developed to assess vigilance level (e.g. Reference [3]). PERCLOS (percentage of time the eyes are at least 80% closed) is highly correlated with performance of PVT[9].

g) **Operating mode awareness:** A user's understanding of the current operating mode of a driving automation system. This understanding reflects an awareness of the possible modes of the driving automation system relative to the one currently engaged (this term is adapted from SAE J3114: 2016, 5.1). [SAE J3114:2016 further distinguishes between operating mode knowledge (5.2), which refers to a user's understanding of the implications of the current mode on which driving subtasks s/he performs versus those of the driving automation system, and operating mode confusion (5.3), which refers to the user condition in which he/she incorrectly believes the driving automation system to be operating in a particular mode, reflecting incorrect or incomplete operating mode knowledge and/or poor awareness of the current driving automation system mode].

Mode of the driving automation system is a system condition defined by the distribution of DDT subtasks and/or DDT fallback between the user and a given driving automation system feature ensuring completion of the DDT and DDT fallback (SAE J3114:2016, 6.2).

h) **Operating state awareness:** A user's understanding of the current operating state of a driving automation system. This understanding reflects an awareness of the possible states of the driving automation system relative to the one it is currently in (this term is adapted from SAE J3114:2016, 5.4). (SAE J3114:2016 further distinguishes between operating state knowledge (5.5), which is a user's understanding of the current behaviour of the driving automation system as an indicator of its current operating mode, and operating state confusion (5.6), which is the user condition in which he/she incorrectly believes the driving automation system to be operating in a particular state, reflecting faulty operating state knowledge and/or operating mode knowledge).

State of the driving automation system here refers to the operating behaviours of the driving automation system within a particular mode [e.g. when adaptive cruise control (ACC) is in ACTIVE mode, potential states include traveling at a constant speed, reducing speed from the set speed to maintain a constant headway, etc. (SAE J3114:2016, 6.3)].

## 6.4 Concepts corresponding to non-driving related driver states

Driver states relating to the NDRA outlined in 5.2.2 and 5.2.3 are explained. States that may occur during automated driving even though they are not caused by any specific activity are also included in this subclause.

a) **Visually distracted/loaded**: Driver's state when driver's visual attention is focused on a non-driving related objects for a certain period of time. If the driver/fallback-ready user is visually distracted when a RtI is issued only through visual display, the driver/fallback-ready user may fail to detect it. It may be affected by the difficulty of visual information processing (i.e. complexity of visual image) and the amount of motivation (see below). It is related to the allocation of mental resource to the visual target.

The time duration of eye glance away from road environment (TORSA/Time Off Road-Scene-Ahead) and the glancing duration can be measured by driver's glancing behaviour[68]. The amount of mental resource allocated to glance obtained can be estimated by Eye Fixation Related Potential (EFRP) that is an event related potential from EEG signals around the onset of fixation. Specific measures can be used to assess the current sensory state of the user for each modality. Head position (e.g. Reference [52]) can also be used to assess visually distracted state. Condition of holding device for visual activity can be detected by body/hand posture.

b) **Visual-manually distracted/loaded:** Driver's state when driver's attentional resource is allocated to perform a non-driving related visual-manual task. The visual-manual task is obtaining information through the visual channel and performing hand/foot operation according to the visual information to achieve the goal of activity. Operating a car navigation system, audio control (e.g. selecting radio channel), climate control (e.g. changing set temperature) and internet browsing are visual-manual tasks. While performing a visual-manual task in automated driving condition, the driver/fallback-ready user may fail to detect a RtI if the driver's/fallback-ready user's attention is focused on the task.

In order to perform a visual-manual task while driving without automated driving system, a driver looks at the display of the device and road environment reciprocally because a driver is required to monitor the driving condition. When a driver uses an automated driving system (higher than level 3), glance duration to the display of visual-manual task will be longer because monitoring is not required. Such visual behaviour can be measured by using an eye tracker system. Another method for measuring visual behaviour is real-time driver-facing video analysis[52] using machine learning approaches[13]. The amount of mental resource allocated to the glance to either the display for non-driving related task or road environment can be estimated by Eye Fixation Related Potential (EFRP). Status of manual operations during visual-manual task can be measured by body posture or detected by signals obtained from the device. Subjective measures such as NASA-TLX[22] can also be applied to estimate amount of load of the task.

c) **Manually distracted/loaded**: Driver's state when driver's attentional resource is allocated to performing a non-driving related manual task. The manual task concerns using body motions to achieve the goal of the activity. It can include use of hands and/or feet, but can also involve reaching out for things as well as changes to posture or even changed locations within the vehicle as elaborated in 6.5. Examples of these manual tasks are taking off the shoes, reaching out for a cooled drink from a refrigerator, or performing a sequence of actions to prepare coffee. While performing a manual task in automated driving condition, the driver/fallback-ready user may fail to detect a RtI if the attention is focused on the task. The driver can also be out of position with hands/arms/feet fully occupied with the task.

d) **Cognitively distracted/loaded**: Driver's state when driver's attentional resource is allocated to performing a cognitive task. Cognitive tasks include internal thoughts, mental tasks such as mental calculations and verbal tasks. An example of a verbal task is a telephone conversation through a mobile phone. During performance of a cognitive task, a driver may look forward to the road scene, and thus any cognitive task may be performed during manual driving and with any level of driver automation system. However, if a cognitive task is difficult and requires a large amount of mental resource, detecting a hazardous event or detecting a RtI may be failed or delayed.

Subjective measures such as NASA-TLX developed to assess mental workload can be applied to estimate cognitive demand of cognitive tasks. Eye related measures are expected to be used as objective measures (See References [53]; [19]; also see [56]).

e) **Mind wandering**: A shift of attention away from a primary task toward internal information[57]. Similar ideas are expressed by being lost in thought[40] and mind-off-the-road[20]. Approaches to the measurement of mind wandering are found in References [34] and [2].

f) **Arousal level**: An individual's degree of responsiveness to stimuli. The arousal level can be thought of as how much capacity the driver has available to work with. Physiological (e.g. blink duration, EEG alpha-wave, theta-wave, etc.), behavioural measures (e.g. PERCLOS) as well as subjective measures (e.g. KSS sleepiness self-rating, Self-Assessment Manikin[14]) are used to quantify aspects of arousal. There is an inverted U-shaped relationship between arousal and performance (Yorkes-Dodson's Performance/Arousal Curve). In the context of driving automation, monitoring driving environment while using a level 2 system in stable condition (e.g. straight highway road) requires a low level of cognitive demand and is monotonous. Arousal level may be lowered when such a situation continues over longer periods of time.

A person's level of arousal can be described as a function of situational awareness, vigilance, level of distraction and direction of attention. It determines how ready a person is to perform appropriate tasks in a timely and effective manner. Significantly low arousal levels are expected to have a negative impact on driver/fallback-ready user performance in take-over situations. On the other hand, extreme high arousal levels such as panic will also have a negative impact on driver/fallback-ready user performance in take-over situations.



 

g) **Motivation to non-driving task**: Apart from the attentional effects due to the current activity there is also a motivational factor to be considered in take-over situations: Even after a RtI has been issued drivers may be strongly motivated to first finish certain NDRA before turning back to the driving task. Potential indications to quantify this factor are related to how a NDRA is continued after a RtI or based on a subjective assessment of the NDRA in a given situation (e.g. Reference [21]).

## 6.5 Driving position and posture

Apart from sensory and cognitive state, physical state of a driver/fallback-ready user is also considered. When a driver/fallback-ready user is required to perform the DDT by operating a steering wheel and pedals, that user maintains a proper driving position. When a user is not required to use pedals and/or hold a steering wheel, they may not keep the proper driving position. If it is quite different from the proper position, the driving position may take time to take-over DDT when a RtI is issued.

a) **Hands on the steering wheel**: Driver's postural state is that of least one of the driver's hands touching the steering wheel. There are several variations of the state of hands on the steering wheel: holding the steering wheel with both hands the same as usually held by the driver in the fully manual driving condition; holding the steering wheel with one hand as the driver usually does in the fully manual condition; and just lightly touching the steering wheel with one hand, which is not a state that occur in fully manual driving. For the one-hand conditions, the other hand may hold something (e.g. nomadic device, food etc.) or be vacant. There are variations in the position of vacant hand(s): hand(s) on the lap, hand(s) on the arm rest (either centre console or door side) and other positions.

   State of hands on the steering wheel may affect the time-based intervention performances (e.g. intervention time and control stabilisation time in 5.3.3.2) and the quality of intervention performance (see 5.3.3.3).

b) **Hands off the steering wheel**: Driver's postural state is that both of the driver's hands are not touching the steering wheel. In this state, the hand(s) hold something or are vacant. In case of holding something, the object is held by either both hands or one hand. The thing can be big and heavy or light and small. There are variations in the position of vacant hand(s); hand(s) on the lap, hand(s) on the arm rest (either centre console or door side) and other positions.

   State of hands off the steering wheel may affect the time-based intervention performances (e.g. take-over time, intervention time and control stabilisation time in 5.3.3.2) and the quality of intervention performance (see 5.3.3.3) (e.g. References [45] and [25]).

c) **Hands occupied:** Inability to instantly use one or both hands to resume manual driving because the user is holding something in his/her hand. Depending on the type and size of the object putting it away in a suitable place may be complex in a transition situation.

d) **Foot position**: Position and posture of driver's foot and leg during driving automation condition where the driver/fallback-ready user is not required to operate pedals. Typical foot posture is putting one or more feet on the floor between pedals and driver's seat. A driver/fallback-ready user may bend their knee(s).

   State of foot position may affect the time-based intervention performances and the quality of intervention performance.

e) **Out of driving position**: In the automated driving condition, a driver may move the seat to the rearmost position to make enough space to work on a laptop computer; may start to prepare food and drinks for a lighter meal; or may lean the seat back to spend time in a relaxed position.

   Driving position affects the time-based intervention performances because more time is needed to reach to steering wheel and/or pedals. It also affects the quality of intervention performance because the driver/fallback-ready user may try to operate the steering wheel and/or pedals with unusual body posture before returning seat to the proper driving position.

## 7 Driver readiness/availability

Driver readiness and availability are synonymous and defined as the state of the driver during automated driving that influences successive driver's intervention performance to regain control of the vehicle from the system (see 5.2) to continue driving manually, avoid a hazard or bring the vehicle to the minimum risk condition. Driver readiness/availability is a continuous index that correlates positively with the driver's intervention performance. The highest value of readiness/availability is allocated to the state of the driver that is sufficient for the intervention performance successful or equivalent to that of full manual driving. The intervention includes both system initiated (i.e. intervention after the RtI) and driver initiated (i.e. the driver finds a hazard and overtakes driving). When the readiness/availability is low, successive intervention performance is low resulting in longer time to achieve the highest value and perform the required intervention. Driver readiness/availability when the driver is performing the OEDR task with the level 2 system is higher than when the driver is performing a non-driving task with the level 3 system (Figure 5).

Driver readiness/availability are still conceptual but can be composed of dynamic and static factors of the driver. The dynamic factors are changeable while driving automatically and include some or all of the subsets of the driver state mentioned in Clause 6. The static factors are driver's attributes such as knowledge of the system functions and skills to use the automated system mentioned in Clause 8. Driver readiness/availability is a predictor of successive intervention performance in case it is initiated by the system or by the driver. Therefore, it is proposed to monitor the readiness/availability during automated driving via a Driver Monitoring System (DMS), (SAE J3016[71] and SAE J3114[72]).

When the DMS detects the readiness/availability lower than the required level, the system is expected to alert the driver to be able to respond to a RtI properly, terminate automated driving after a RtI or bring the vehicle to the minimum risk condition to avoid risk that can happen in the near future[30][31][32][39].

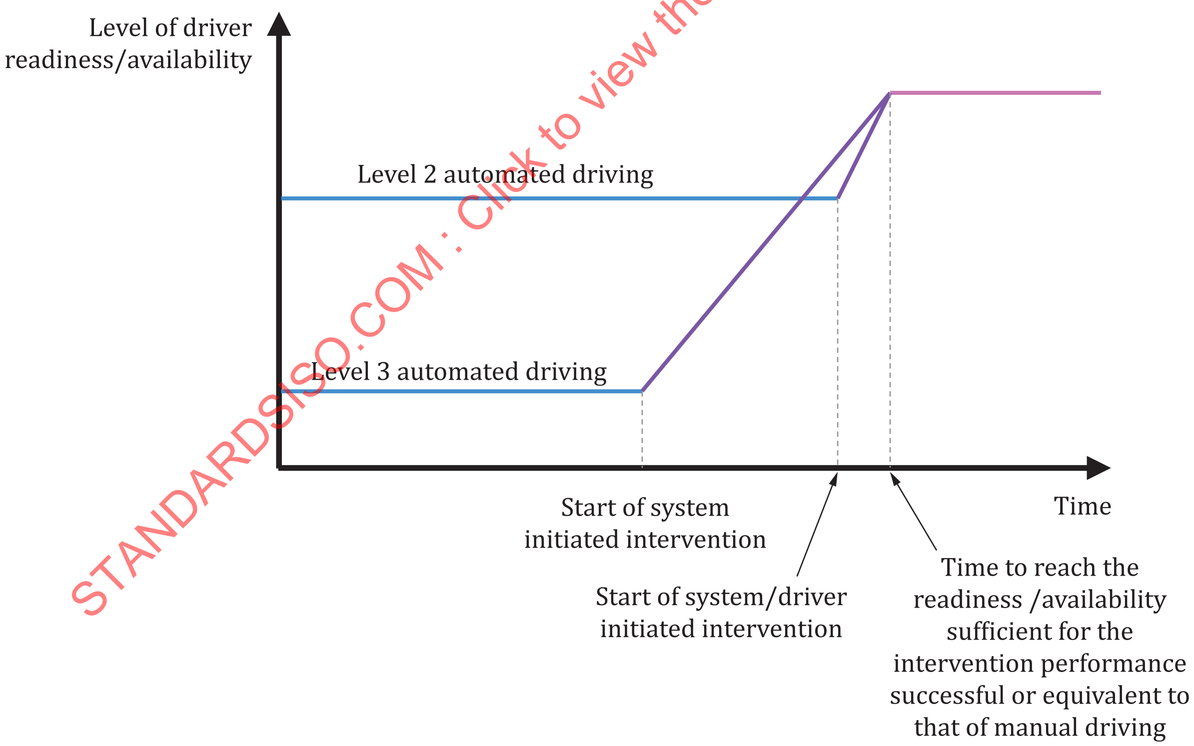


**Figure 5 — Conceptual model of the "driver readiness/availability" in transition**

## 8 Drivers' experiences and attitudes regarding driving automation system

Drivers' state and intervention performance in the context of automated driving depends on driver's understanding and behavioural attitude to the use of the driving automation system. If a driver/



 

fallback-ready user completely relies on the system, for example, the driver/fallback-ready user may concentrate on non-driving related tasks while using the driving automation system and may not care about the driving environment. The driver's understanding and the behavioural attitude are developed in the process of being a user of the system.

Even before actually experiencing the system, people may have some system image that is formed by information through, for example, mass media. This image can be called a prior system image. When a driver has a chance to use the system (e.g. buy a vehicle with driving automation system), they will have the opportunity for education and training (at a car dealer, for example). In the education and training, knowledge of the driving automation system is given. Knowledge includes functionality, functional limit, mechanisms of the system, and so on. When this knowledge is given, a driver gets a primary understanding of the system. Then, a user starts to use the system and the user's understanding of the system is changing as user experiences the use of the system. A user's understanding includes operations to use the system and user's thought about how the system work (i.e. mental model). Based on it, a user's mental attitude to the system, such as trust is developed. User's understanding of the system influences the user's behavioural attitude and actual behaviour while using the system (Figure 6).

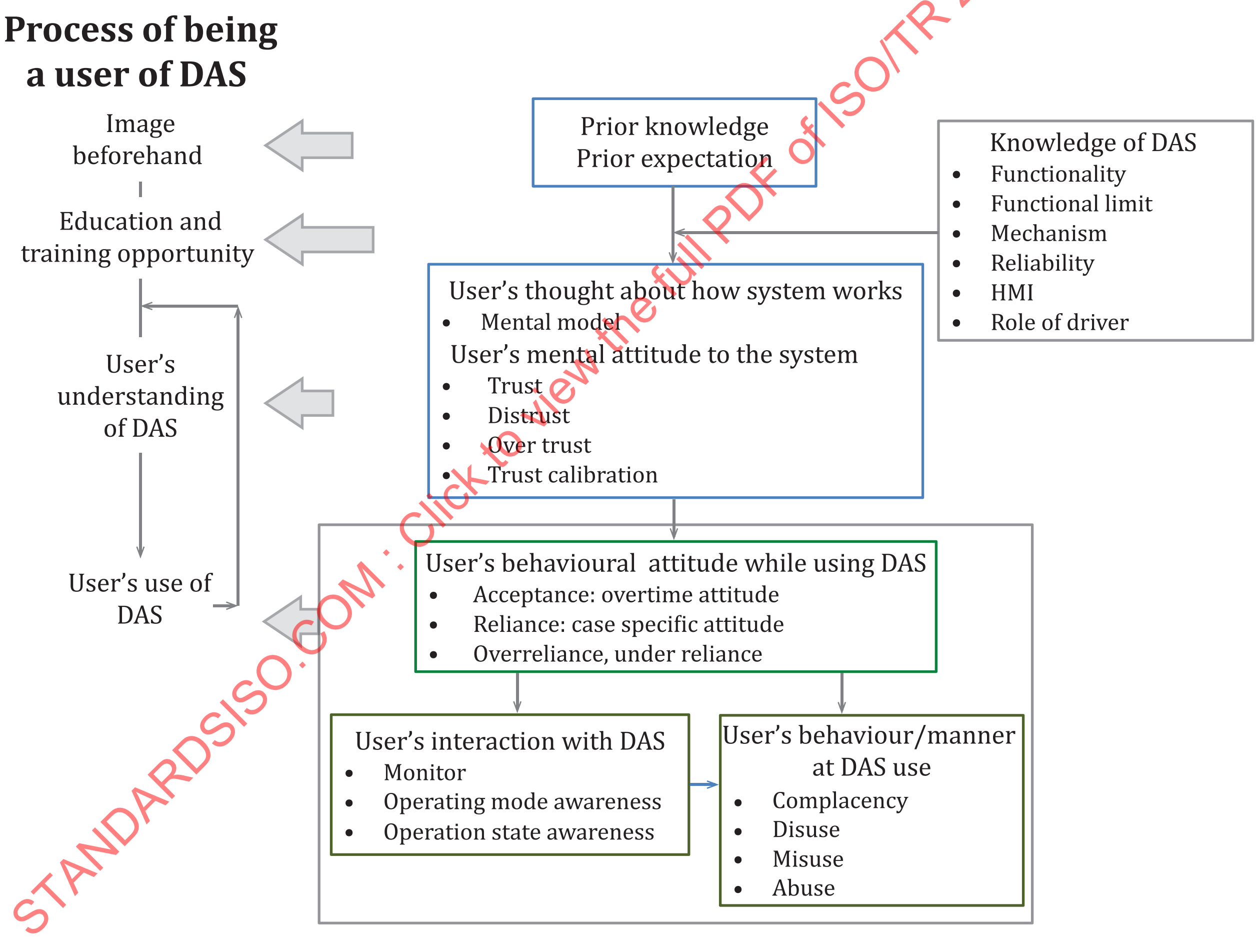


**Figure 6 — Process of being a user of a driving automation system**



## 8.1 Prior system image

a) **Prior knowledge of driving automation system**: Driver's mental model of driving automation systems based on information available prior to personal hands-on experience with the driving automation system. The prior knowledge may be based on information via mass media, internet, and word-of-mouth. The user's prior knowledge may affect the mental model of, trust in, and use of the driving automation system.

b) **Prior expectation of driving automation system**: Driver's expectation and belief of what driving automation system can do or how it works based on the driver's needs or social needs. It is created before a user has gained personal experience with the driving automation system. The prior expectation may be inconsistent with the prior knowledge of driving automation system.

## 8.2 Education and training

a) **Knowledge on driving automation system**: The explicit information about the driving automation system that is supposed to be informed to users at the official education and training. The knowledge includes the functionality, the functional limit of a driving automation system, the mechanism of the driving automation system, the reliability of the driving automation system, HMI, how to use the driving automation system, and the user' role.

b) **Functionality (purpose) of driving automation system**: The function that the driving automation system is supposed to achieve. The functionality is described in the design specification. The functionality is related to user's trust in driving automation system. If the user's prior expectation on the functionality of the driving automation system is inconsistent with the actual one, the user's trust may be inappropriate. This is related to the "purpose" dimension of trust[35].

c) **Functional limit of driving automation system**: Driving automation system operating state in which the system's manner of behaviour is undesirable from a user's standpoint due to transient lapses in performance that are inherent in the system as designed and specified, rather than due to a system failure of driving automation system, silent failure (SAE J3114:2016, 6.1.2).

d) **Mechanism (process) of driving automation system**: The way the driving automation system achieves its functionality. The functional limit of a driving automation system depends on the mechanism. The mechanism is related to the "process" dimension of trust[35].

e) **Reliability (performance) of driving automation system**: Ability of the ADAS to perform as required, without failure, for a given time interval, under given conditions[73] (this is inconsistent with the definition in Reference [72] which is from the user's perspective).

f) **Human-machine interface (HMI) of driving automation system**: The medium through which the user and the driving automation system interact with each other. A visual display is a typical example of an HMI, but there are other types of HMIs. The contents of the HMI include RtI as well as information on the status of the driving automation system.

g) **Role of user**: The expected activity of a given primary actor, based on the design of the driving automation system in question and not necessarily to the actual performance of a given primary actor. The user's role depends on the level of driving automation system, and may include monitoring, OEDR and fallback[70].

## 8.3 User's understanding of driving automation system

### 8.3.1 User's thought about how driving automation system works

**Mental model of the driving automation system**: Driver's individual personal thought processes about how the driving automation system behaves. Mental model is consciously or unconsciously formed from our experiences, and it (when formed) guides our thoughts and actions to the system. Mental model provides predictive and explanatory power for the understanding the interaction[49].

### 8.3.2 User's mental attitude to driving automation system

a) **Trust in driving automation system**: Trust includes from general trust in automated systems to trust in a particular automated system. The human propensity for relying on driving automation technology (SAE J3114). Trust is the attitude that an agent will help achieve an individual's goals in a situation characterised by uncertainty and vulnerability[37]. According to Lee & See (2004)[37], trust has three dimensions: (i) purpose, (ii) process, and (iii) performance.



 

b) **Distrust**: Inappropriately low trust in the driving automation system compared to the system capability. In Reference [37], distrust is defined as "trust falling short of automation capabilities." Distrust is based on dissatisfaction with driving automation system performance. The dissatisfaction may come from the gap between the user's prior expectation and his/her understanding of the driving automation system. Distrust thus may occur even if the user understands the driving automation system appropriately. Several types of distrust can be distinguished according to the dimensions of trust[24].

c) **Overtrust**: Inappropriately high trust in the driving automation system compared to the system capability. In Reference [37], overtrust is defined as "poor calibration in which trust exceeds system capabilities."

d) **Trust calibration**: Trust calibration refers to the correspondence between a person's trust in the automation and the automation's capabilities[36][43].

## 8.4 User's use of driving automation system

### 8.4.1 User's behavioural attitude while using driving automation system

a) **Acceptance**: A dynamic bidirectional process of how trust in and use of an automated system is developed through interaction [Technology Acceptance Model (TAM)[15]]. Acceptance can be measured as attitude, behavioural intention, or actual use of the automated system.

b) **Reliance**: By using the driving automation system, to let the driving automation system have control in a specific situation. Reliance could be case-specific.

c) **Overreliance**: The situation in which, despite apparently degraded driving automation system performance, the user does not intervene because the system has not issued a warning or otherwise seems to be performing adequately (SAE J3114:2016, 4.5.1).

d) **Underreliance**: The intentional sceptical use of a driving automation system feature. (SAE J3114: 2016, 4.5.2).

### 8.4.2 User's interaction with driving automation system

— Monitor the driving automation system performance: see 6.3.

— Operating mode awareness: see 6.3.

— Operating state awareness: see 6.3.

### 8.4.3 User's behaviour/manner at driving automation system

a) **Complacency**: Overconfidence on the part of a driver or fallback-ready user in his or her knowledge of what to expect in terms of performance by a given level 1 through 2 driving automation feature; such overconfidence may lead to over-reliance and/or lack of monitoring the driving automation system (SAE J3114: 2016, 4.5.1.1, modified).

b) **Disuse**: The intentional non-use of a driving automation system feature (SAE J3114).

c) **Misuse**: The unintentional use of a driving automation system feature in a manner contrary to the manufacturer's instructions (SAE J3114:2016, 4.3).

d) **Abuse**: The intentional use of a driving automation system feature in a manner contrary to the manufacturer's instructions (SAE J3114:2016, 4.1, modified).