



SURFACE VEHICLE INFORMATION REPORT

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Human Factors Definitions for Automated Driving and Related Research Topics

RATIONALE

This Information Report covers the human factors issues involving the integration of driving automation system features into the vehicle, focusing on issues that affect driver/user performance and experience through the driver/user-vehicle-interface (DVI). This report is intended to aid research and facilitate improved DVI design and usability by establishing working definitions for key concepts of levels 2 through 4 driving automation system features (SAE J3016), and to provide references to relevant research. This report serves as a complementary document to SAE J3016.

INTRODUCTION

This Information Report provides a summary of the activities to date of Task Force #5 - Automated Vehicles and DVI Challenges of the SAE's Driver Vehicle Interface (DVI) committee. A literature review was conducted of journal articles and conferences papers within the Human Factors, Ergonomics and other human performance fields. The literature was queried to identify those articles/papers that relate to driving automation. Over 200 articles were reviewed, summarized and categorized into key concept areas. Those categories were then used to develop a list of key definitions. This information report provides a foundation for conversations regarding driving automation system features and their interfaces with the human. This information report includes important definitions, which are intended to establish a common language and understanding of terms used in research relating to human factors issues for automated driving technologies, and will be updated as the technology evolves. These terms are written from the perspective of the human user and are not written from the driving automation system perspective.

1. SCOPE

The aim of this Information Report is to provide terms and definitions that are important for the user's interaction with L2 through L4 driving automation system features per SAE J3016, which provides a basis for this document.

2. REFERENCES

- 2.1 SAE J3016, Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles (J3016:SEP2016).
- 2.2 SAE J3063, Active Safety Systems Terms & Definitions (J3063:NOV2015).
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3. DEFINITIONS

3.1 Terms defined in SAE J3016 and/or SAE J3063:

- 3.1.1 Active Safety System (SAE J3063)
- 3.1.2 Automated Driving System (ADS)
- 3.1.3 ADS-Dedicated Vehicle (ADS-DV)
- 3.1.4 Driving Automation
- 3.1.5 Driving Automation System or Technology
- 3.1.6 [Driving Automation System] Feature or Application
- 3.1.7 Driving Mode
- 3.1.8 Dynamic Driving Task (DDT)
- 3.1.9 (DDT) Fallback
- 3.1.10 (DDT Performance-Relevant) System Failure
- 3.1.11 Lateral Vehicle Motion Control
- 3.1.12 Longitudinal Vehicle Motion Control
- 3.1.13 Minimal Risk Condition
- 3.1.14 Monitor
 - 3.1.14.1 Monitor the Driver
 - 3.1.14.2 Monitor the Driving Environment
 - 3.1.14.3 Monitor Vehicle Performance (for Vehicle Conditions that Adversely Affect DDT Performance)
 - 3.1.14.4 Monitor Driving Automation System Performance
- 3.1.15 Object and Event Detection and Response (OEDR)
- 3.1.16 Operate [a Motor Vehicle]

- 3.1.17 Operational Design Domain (ODD)
- 3.1.18 Receptivity (of the User)
- 3.1.19 Request to Intervene
- 3.1.20 Supervise (Driving Automation System Performance)
- 3.1.21 Sustained (Operation)
- 3.1.22 (Human) User
 - 3.1.22.1 Driver
 - 3.1.22.1.1 (Conventional) Driver
 - 3.1.22.1.2 Remote Driver
 - 3.1.22.2 Passenger
 - 3.1.22.3 (DDT) Fallback-Ready User
 - 3.1.22.4 Dispatcher
- 3.1.23 Trip
- 3.1.24 Usage Specification
- 3.1.25 Vehicle
- 3.1.26 Level 2 – Partial Driving Automation
- 3.1.27 Level 3 – Conditional Driving Automation
- 3.1.28 Level 4 – High Driving Automation

4. TERMS RELATED TO USER INTERACTION WITH DRIVING AUTOMATION

4.1 Driving Automation Abuse

The intentional mis-use of a driving automation system feature in a manner contrary to the manufacturer's instructions.

EXAMPLE: The driver of a vehicle equipped with and engaged level 2 driving automation system straps a weight to the steering wheel in order to defeat the feature designed to ensure that the driver is paying attention to the driving task by requiring frequent or consistent steering wheel torque. S/he then uses both hands to browse the internet on a tablet computer. Given that level 2 features require the driver to supervise the system's performance of the dynamic driving task (DDT) throughout the period that it is engaged, this behavior constitutes abuse.

4.2 Eutactic Behavior

The intentional use of a driving automation system feature in a manner inconsistent with its design intent, but which is perceived by the user to be safe and practical based on experience.

NOTE: Eutactic behavior is different from forms of abuse such as risk-taking or negligence in that the driver is intentionally acting to balance the risks versus the perceived benefits associated with using the system in a manner that is inconsistent with its design intent.

EXAMPLE: The driver of a vehicle equipped with and engaged SAE level 2 driving automation system feature that is explicitly not designed to be used in poor weather may continue to use it in poor weather even if it periodically fails to detect lead vehicles and/or lane markings because it still provides some support to the driver in performing the DDT.

4.3 Driving Automation Misuse

The unintentional use of a driving automation system feature in a manner contrary to the manufacturer's instructions.

NOTE: This comprehends instances when instructed use from or by the manufacturer is not available to the user, or when the user does not access the provided instructions.

EXAMPLE: The fallback-ready user (FRU) of a vehicle equipped with and engaged SAE level 3 Automated Driving System (ADS) feature that performs the complete DDT in congested traffic on fully access-controlled freeways falls asleep, which is not permitted according to the manufacturer's instructions, since the FRU must be able to perform the DDT fallback on short notice when needed.

4.4 Driving Automation Disuse

The intentional non-use of a driving automation system feature.

NOTE: Automation disuse is usually the result of complete lack of trust in the system's capabilities.

4.5 Inappropriate Reliance

4.5.1 Over-Reliance

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.

NOTE 1: Over-reliance results in errors of omission.

NOTE 2: Over-reliance is distinct from over-compliance, in which compliance refers to the situation in which the operator acts in response to a warning or a command from the automation that leads to an error of commission (cf. Skitka, Mosier, & Burdick, 2000).

NOTE 3: Over-reliance may lead to hazardous usage, which may constitute abuse or misuse.

4.5.1.1 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.

Key Reference: A driver's belief that may result in a lack of vigilance based on an unjustified assumption of satisfactory system state (Billings et al., 1976).

Reference: Billing, C.E., Lauber, J.K., Funkhouser, H., Lyman, G., & Huff, E.M. (1976). NASA Aviation Safety Reporting System (Tech. Report TM-X-3445). Moffet Field, CA: NASA Ames Research Center.

NOTE 1: A lack of vigilance presumes that the driver is monitoring the driving automation system's performance at a lower frequency than a standard or optimal frequency such that there is an observable deleterious effect on DDT performance (e.g., as missed detection of a potential collision partner or delayed or missed detection of a request to intervene). In this document, we are using complacency to refer to neglect of DDT performance only rather than using it to mean user neglect in any context.

NOTE 2: Over-reliance on a driving automation system is sometimes termed complacency when it results from trusting a system more than is warranted.

NOTE 3: This definition refers to the cognitive state of the driver not the observed action or lack thereof that results from this state.

EXAMPLE: The driver of a vehicle equipped with an engaged level 2 traffic jam assist feature misuses the feature to operate the vehicle in freeway traffic while s/he reads a novel. Due to his failure to supervise the driving automation feature's performance of the DDT, s/he fails to take over when the vehicle encounters a policeman directing traffic to exit the freeway.

4.5.1.1.1 Driving Automation Bias

The omission and commission errors that result from the use of driving automation system-issued cues as a replacement for vigilant information seeking and processing.

NOTE 1: Omission errors occur when the operators do not take appropriate action because they are not informed or have a misunderstanding about the operation of the driving automation system feature.

NOTE 2: Commission errors occur when operators make inappropriate action based on the recommendation of the automation despite having evidence to the contrary in the world.

NOTE 3: Automation bias only applies to levels 1 through 2 driving automation system features, as levels 3 through 5 ADS features perform the complete DDT while engaged and thus do not invoke automation bias.

NOTE 4: This is different than over-reliance; Automation Bias is rather a type of complacency. Complacency is typically associated with the types of misuse or abuse that have safety implications.

EXAMPLE 1: The driver of a vehicle equipped with and engaged level 2 driving automation system feature that automatically changes lanes when requested by the driver fails to supervise the maneuver as required and thus has a conflict with another vehicle that appears suddenly in the destination lane.

EXAMPLE 2: A level 2 automated parking system is unable to recognize fire hydrants; an inattentive driver nevertheless accepts the illegal parking space suggestion.

4.5.1.2 Lack of Receptivity (Level 3)

The user is not receptive to a vehicle system failure or a request to intervene issued by a level 3 feature.

Reference: Receptivity (see SAE J3016).

EXAMPLE: The fallback-ready user of a vehicle equipped with an engaged level 3 ADS feature does not respond to a request to intervene due to having fallen asleep.

4.5.2 Under-Reliance

The intentional skeptical use of a driving automation system feature.

NOTE 1: A user under-relies on the driving automation system when s/he redundantly performs a role that the system is designed to do.

NOTE 2: A potential consequence is not taking advantage of the systems may lead to automation disuse or misuse.

EXAMPLE: A driver who has engaged a level 2 automated parallel parking feature constantly overrides it during the maneuver, because he doesn't trust it.

5. TERMS RELATED TO USER PERCEPTIONS AND UNDERSTANDING OF DRIVING AUTOMATION

5.1 User Operating Mode Awareness

The user's comprehension of the current operating mode of the driving automation system and its ability to transition to another mode, as well as an understanding of the subtasks (or actions) that they as the driver are required to perform (if any) versus those the driving automation system is performing.

NOTE 1: Mode awareness includes a predictive ability. "Awareness" refers to the ability of the user to track and to anticipate the behavior of a given driving automation system feature (Sarter & Woods, 1995).

NOTE 2: Mode transitions can either be user-initiated or system-initiated. Mode awareness includes an understanding of the possible mode transitions based the user's vehicle motion control inputs (e.g., pressing down on the brake pedal versus turning the steering wheel versus engaging a driving automation system) – these are the user-initiated mode transitions. Mode awareness also includes an understanding of the possible mode transitions based on the system's interactions with the roadway and environmental conditions – these are the system-initiated mode transitions.

NOTE 3: Mode awareness refers to both comprehension of the set of modes for a particular system, as well as of the possible mode transitions relative to the current operating mode.

5.2 User Operating Mode Knowledge

The user's comprehension of the current driving automation system mode.

NOTE 1. This means the driver knows which subtasks s/he is to perform versus those the driving automation system is to perform.

NOTE 2: User operating mode knowledge does not include predictions regarding future modes or states.

5.3 User Operating Mode Confusion

A user condition in which s/he believes the system is operating in a particular mode when in fact it is operating an another mode.

NOTE 1: When mode confusion occurs, the user does not recognize the current operating mode of the driving automation system, nor which subtasks (or actions) are appropriate for the mode.

NOTE 2: Mode confusion can also refer to complete ignorance of operating mode (i.e., the user has no understanding of what modes are).

NOTE 3. The actual action taken in these instances can lead to mode errors of two types: (1) omission errors: failing to take necessary measures, or (2) commission errors: taking actions that are not appropriate for the situation.

Key Reference: Cf. Sarter & Woods, 1995.

5.4 User Operating State Awareness

The user's comprehension of what state the driving automation system is operating in or will imminently be operating in.

NOTE: State awareness includes predictions regarding future modes or states.

5.5 User Operating State Knowledge

The driver's real-time comprehension of what state the system is operating in.

NOTE: State knowledge does not include predictions regarding future modes or states.

5.6 User Operating State Confusion

When the driver believes the system is operating in one state when in fact it is operating in another state.

NOTE: State confusion can also refer to complete ignorance regarding the existence of multiple operating states; this could also be considered as a lack of Operating State Knowledge.

5.7 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 (Endsley, 1995B; this includes Operating Mode Awareness).

NOTE: "Elements of the environment" could refer to other vehicles, pedestrians, objects, signage, roadway type, or weather conditions, any of which may affect the current or predicted state of the vehicle as it travels through its environment.

5.8 Trust in Driving Automation

The human propensity for relying on driving automation technology.

NOTE: Inappropriate trust in driving automation may lead to over reliance (3.4.1).

5.9 First Failure Effect

The behavioral and attitudinal adjustment that a user undergoes upon occurrence of a driving automation system failure after having implicitly trusted the system for some period of time without failure, thus resulting in recalibration to an appropriate level of trust.

NOTE: This term is also used to describe the phenomenon where error rates when handling the first driving automation system failure experienced are expected to be higher than the error rates while handling subsequent failures due to the initial inappropriate trust in the system.

6. TERMS RELATED TO DRIVING AUTOMATION STATUS AND BEHAVIOUR

6.1 Reliability of a Driving Automation System

The relative frequency of failures and performance limitations for a given driving automation system feature that impede users from having full utility of the system.

NOTE: Because this document aims to specify and define terms related to the Human Machine Interface (HMI) aspects of driving automation, this definition defines system reliability from the perspective of the user, rather than from the perspective of the system designer. Thus, it does not distinguish between actual system failures and system performance limitations that users often perceive as system failures. It should be noted that from the perspective of the system designer, only actual system failures count in assessing system reliability.

6.1.1 Failure of a driving automation system (see SAE J3016 DDT performance relevant system failure).

6.1.2 Performance limitation of a level 1 or 2 driving automation system.

A level 1 or 2 driving automation system operating state in which the system's manner of behavior 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.

NOTE 1: To a user who experiences it, a driving automation system performance limitation may be indistinguishable from a driving automation system failure.

NOTE 2: A driving automation system feature may or may not be capable of diagnosing a given performance limitation that adversely affects driving automation system performance, and therefore may or may not alert the user of its imminent or actual occurrence.

EXAMPLE 1: Due to limitations in image processing software, the camera system used to track lane lines for a level 1 lane centering feature mistakes partially erased lane lines as currently applicable lane lines and wrongly steers the vehicle into an adjacent lane, requiring the driver to manually steer the vehicle to avoid the mistaken lane change.

EXAMPLE 2: Due to sensor specification, mounting height and programming, the level 1 ACC radar on a given vehicle undershoots the heavy-duty truck in front of the vehicle and instead picks up a car in front of the heavy-duty truck. As a result, the driver has to apply the brakes to avoid colliding with the heavy-duty truck.

6.2 Operating Mode

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. Figure 1 describes the distribution of roles.

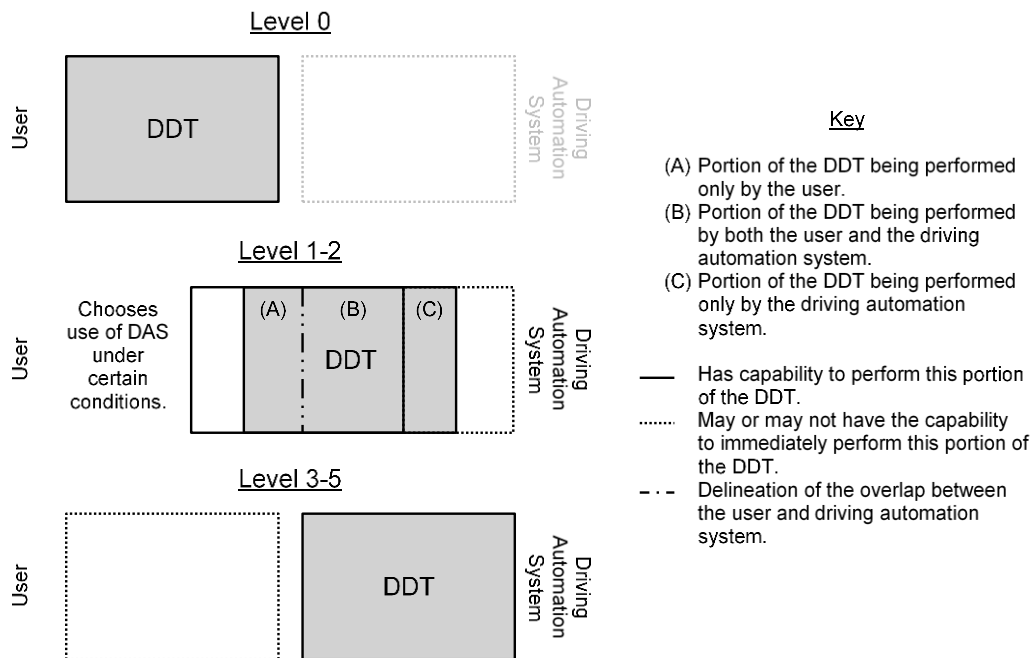


Figure 1 – Operating mode roles

NOTE 1: This definition refers to how the user perceives the operating mode(s) of the driving automation system and the consequent subtasks of the DDT that the user is required to perform versus those of the driving automation system.

NOTE 2: The DDT fallback is allocated to the driver in level 3 and allocated to the ADS in levels 4 through 5 (see SAE J3016).

NOTE 3: Figure 1 represents mode when the system is engaged.

NOTE 4: A change in the distribution of DDT subtasks between the user and the driving automation system results in an operating mode change.

NOTE 5: The “user” could be a conventional (in-vehicle) driver or a remote driver.

NOTE 6: SAE J3016 defines Driving Mode which is different than Operating Mode as used herein.

Key Reference: Michon (1985)

EXAMPLE: An engaged level 2 driving automation system feature performs the lateral and longitudinal vehicle motion control subtasks of the DDT and part of the OEDR subtask, but relies on the driver to complete the OEDR subtask, as well as to manage conspicuity subtasks, such as turning on headlamps. The operating mode consists of the subtasks performed by the driving automation system, while all other subtasks necessary to complete the DDT are performed by the user.

6.2.1 Operating Mode Change

A change in the driving automation system condition, initiated either by the user or by the system, that results in a re-distribution of DDT subtasks between the user and the driving automation system.

6.2.1.1 User-Initiated Mode Change

EXAMPLE: The user of an engaged level 3 feature that performs the complete DDT in dense freeway traffic disengages the system in order to drive more strategically in traffic. The disengagement constitutes a mode change.

6.2.1.2 System-Initiated Mode Change

EXAMPLE: The driver of an vehicle with an engaged level 1 ACC feature set at 70 mph decides to pass another vehicle and overrides the set speed by accelerating to 95 mph; because 95 mph exceeds the ACC design speed range, the ACC system cancels the 70 mph set speed. As a result, when the driver releases the accelerator pedal s/he may expect the vehicle to decelerate to the previously-set 70 mph ACC set speed, but it does not do so. The disengagement of the ACC constitutes a mode change.

6.2.2 Operating Mode Increase

When the operating mode changes such that the number of DDT subtasks the driver is expected to perform decreases.

NOTE: This term applies to level 1 and 2 driving automation system features, as starting with level 3, there are no DDT subtasks performed by a driver (i.e., ADS performs the complete DDT).

NOTE: This term also applies to level 0.

EXAMPLE: An operating mode increase occurs when transitioning from driving with the adaptive cruise control system engaged, where the driver no longer needs to perform the longitudinal vehicle motion control subtask of the DDT, to driving with a traffic jam assist system engaged, where the driver is required to supervise the driving automation system's performance, but no longer needs to perform either the lateral and longitudinal vehicle motion control subtasks of the DDT

6.2.3 Operating Mode Decrease

When the operating mode changes such that the number of DDT subtasks the user is expected to perform increases.

NOTE: An operating mode decrease from levels 3, 4 or 5 to levels 0, 1 or 2 requires that the user seated in the driver's seat transitions from performing no DDT subtasks to performing some or all of them (e.g., transitions from being a fallback-ready user or passenger to being a driver).

EXAMPLE: An operating mode decrease occurs when transitioning from driving with an engaged level 2 traffic jam assist system, where the driver is required to supervise the driving automation system's performance, but no longer needs to perform the lateral and longitudinal vehicle motion control subtasks of the DDT, to driving with just the level 1 adaptive cruise control system engaged, where the driver must now perform the lateral vehicle motion control subtask of the DDT, as well as complete the OEDR subtask while supervising the ACC performance.

6.3 Operating State of a Driving Automation System

A condition of a driving automation system characterized by the particular manner in which it performs part of or all of the DDT on a sustained basis.

NOTE: There can be particular manners of performing part or all of the DDT (i.e., many operating states) within an operating mode, which can vary based on quality and performance. How a driving automation system executes within an operating mode can have implications for a user in terms of their physical response and perception of the driving automation system's performance, including their propensity for use or misuse.

EXAMPLE 1: A level 1 adaptive cruise control system could perform in the following different ways:

- by travelling at a constant speed,
- by reducing speed from a set speed to maintain a constant headway to a slower preceding vehicle, or
- by increasing speed to a set speed when a preceding vehicle, travelling slower than the set speed, changes lanes.

Each of these ways exhibits a manner of performing a portion of the DDT and represents an operating state of the driving automation system.

EXAMPLE 2: A level 1 lane centering system could perform in the following different ways:

- by following the path of a preceding vehicle,
- by detecting lane markers to position the vehicle within the lane, or
- by using highly detailed map information to position the vehicle within the lane.

Each of these ways exhibits a manner of performing a portion of the DDT and represents an operating state of the driving automation system.

EXAMPLE 3: A level 3 traffic jam pilot system could perform in the following different ways:

- by maintaining a vehicle's position within a freeway lane and relative to a lead vehicle, or
- by conducting a passing maneuver (change lanes and overtake a slower moving vehicle).

Each of these ways exhibits a manner of performing the complete DDT and represents an operating state of the ADS.

EXAMPLE 4: A level 4 closed campus shuttle could perform in the following different ways:

- by following other vehicles driving along campus roads,
- by maneuvering independently of a lead vehicle using GPS, digital maps and on-board sensing, or
- by maneuvering within a marshalling yard prior to, or following, dispatch.

Each of these ways exhibits a manner of performing the complete DDT and represents an operating state of the ADS.

6.3.1 Operating State Change

Any change in the driving automation system's condition that alters the particular manner in which it performs part or all of the DDT.

EXAMPLE: An operating state change occurs when a level 3 traffic jam pilot system transitions from following a preceding vehicle (where the system maintains the vehicle's position within the lane) to changing lanes (where the vehicle overtakes a slower lead vehicle).

6.4 Inappropriate Use Countermeasure

A driving automation system function intended to mitigate *inappropriate reliance* on the part of the user.

NOTE 1: User misbehavior countermeasures are not relevant for level 4 and 5 ADSs, which are always capable of achieving a minimal risk condition automatically.

NOTE 2: Countermeasures do not necessarily include detection of driver behavior.

NOTE 3: The expected user role and associated behaviors, varies for different driving automation features (SAE J3016) that operate at different levels; therefore, inappropriate reliance is manifested differently as well.

EXAMPLE 1: A level 2 (SAE J3016) driving automation feature that performs the lateral and longitudinal vehicle motion control subtasks of the DDT is designed to include a countermeasure that detects if the driver has taken their hands off of the steering wheel for more than a specified amount of time and to provide an alert when that time is exceeded in order to prompt the driver to take hold of the steering wheel (and resume supervising the driving automation system feature's performance).

EXAMPLE 2: A level 2 (SAE J3016) feature is designed to include a positional sensor worn in a band on the driver's head. If the sensor determines that the driver's head has turned away from the forward road scene for more than a specified amount of time, a spatially specific (in the driving direction) audible alert is issued to focus the driver's visual attention back to the forward road scene.

EXAMPLE 3: A level 3 (SAE J3016) feature measures biometric indicators of a DDT fallback ready user (SAE J3016) with the intention to determine if the FRU (SAE J3016) is falling asleep. If a measurement indicates the FRU is sleeping, a tactile stimulus is provided with the intention of waking/preventing sleep to maintain receptivity.

EXAMPLE 4: In an ACC system, the icon which depicts the vehicle ahead provides the user confidence, and therefore is an example of countermeasure for under reliance.

6.4.1 Prompting System

Display/alerting subsystem of a *UMAPS* type of *countermeasure* designed to motivate the user to perform his/her role in completing the DDT.

EXAMPLES: See countermeasure examples.

NOTE 1: "Display/alerting" here could refer to any sensory modality, including audible, visual, haptic, or any combination.

NOTE 2: Prompts as part of a *UMAPS* are different than requests to intervene. Prompts are used while the driving automation system feature is operating nominally.

6.5 User State Monitoring (USM)

The process or activity for measuring user behavior.

EXAMPLES: Steering wheel conductance, biometric measures, eye/head tracking.

6.5.1 User Monitoring System (UMS)

Systems that measure some aspect of user behavior as part of a countermeasure.

NOTE: The expected user role and associated behaviors are different for driving automation features that operate at different levels (e.g., 2 or 3); therefore, the behavior measurement design of a user monitoring system may be different.

EXAMPLES: See countermeasure examples.

6.5.2 User Monitoring and Prompting System (UMAPS)

A type of countermeasure that utilizes a user monitoring system to measure some aspect of user behavior, which is compared with a threshold value on that behavior measurement, and, when exceeded provides a prompt designed to correct the user behavior.

EXAMPLES: See countermeasure examples.

NOTE: The expected user role and associated behaviors are different for driving automation features that operate at different levels (e.g., 2 or 3); therefore, the design of a UMAPS may be different.

7. DDT TRANSFER AND OPERATING MODE CHANGE FRAMEWORK AND DEFINITIONS

This framework and accompanying set of definitions is meant to capture the range of operating mode changes that occur within the levels of automation (SAE J3016; 2016) that carry implications for the humans' role. Figure 2 shows the relevant mode changes.

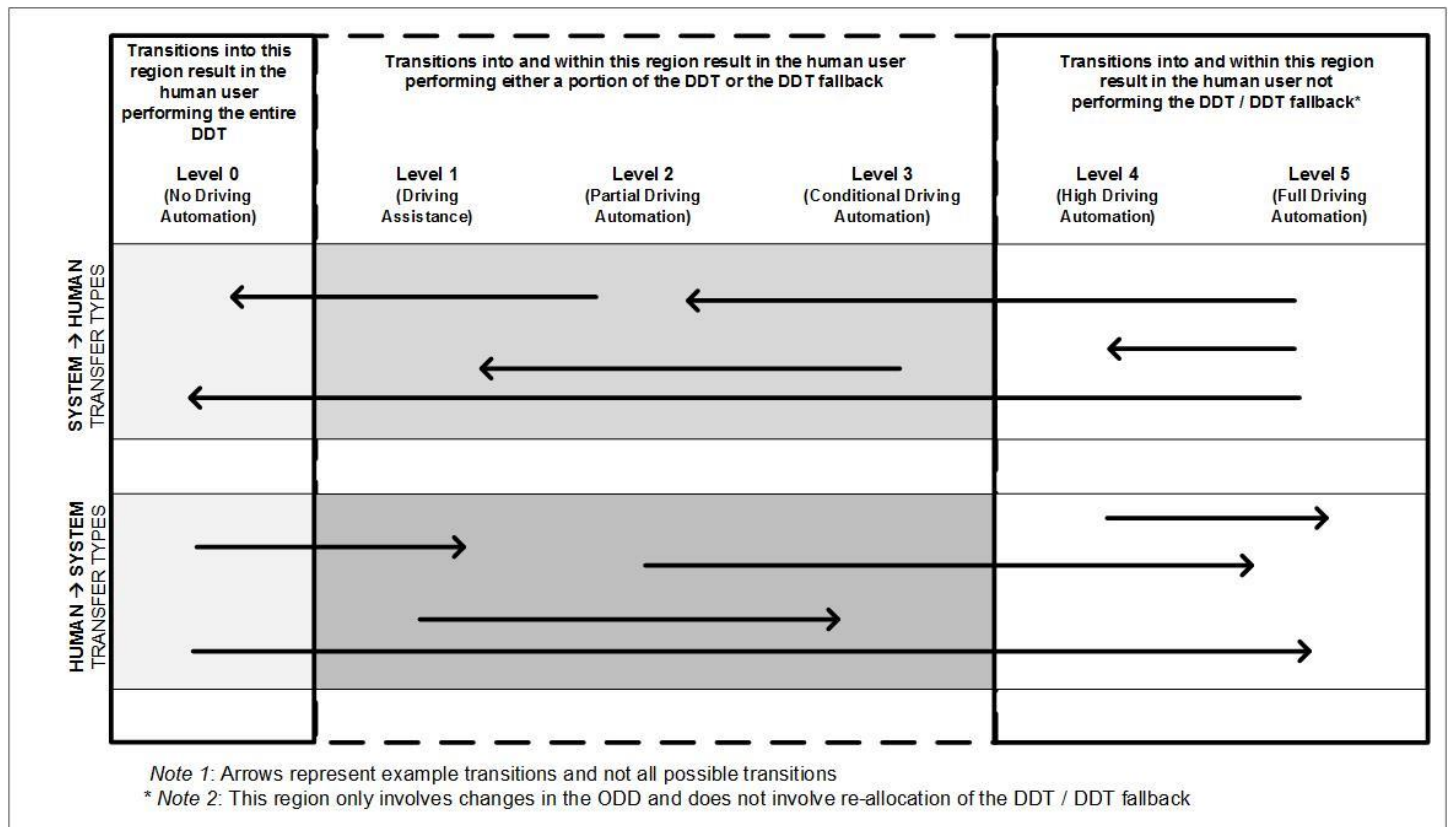


Figure 2 - DDT transfer types

7.1 Transfer Types

There are multiple types of transfers that this Transfer of the complete DDT and/or DDT subtasks Function Framework needs to comprehend; including transfers from lower levels to higher levels and vice versa, as well as transfers initiated by the system or by the human user.

For each of the transfer types shown in Figure 2, the following sequence and set of terms exists.

7.2 Transfer of DDT Function Sequence

This sequence (Figure 3) represents the period of time from when a transfer is initiated, either by the human user or the system, to when stable performance is (re-)established (Seppelt, 2016).

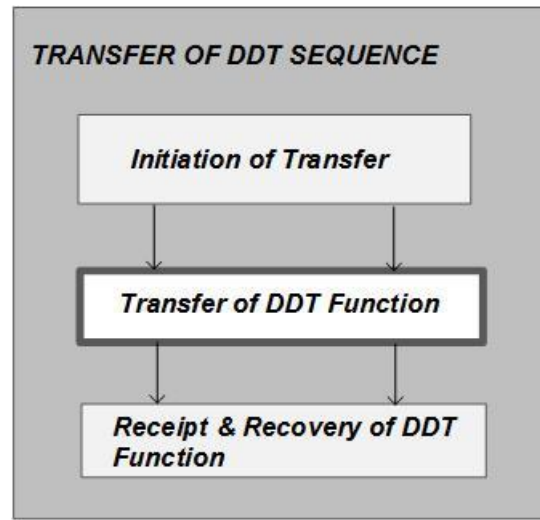


Figure 3 - Transfer of DDT function sequence (Seppelt, 2016)

7.2.1 Initiation of Transfer

Defined as the period from when an event/condition change occurs that induces either a Driver Engagement Prompt or a Request to Intervene as issued by the automation (system→human) or a user-initiated mode switch that transfers to a different level of automation (human→system) until the start of the DDT function transfer. As such, transfers can be of two types: "User-Initiated" or "System-Initiated".

7.2.1.1 Human User-Initiated

The user indicates to the system that a transfer of control is desired either to increase or decrease the level of automation. There are several categories of user-initiated transfers:

NOTE: For automation levels 1 and 2 the driver is responsible for choosing when and where the automation is enabled (i.e., for knowing the operational design domain). For automation levels 3, 4, and 5 the system recognizes its ODD.

7.2.1.1.1 Intended

The user knowingly transfers all or a portion of the dynamic driving task either in response to a system limitation or chooses to as a matter of preference.

7.2.1.1.2 Unintended

The user unknowingly transfers all or a portion of the dynamic driving task.

EXAMPLE: The user unintentionally bumps the steering wheel thereby the lateral vehicle motion control is transferred back to him/her.

7.2.1.1.3 Non-Permitted

The system prevents a transfer of control in the instance that the user attempts to change the level of automated control, but the system deems the human unsafe to take control and does not fulfill the request.

NOTE 1: This may be due to safety or efficiency purposes and is limited to transfers out of levels 4 and 5.

NOTE 2: A transfer would not be permitted in a ride sharing scenario.

7.2.1.1.4 Deferred

The transfer of control occurs a designated amount of time after the request because the system is waiting until it is deemed safe based on condition or on driver readiness.

NOTE 1: This may be due to safety or efficiency purposes and is limited to transfers out of levels 4 and 5.

NOTE 2: User request for initiation of tactical maneuvers (e.g., lane change or changes in mode settings) that are not immediately fulfilled represent delayed State Changes not Deferred Transfers of the DDT.

7.2.1.2 System-Initiated

The system initiates a transfer of control to maintain safe operation or due to approaching functional or operational design domain limits. There are several categories of system-initiated transfers (as written from the perspective of the human's understanding of the system):

7.2.1.2.1 Scheduled

The system initiates an expected transfer of all or a portion of the dynamic driving task based on the operational driving domain or environmental conditions.

EXAMPLE: The system approaches the end of the ODD and informs the human user.

7.2.1.2.2 Imminent

The system initiates an unexpected transfer of all or a portion of the dynamic driving task based on the operational driving domain or environmental conditions.

EXAMPLE: The system detects when a medical emergency is occurring and the system automatically takes control and drives to the hospital.

EXAMPLE: A system has a radar sensor blockage and alerts the driver to take over.

7.2.1.2.3 Nuisance

The system initiates a transfer of all or a portion of the dynamic driving task when it is not wanted for the situation.

EXAMPLE: The system enters its ODD and takes over the complete DDT.

7.2.1.2.4 Request to Intervene (SAE J3016)

Notification by an ADS to a driver indicating that s/he should promptly perform the DDT fallback.

NOTE 1: In the case of a level 3 ADS feature, the request to intervene requires a prompt response by the fallback-ready user whose assigned task is DDT fallback performance.

NOTE 2: In the case of level 4 or 5 ADS feature, because fallback is automated by the system, a prompt response is not needed because the vehicle will reach a minimal risk condition as needed.

7.3 Driver Engagement Prompt

For a level 1 or 2 driving automation feature, a system issued prompt designed to remind the driver to perform his/her subtask(s) as defined by Figure 4.

NOTE: A Driver Engagement Prompt is design dependent and its implementation is at the discretion of the manufacturer.

EXAMPLE: For a particular level 1 lane centering feature the driver is required to periodically provide steering torque to the steering wheel as an indication of their continued supervision of the feature's performance.

7.4 Transfer of DDT Function

The period of time when the transfer switches from one entity to the other (automation → user, or, user → automation) – i.e., the moment of handover.

NOTE: This point demarks the transfer of driving subtasks between the human and the system. Transfer begins at the start of the release of the DDT subtask until the moment when the subtask is taken up by the other entity (e.g., when the driver places their hands on the steering wheel and/or on the brake or accelerator pedal). The set of subtasks that each performs are shown in Figure 4. This figure is distinct from SAE J3016's Levels of Automation in that it shows the division of DDT subtasks that are performed by the human versus those performed by the system at each level. It is drawn to capture, from the perspective of the human in their use of automated systems, the change in subtask responsibility that occurs at the point of transfer.

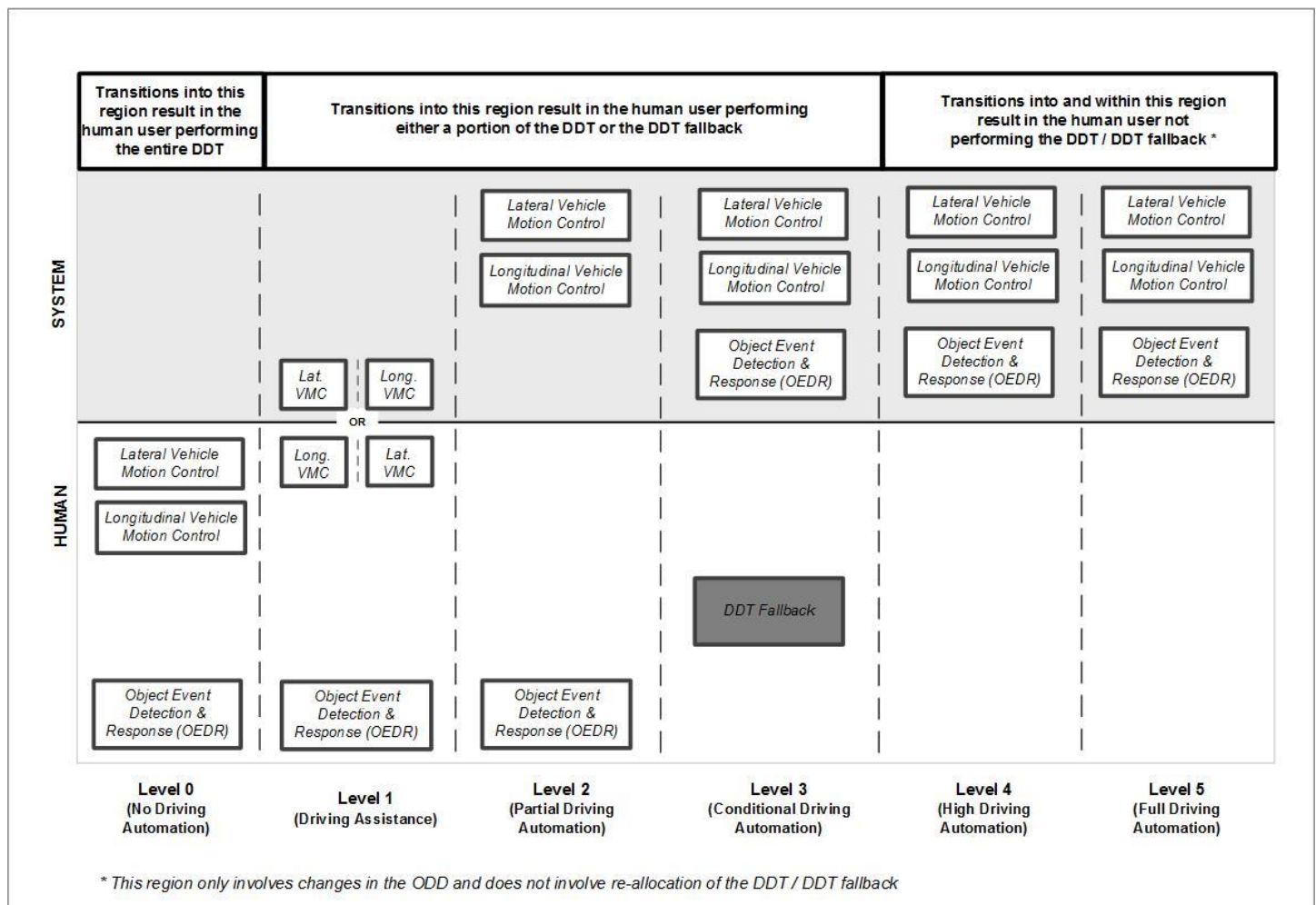


Figure 4 - A diagram of the set of subtasks (white boxes) that are either performed by the human or the system for each level of automation (SAE J3016). 'DDT fallback' (dark grey box) is not a driving subtask, it is a period in time in which the driver temporarily performs subtask(s) of the DDT (white boxes).

Transfer of the DDT Function is of two types: (1) transfer of the DDT (partial), or (2) transfer of the DDT (complete):

7.4.1 Transfer of the DDT (Partial)

The actions taken by driving automation system or a user to re-allocate performance of one or more DDT subtasks from one to the other.

EXAMPLE 1: While driving a vehicle with a level 1 ACC feature engaged, the driver notices that his/her exit is approaching and decides to disengage the ACC by tapping the brake pedal. Disengagement of the ACC by the driver in this example constitutes transfer of the longitudinal vehicle motion control subtask of the DDT from the level 1 driving automation system feature (providing the ACC function) to the driver.

EXAMPLE 2: While driving a vehicle with an engaged level 2 traffic jam assist feature, the driving automation system detects that the lane lines have disappeared to the left of the vehicle and alerts the driver that s/he must resume steering the vehicle (even while the driving automation system continues performing the longitudinal vehicle motion control subtask of the DDT). Resumption of steering by the driver in this example constitutes transfer of the lateral vehicle motion control subtask of the DDT from the level 2 driving automation system feature (providing the traffic jam assist function) to the driver.

NOTE: This term only applies for level 1 and 2 driving automation system features, which perform only part of the DDT when engaged. The reallocation of DDT subtasks between the driver and the driving automation system for level 1 and 2 features may not involve system-issued requests to intervene or coordinated actions on the part of the driving automation system and the driver, as the driver of a vehicle with and engaged level 1 or 2 driving automation system feature is expected to be fully engaged in supervising driving automation.

7.4.2 Transfer of the DDT (Complete)

The coordinated actions taken by an ADS and a user to re-allocate performance of the complete DDT from one to the other.

EXAMPLE 1: As traffic clears in front of a vehicle equipped with an engaged level 3 traffic jam pilot, the ADS issues a request to intervene to the DDT fallback-ready user. S/he responds by applying torque to the steering wheel and pressure to the accelerator pedal (thus transitioning from DDT fallback-ready user to driver); at the same time, the ADS senses the driver's steering and accelerator inputs and ends automation of DDT performance.

EXAMPLE 2: While a vehicle equipped with an engaged level 4 highway pilot is operating as part of a close-coupled, high-speed platoon, the passenger seated in the driver's seat signals his/her wish to resume performance of the DDT. The ADS delays the transfer of the DDT briefly while it communicates with the other platoon partners to enable it to exit the platoon. After safely exiting the platoon, the ADS issues the fallback-ready user in the driver's seat with a request to intervene, and s/he responds by applying torque to the steering wheel and pressure to the accelerator pedal (thus transitioning from passenger to driver); at the same time, the ADS senses the driver's steering and accelerator inputs and ends automation of DDT performance.

NOTE: This term only applies for level 3 through 5 ADS features, which perform the complete DDT when engaged. The incomplete re-allocation of one or more DDT subtasks between a level 1 or 2 driving automation system and a driver does not constitute transfer of the complete DDT (see Transfer of DDT subtasks (partial)).

7.5 Receipt and Recovery of DDT Function

The period of time when stabilized DDT performance is resumed or achieved.

NOTE 1: The initial transfer back to the human user to when the user has achieved full and optimal DDT performance for system → human transfers, or, as the time it takes for the system to achieve steady state when the user transfer control to the automated system (for human → system transfers).

NOTE 2: This does not apply to transfers between levels 4 and 5.

7.5.1 Take-Over Response

The specific, measurable action taken by the human user or the system to partially or fully resume the DDT.

7.6 Examples of DDT Transfers and Operating Mode Changes

A number of transfer types are further defined next that have particular relevance to the AV HF community at present.

7.6.1 Transition of DDT Function Sequence for the Automated Driving to Manual Control (System-Initiated) Transfer Type

The period of time starting from stable automated driving control to when an event/condition or system state prompts the driving automation system to issue a request to intervene to the human until when the human has resumed stable performance of the DDT. There are five phases of this sequence that are meaningful to the human (Figure 5):

7.6.1.1 The initial (or zero) phase – stable performance – is defined as the period of time of sustained automated driving control to when an event/condition or system state induces the need for a request to intervene.

7.6.1.2 The first phase – event/condition or system state change – The first phase is defined from when a system state change occurs until the moment when the system recognizes the need to inform the human

- 7.6.1.3 The second phase – request – is defined from when a request to intervene is issued until the start of the transfer.
- 7.6.1.4 The third phase – transfer – is defined from the start of the release of automated control until the moment when the human user first resumes manual control (e.g., when the driver places their hands on the steering wheel and/or foot on the brake or accelerator pedal).
- 7.6.1.5 The fourth phase – receipt and recovery – is defined from the initial transfer back to human control to when s/he has achieved stable DDT performance.

Transfer of Control Sequence

AD to Manual control

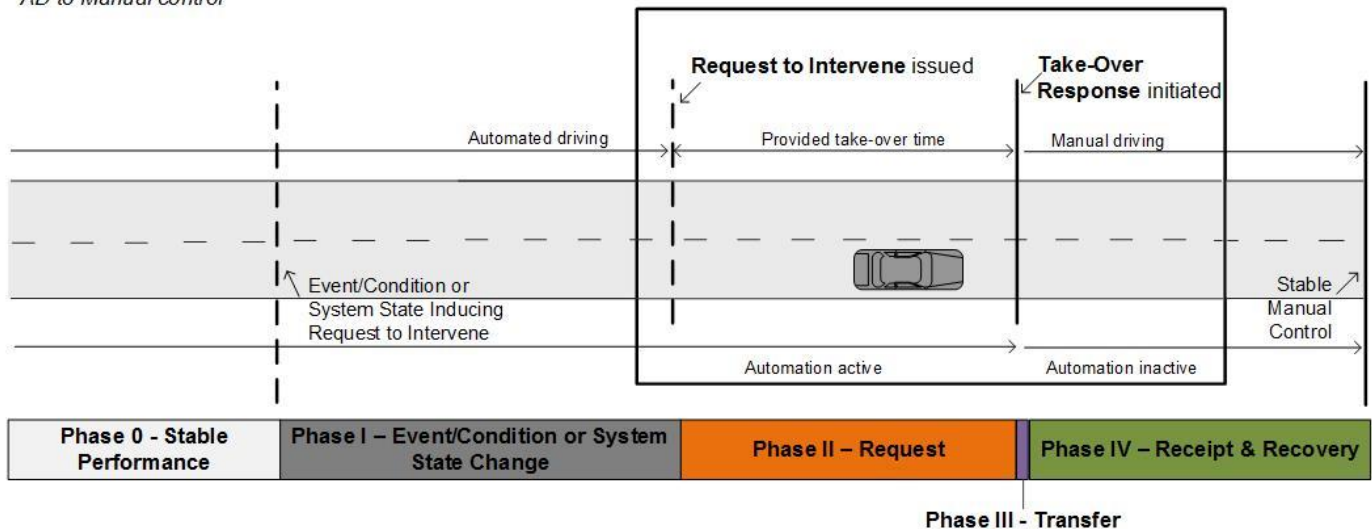


Figure 5 - Transfer of DDT function sequence for automated driving (labeled as “AD”) to manual control (system-initiated) (Seppelt, 2016). This figure is adapted from Seppelt & Victor (2016) and from Damböck et al., 2012a.

7.6.2 Transition of DDT Function Sequence for *Automated Driving to Manual Control* (Driver-Initiated) Transfer Type

The period of time starting from stable automated driving performance to when an event/condition or system state prompts the driver to initiate a take-over response until when the human has resumed stable performance of the DDT. There are four phases of this sequence that are meaningful to the human (Figure 6):

- 7.6.2.1 The initial (or zero) phase – stable performance – is defined as the period of time of sustained, automated driving performance to when an event/condition or system state induces user intent.
- 7.6.2.2 The first phase – change in user intent – is defined from when an event or condition induces a change in user intent until the moment when the user decides to initiate a take-over response.
- 7.6.2.3 The second phase – transfer – is defined from the start of the driver-initiated take-over from automated driving until the moment when the human user resumes manual control (e.g., when the driver places their hands on the steering wheel and/or foot on the brake or accelerator pedal).
- 7.6.2.4 The third phase – receipt and recovery – is defined from the initial transfer back to human control to when s/he has achieved stable DDT performance.