General Safety Regulation - Technical study to assess and develop performance requirements and test protocols for various measures implementing the new General Safety Regulation, for accident avoidance and vehicle occupant, pedestrian and cyclist protection in case of collisions

Driver Availability Monitoring Systems (DAMS)

Final Report

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EXECUTIVE SUMMARY

Introduction

Driver Availability Monitoring Systems (DAMS) for Automated Driving Systems (ADS) (SAE Level 3 and 4) are an integral measure to ensure road safety. A DAMS system must ensure that the driver is available, ready, willing and able to take back control of the vehicle from automated mode safely. The aim of this study was to suggest as many of the DAMS system requirements as feasible and finalise the preliminary list of items that should be covered by requirements and tests in the future DAMS technical annex.

Method

To finalise the potential list of items that will be regulated in relation to the implementation and performance of DAMS for Level 3 and 4 Automated Vehicles within Europe and to establish as many of the DAMS system requirements as possible, TRL undertook the following tasks:

- Expert engagements
- A review of automated driving and driver drowsiness
- A review of secondary task engagement and driver drowsiness
- A review of secondary tasks and takeover performance
- A review of HMI design for automated vehicles
- A review of UNECE guidelines
- Development of a takeover manoeuvre chronogram

Driver drowsiness and automated driving

Automated driving is likely to induce passive fatigue, which has been shown to impair the driver’s driving performance after the takeover and the driver’s perception of their state to drive safely. These findings, along with expert opinions, highlight the importance of monitoring the driver’s level of drowsiness when a Level 3 or 4 ADS is engaged. The engagement in secondary tasks may counteract the onset or at least mitigate some of the negative effects from the induced passive fatigue by increasing the driver’s arousal.

Secondary task engagement

There is limited guidance on what secondary tasks are acceptable and unacceptable when a Level 3 or 4 ADS is engaged. TRL believes the permitted secondary tasks are dependent on two main factors: the traffic rules of the country; and the ADS and DAMS capabilities and limitations, for example, the transition phase, support after the takeover and the driver-facing camera’s field of view.

- Transition phase: Visual and visual-manual secondary tasks have shown to elicit longer reaction times to a takeover request.
- Post-takeover support: When engaged in secondary tasks, the likelihood of the driver not being able to drive safely immediately after the handover increases.
- Driver-facing camera’s field of view: To continuously monitor drowsiness, the driver’s eyes need to be within the camera’s field of view. This restricts the driver’s eye gaze and potentially the ability to perform some secondary tasks.

Takeover manoeuvres

It appears that drivers not performing a secondary task prior to a transition demand generally can respond within 10 s. Similar findings were found when drivers were engaged in handsfree secondary tasks. For secondary tasks requiring a handheld device or item, drivers may need 15 s to react safely.

There is substantial evidence suggesting that driving performance is likely to be impaired after the takeover. This has been attributed to the driver being out-of-the-loop prior to

takeover and having reduced situation awareness. The likelihood of this occurring is increased with the engagement in secondary tasks, specifically those requiring the driver's visual attention, and even more so if the task includes use of a handheld device or item.

HMI

The HMI of ADS must account for a higher and more complex level of interaction and communication between the driver and the system compared to conventional vehicles. Commonality amongst the HMI of DAMS is recommended, as well as the use of multimodal escalating warnings. It is recommended that secondary tasks displayed on the entertainment console should be suspended or deactivated when a transition demand is initiated. While there have been some design principles and recommendations proposed in the literature and standards, further research is required to understand the key design characteristics for Level 3 and Level 4 Automated vehicles.

DAMS system requirements

- DAMS are required to continuously and directly monitor the driver to ensure they are available, ready, willing and able to take over control of the vehicle from automated mode safely.
- DAMS are required to monitor the following driver states: Driver Presence, Wakefulness, Attentiveness, Secondary Task Engagement and Sudden Sickness. If the driver exceeds the threshold for one of these states or does not respond as planned, the system should take appropriate action.
- The transition phase is required to be a minimum of [10] s. The same transition phase is required if handheld secondary tasks are permitted, where a minimum transition phase of [15] s is required for secondary tasks performed on a hand-held device or item.
- The system is required to continue to monitor and support the driver after the transition phase is completed until the driver has regained situation awareness and achieved full longitudinal and lateral control of the vehicle.

The findings from this report were used to refine and update the preliminary list of aspects that should be covered by requirements and tests in the future DAMS technical annex (Annex 1).

1 Introduction

During conditional and highly automated driving (i.e. SAE Level 3 and 4), the role of the driver changes from being in control of the driving task to monitoring the driving task. The change in role has been suggested to reduce the driver's attention and alertness, resulting in a loss of situation awareness and becoming out-of-the-loop (OOTL). Situation awareness can be linked with a driver's consciousness towards the environment, while OOTL is specifically linked with the automation system and arises from a lack of physical control (Endsley, 1995). A driver OOTL or with a lack of situation awareness can result in reduced responses to safety critical events. As such, Driver Availability Monitoring Systems (DAMS), which monitor the driver to ensure that they are safely able to take over control of the vehicle from automated driving, are essential for Level 3 and Level 4 Automated Vehicles. These systems must ensure that the driver is available, ready, willing and able to take back control from the automated mode safely, as well as interact with and alert the driver when necessary.

TRL have been commissioned by the European Commission to support in the development of a draft technical annex suggesting requirements and test procedures for the type-approval of DAMS (SAE Level 3 and 4). The DAMS first interim report highlighted that it is currently not possible to draft a technical annex for DAMS (Huysamen *et al.*, 2020). The reasons for this were the limited information regarding DAMS, the lack of consensus surrounding the requirements and acceptable states for drivers using Level 3 and 4 DAMS, the technological challenges to monitor certain driver states and the limited number of systems on the market.

- The technology to monitor the driver's eyes, face, head and/or body exists. This technology, normally in the form of a driving-facing camera, is one component of the DAMS, where manufacturers are responsible for taking this piece of technology and creating a DAMS with it (i.e. integrating it into the vehicle, developing algorithms to determine the availability and readiness state of the driver, optimising the interaction with the vehicle and driver, interacting with the driver when needed etc); something which manufacturers are still trying to achieve (i.e. many systems are still under development). Because of this TRL was unable to determine how these systems will operate, function and be validated, making the development of a technology neutral regulation challenging.
- There were also several technological limitations identified which prevents the continuous and reliable monitoring of driver drowsiness, cognitive attention and secondary task engagement. These limitations are important to determining whether a driver is available, ready, willing and able to take back control of the vehicle from automated mode.
- There was a lack of consensus about how to define an Automated Driving System (ADS), as well as the human states to be monitored by a DAMS and what states are acceptable and unacceptable during ADS engagement and takeover manoeuvres. These factors dictate the requirements of the system, and as such need to be specified in order to create a regulation. It would also ensure that manufacturers design appropriate and safety critical systems.

Moreover, the DAMS first interim report stated that in order to establish the validation testing and documentation package requirements, the system requirements need to be established first (i.e. based on these). As such, in this phase of the research, TRL aimed to establish as many of the system requirements as feasible, by continuing to gather information on the topics-related to DAMS, specifically those highlighted in the DAMS first interim report (i.e. secondary tasks and takeover manoeuvres). The information gathered from this phase of the research project was also used to refine and update the preliminary list of aspects that should be covered by requirements and tests in the future DAMS technical annex.

2 METHOD

To finalise the potential list of items that will be regulated in relation to the implementation and performance of DAMS for Level 3 and 4 Automated Vehicles within Europe and to establish as many of the DAMS system requirements as possible, TRL undertook the following tasks:

1. Expert engagements
2. A review of automated driving and driver drowsiness
3. A review of secondary task engagement and driver drowsiness
4. A review of secondary tasks and takeover performance
5. A review of HMI design for automated vehicles
6. A review of UNECE guidelines
7. Development of a takeover manoeuvre chronogram

The full details of the methodology may be found in Annex 2.

3 RESULTS

3.1 Expert engagements

TRL engaged with nine experts in the field of driver behaviour and automated driving on topics related to DAMS to assist in the creation of a regulation for these types of systems. Most of the experts recognised the SAE definitions as the most well used industry standard for automated vehicles but suggest that more detail is required with regards to defining ADS. In particular, more information is required about takeovers and the division of responsibility between the driver and the ADS for Level 3 systems. The bullets below highlight the key findings from the expert engagements. The full results can be found in Annex 3.1.

- Role of the driver when the ADS is engaged:
  - Level 3: Some experts believe the driver must remain engaged in the driving task (i.e. secondary tasks are not allowed), whilst others believe constant monitoring is not required (i.e. secondary tasks are allowed).
  - Level 4: All experts believe that drivers can partake in secondary tasks; however, some believe that the driver should have some degree of situation awareness and as such secondary tasks such as sleeping are not seen as appropriate.
- Acceptable and unacceptable driver states:
  - Most experts agree that drivers must have a reasonable level of alertness and attentiveness when a Level 3 or 4 ADS is engaged.
  - Some experts state that certain levels of visual and cognitive distraction could be acceptable and beneficial in enabling the driver to avoid cognitive underload during automated driving.
  - Most of the experts deem drowsiness/fatigue, low levels of attention, and impairment from substances to be unacceptable driver states for Level 3.
- Below are the most commonly reported characteristics to describe an available, ready, able and willing driver:
  - The driver is alert (i.e. not drowsy) and/or awake (i.e. not sleeping) during the engagement of the ADS.
  - The driver is situationally aware of the driving task and environment, and/or attentive to the driving task during the takeover, where some also stated when the ADS is engaged.
  - The driver is present in the driver’s seat throughout the Dynamic Driving Task (DDT).
  - The driver is not engaged in a secondary task or is not distracted during a takeover, where some also stated when the ADS is engaged.
  - The driver is able to fulfil the re-engagement actions of the system (e.g. hands on wheel and engaging the pedals) or provide input by, for example, pressing a button to confirm they are willing to resume control.
- Takeovers:
  - Timeframes reportedly required for takeovers varied from 5 seconds to 20 seconds
  - Most experts also stated that the type of secondary task would have an effect on takeover time based on the physical and cognitive demand of the task.

  - Majority of experts commented that continuous monitoring of the driver is important, specifically before and after the transitional takeover period to ensure the driver is in a safe state to take over control of the vehicle.
  - The following factors were reported to negatively affect driving performance after a takeover: type of secondary task (e.g. high visual and cognitive attention), degree of situation awareness before the takeover, and if the driving environment has changed after the takeover.
- DAMS validation testing:
  - Testing DAMS with a range of ethnicities, nationalities and genders was recommended by most experts.
  - According to experts, simulators are effective at monitoring certain human states such as drowsiness in a controlled and safe environment, while real-road or test track environments allow for high fidelity testing.
  - Concern was expressed between some experts over the different driver behaviours and lower levels of risk perception experienced by driver's in a simulator versus on real roads or on a test track.
  - Testing the system sensitivity and specificity was recommended by a number of experts.

3.2 Literature review

This section of the report highlights the main findings from the literature review. The full results are detailed in Annex 3.2 of this report.

3.2.1 Driver drowsiness and automated driving

The evidence in the literature suggests that automated driving is likely to induce passive fatigue in driver's due to cognitive underload (i.e. several studies found driver drowsiness to be higher and task demand to be lower during automated driving compared to manual driving) (Kudinger *et al.*, 2018;Saxby *et al.*, 2013;Schömig *et al.*, 2015;Kaduk *et al.*, 2020;Goncalves *et al.*, 2016;Cunningham and Regan, 2017). This is due to the role of the driver changing from being in control of the driving task to monitoring the driving task. It is suggested that the negative effect of automated driving on driver drowsiness may impair driving performance after a takeover, as well as impair the driver's perception of their state to drive safely. There is evidence to suggest that engagement in a secondary task could act as a countermeasure against driver drowsiness induced by passive fatigue or at least mitigate some of the negative effects by increasing the driver's arousal.

3.2.2 Takeover times and driving performance

Drivers are more likely to engage in non-driving tasks with increasing levels of automation, where smartphone use is the most common task adopted followed by a reading task. Engaging in a non-driving task is likely due to drivers trying to increase their arousal levels or fight boredom. Evidence suggests that drivers may change their environment to suit the non-driving task adopted such as moving the seat backwards to accommodate a laptop or swapping driving glasses for glasses they use to read or watch TV. With automated driving experience, the driver's level of trust with the ADS increases. This results in the driver gazing less at the road when the ADS is engaged.

The research undertaken in this part of the research project confirms that drivers are likely to take longer to respond to a takeover request when engaged in a secondary task prior to the takeover request, especially for visual and visual-manual demanding tasks. The lengthened duration is attributed to factors such as a lack of situation awareness caused by being engaged in another task and needing to place handheld items in a safe place prior to responding to the takeover request.

The reaction times to takeover request in the literature commonly provide the mean reaction time only, where some also report the 95th percentile data. Majority of the studies investigating the driver's reaction time to a takeover request are performed in a driving simulator, where there is a limited amount conducted on real roads. From the papers reviewed, the mean reaction times, including papers investigating the effects of secondary task engagement, were less than 10 s. Seven of the papers reviewed reported the 95th percentile reaction time, where four of these reported reaction times greater than 10 s. This was likely attributed to the following factors: alert type being only visual in nature (Naujoks *et al.*, 2014), providing the driver with up to 30 s to respond (Payre *et al.*, 2016), reducing the takeover urgency (Eriksson and Stanton, 2017)and the secondary task being visual-manual in nature (i.e. reading task) (Eriksson and Stanton, 2017;Naujoks *et al.*, 2019) (please refer to Section Annex 3.2.2 for more details). There is insufficient reporting of the 95th percentile reaction time data in the literature. This data is important to understand the amount of time the driving population requires to takeover safely. This is especially the case for secondary tasks, particularly for visual and visual-manual task which have shown to elicit longer reaction times. For example, Kuehn *et al*. (2017) reports that when engaged in a reading task, participants take on average 7-8 s to switch off the ADS. It would be beneficial for the authors to report the 95th percentile reaction times as it may be similar to (Naujoks *et al.*, 2019) which reported a 95th percentile reaction time greater than 10 s for a reading task.

Another important factor to consider is the time to first glance at the mirrors and speedometer. Evidence suggests that driver may be able to react quickly to a takeover request but require more time to become situationally aware. For example, Keuhn *et al.* (2017) reported that it takes drivers up to 15 s to glance at the mirrors and speedometer when performing a secondary task. Vogelpohl *et al*. (2018) found that the first glance to the mirrors took on average 5.57 s, 7.01 s and 7.80 s (SD: 3.34 s, 2.85 s, 2.56 s) when engaged in no task, a reading, and a gaming task respectively prior to the takeover and 6.31 s, 9.33 s and 10.42 s to glance at the speedometer (SD: 4.48 s, 4.44 s, 5.56 s). The standard deviation values reported by Vogelpohl *et al.* (2018) are large, suggesting the 95th percentile times may be greater than 10 s for all conditions highlighted above, emphasizing the need for the 95th percentile data to be reported. These two studies suggest that drivers may need more than 10 s to become situationally aware of the DDT and driving environment.

The concept of reduced situation awareness induced by automated driving, particularly when a secondary task is being performed, is further supported by the evidence suggesting that drivers gaze less at the road when the ADS is engaged, especially when performing a visually demanding task, and gaze at their feet during the takeover to ensure they are in the correct position. Furthermore, there is substantial evidence suggesting that driving performance is likely to be impaired after a takeover request especially if a non-driving task or secondary task is performed prior to the takeover. The impairment, resulting in, for example, lane excursions and speed variability, is attributed to the driver's low level of attention to the DDT and road scene (i.e. situation awareness). It appears visual and visual-manual tasks result in the greatest driving performance impairments after the takeover.

It has been suggested that the driver's situation awareness can be improved or maintained by encouraging the driver to divert their attention to the DDT and roadway a number of time whilst the ADS is engaged. For example, divide their attention appropriately between the driving task, including monitoring of the roadway, and a secondary task.

3.2.3 HMI of DAMS

The human-machine interface (HMI) of an ADS is of vital importance as it acts as the point of communication between the ADS and the driver. The HMI design of an ADS must account for a higher level of interaction between the driver and the system than that of other driver assistance or warning systems. This interaction is more complex with ADS due to the changing responsibilities of the driver between partial or full control of the vehicle and the required two-way communication. The HMI must be designed to provide adaptable and relevant information to the driver to ensure appropriate and safe control of the vehicle during different levels of automation. While a number of studies recommend several principles to consider for HMI, it is clear that more research is required to understand the key design characteristics. The bullets below highlight some of the key design principals identified in the literature:

- To reduce the risk of operator errors such as mode confusion, commonality amongst manufacturers HMIs is recommended. This includes standardising the functional logic, transition of control and control elements of the HMI.
- To ensure mode awareness, it is recommended to display the automation status to the driver.
- To reduce the risk of a driver not responding appropriately or in time, multi-modal warnings are recommended for the transition demand, with a minimum of visual and audio feedback:
    - Visual feedback to communicate automation status and display information to help drivers regain situation awareness (e.g. to alert the driver to an area in the environment where a hazard is located).
    - Audio feedback to alert the driver to a warning using tones or messages.
- It is recommended that staged warnings, with escalating tones to highlight urgency, should be used to assist the driver in recognising and responding to a warning.
- An adaptive HMI to support the driver as they build trust in the system should be considered.

3.3 UNECE guidance on secondary tasks

The UNECE have two working groups that have addressed the use of secondary activities whilst the ADS of a Level 3 and 4 Automated Vehicle is engaged:

- The Global Forum for Road Traffic (WP.1)
- The World Forum for Harmonisation of Vehicle Regulations (WP.29)

Both groups agree that secondary activities can be performed by a driver when a Level 3 or 4 ADS is engaged, so long as the secondary task does not interfere with the safe resumption of control when a takeover request is initiated. Both also recommend that secondary activities displayed via the vehicle infotainment system should be suspended or deactivated when a takeover request is issued. More stringent advice is given for Level 3 Automated Vehicles versus Level 4 Automated Vehicles due to Level 3 ADS incorporating unplanned takeovers.

The Global Forum for Road Traffic (WP.1) developed a framework comprising four criteria which driver's need to adhere to in order to engage in tasks unrelated to driving when the ADS is engaged:

- The activities conducted must not prevent the driver from being able to respond to any manual take-over demand that is received from the vehicle;
- The activities must align with the prescribed use of vehicle systems and their pre-defined functions;
- The driver must continue to abide by any traffic laws that apply including the secondary activities that are permitted; and
- The driver must still have the required capabilities to meet their duties during automated and manual driving.

For a more in-depth explanation of each criterion, please refer to Annex 3.3.

The working group further states that manufacturers should provide the driver with information regarding their role and responsibilities, as well as expected behaviour during the takeover. It recommended that member states should develop regulations surrounding the engagement in non-driving related activities whilst the ADS is engaged, where drivers should familiarise themselves with these to ensure compliance. An informal document published by WP.1 gathered thoughts about acceptable secondary tasks during ADS engagement. There was a lack of consensus between countries, which will potentially result in different rules and regulations being developed, which further creates challenges for the development of the DAMS regulation; for example, Spain will allow the use of a mobile phone, where UK currently will not.

A full detail of the results can be found in Annex 3.3.

3.4 Definitions

To ensure consistency amongst standards and guidelines, the terms and definitions used in this report are aligned with the SAE guidelines and ALKS regulation (SAE:J3016, 2018;UN, 2020).

- Automated Driving System (ADS): The hardware and software that are collectively capable of performing part or all of the DDT on a sustained basis for Level 3-5 systems.
- Dynamic Driving Task (DDT): All of the real-time operational and tactical functions required to operate a vehicle in on-road traffic, excluding the strategic functions such as trip scheduling and selection of destinations and waypoints, and including without limitation: object and event detection, recognition, and classification; object and event response; manoeuvre planning; steering, turning, lane keeping, and lane changing, including providing the appropriate signal for the lane change or turn manoeuvre; and acceleration and deceleration etc.
- Operational Design Domain (ODD): Operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics.
- Minimal Risk Manoeuvre: a manoeuvre performed by the system after the end of a transition phase as risk mitigation strategy in case the human driver has not resumed manual control of the vehicle.
- DDT Fallback: The response by the user to either perform the DDT or achieve a minimal risk manoeuvre after occurrence of a DDT performance-relevant system failure(s) or upon ODD exit.
- Automated DDT Fallback and Automated Risk Manoeuvre (Level 4 only): The ADS performs the DDT fallback and transitions automatically to a minimal risk manoeuvre when:
    - A DDT performance-relevant system failure occurs,
    - A user does not respond to a request to intervene, or
    - A user requests that it achieve a minimal risk manoeuvre.
- Transition Demand: a logical and intuitive procedure to transfer the dynamic driving task from automated control by the system to human driver control. This request given from the system to the human driver indicates the transition phase.
- Transition Phase: the duration of the transition demand
- Override: an action of the user providing intentional input to control elements of the vehicle which have priority over the longitudinal or lateral movement of the vehicle, while the system is still active.

4 DISCUSSION

Results from DAMS first interim report have been integrated in this report to form the following discussion (Huysamen *et al.*, 2020).

4.1 Readiness of DAMS

TRL believes it is not yet feasible to develop a regulation for the type-approval of DAMS for Level 3 and 4 Automated Vehicles (Huysamen *et al.*, 2020). One of the reasons for this is the lack of consensus amongst standards, guidance documents, stakeholders and academic research on the requirements and acceptable states for drivers using Level 3 and Level 4 DAMS. This lack of consensus was also noted amongst the experts, where opinions on the role of the driver (specifically for Level 3 Automated Vehicles) and acceptable states when the ADS is engaged, as well as safe transition times, differed. These findings emphasize the need for the levels of automation and the way in which an ADS is defined, as well as the role of the driver when the ADS is engaged, to be specified and standardised for application in vehicle safety legislation. According to the experts, clarification is particularly needed around takeovers and the responsibility between the driver and a Level 3 ADS.

4.2 Available, ready, able and willing driver

In the DAMS first interim report, TRL proposed that the following five states could indirectly infer whether a driver is available, ready, able and willing to take back control of the vehicle from automated mode safely (Huysamen *et al.*, 2020):

- Presence: The driver’s presence in the driver’s seat
- Wakefulness: The driver’s state of consciousness
- Attentiveness: The driver’s state of attention and readiness to resume the driving task
- Secondary Task Engagement: The driver’s engagement with a secondary task
- Sudden sickness: The driver’s state of health

The experts engaged in this study agreed with these five states, commonly describing an available, ready, willing and able driver as being:

- Present and alert/awake throughout the DDT,
- Situationally aware, attentive and undistracted during a takeover (and in some cases during ADS engagement), and
- Able to fulfil the reengagement actions of the system.

The findings from the expert engagement verify that Presence, Wakefulness, Attentiveness, Secondary Task Engagement and Sudden Sickness, should be the states monitored by a DAMS to determine whether a driver is in a position to resume the driving task safely.

4.3 Driver drowsiness and automated driving

TRL previously reported that “the driver should not be allowed to take back control of the vehicle if their drowsiness level is not within safe limits due to the well-established knowledge regarding the negative effects of drowsiness on human performance and road safety” (Huysamen *et al.*, 2020). This was corroborated by most experts who deem drowsiness / fatigue to be unacceptable driver states, particularly when a Level 3 ADS is engaged. Moreover, the evidence from the literature suggests that automated driving is likely to induce passive fatigue, which has been shown to impair the driver’s driving performance after the takeover and the driver’s perception of their state to drive safely. The findings from this study further highlight the importance of ensuring the driver is sufficiently alert to resume control of the vehicle and for DAMS to monitor the driver's level of drowsiness when a Level 3 and 4 ADS is engaged.

Currently, it is challenging to monitor the driver's level of drowsiness continuously whilst the ADS is engaged. This is mainly because the driver's eyes need to be within the driver-facing camera's field of view, meaning the driver's gaze will be restricted to a specific area reducing their glancing freedom and, if permitted, ability to perform some secondary tasks. The restricted visual area will be dependent on the field of view size of the driver-facing camera. This can be increased by a better-quality camera or by having more than one camera. Moreover, the location of the camera in the vehicle will also have an impact (i.e. the ability to monitor head position and movement is dependent on camera location). If a driver-facing camera is utilised to monitor driver drowsiness, the secondary tasks that the driver will be able to perform will likely depend on the camera's field of view. For example, the camera may not be able to monitor the eyes when the driver is gazing downwards to read a book.

4.4 Secondary task engagement

UNECE WP.1 and WP.29, and some experts, agree that secondary activities can be performed by the driver when a Level 3 or 4 ADS engaged, so long as the secondary task does not interfere with the safe resumption of control. In contrast, for Level 3, some experts believe that when the ADS is engaged, the driver should remain engaged in the driving task (i.e. secondary tasks are not allowed). However, evidence in the literature suggests that this may induce passive fatigue, where engagement in a secondary task may counteract the onset or at least mitigate some of the negative effects by increasing the driver's arousal. This finding was supported by some experts who believe certain levels of visual and cognitive distraction could be beneficial in enabling the driver to avoid cognitive underload experienced during automated driving.

Collating these findings with those of the DAMS first interim report, it appears that there is general acceptance surrounding the engagement in secondary tasks when a Level 3 or 4 ADS is engaged. This is particularly the case for Level 4 Automated Vehicles as they incorporate only planned takeovers (no unplanned takeovers). However, there is no guidance on what secondary tasks are permitted or allowed when a Level 3 or 4 ADS is engaged. The only guidance available is the framework developed by UNECE WP.1, which comprises four criteria which driver's need to adhere to in order to engage in tasks unrelated to driving when the ADS is engaged (Section 3.3).

TRL believes the permitted secondary tasks are dependent on two main factors: the traffic laws of the country and the system's capabilities and limitations. The UNECE recommends member states to develop rules and regulations on the engagement in non-driving related activities whilst the ADS is engaged. Early evidence suggests that these rules and regulations are likely to differ, where manufacturers and drivers need to be familiar with these rules, in order to adhere and abide by them. For example, Spain suggests they will allow the use of mobile phones, whereas the UK currently will not permit this activity.

With regards to the system's capabilities and limitations, evidence from the literature, as well as from stakeholders and experts, suggests that secondary task type is dependent on factors such as the transition phase, support after the takeover, and the camera's field of view (i.e. continuous monitoring of driver drowsiness; see Section 4.3 for more information). When a driver is engaged in a secondary task, their situation awareness is reduced. The lack of attention to the driving task and environment results in the driver responding more slowly to takeover requests and increases the likelihood of the driver not being able to drive safely after the handover. Visual and visual-manual secondary tasks have been shown to elicit longer reaction times to a takeover request and greater driving performance decrements after a takeover compared to an auditory task and no task. When engaged in a visual task, drivers tend to gaze less at the road (i.e. visual attention is fully engaged in the secondary task). This behaviour impairs their situation awareness of the DDT and environment, which in turn negatively effects their takeover time and driving performance. This is exacerbated by a visual-manual task being conducted on a hand-held device or item, because the driver needs to place the item down prior to initiating the re-engagement process.

In order for a driver to be able to perform secondary tasks when the ADS is engaged, the system must be able to provide the driver with sufficient time to takeover safely and support after the takeover until they have reached full, stable control of the vehicle (see Section 4.5). If the system is unable to provide this, it is recommended, for safety purposes, that the driver should not be allowed to perform secondary tasks. It is highly possible that some systems will be able to provide a transition phase for some secondary tasks, but not for others. For example, a system may be able to provide a safe transition phase for an auditory task and a visual task, but, due to system limitations, is unable to provide a longer transition phase for hand-held visual-manual tasks. In this example, hand-held visual-manual tasks will be deemed unacceptable and the driver may only perform handsfree tasks.

It was noted that when drivers are engaged in a secondary task, they may change their environment to suit the secondary task adopted. This includes changing the position of the seat into a more relaxing position or to accommodate devices such as laptops. Due to the unplanned nature of Level 3 takeover manoeuvres, the driver should not be allowed to adjust or reposition their seat (because they are required to take back control of the vehicle at any given time). Whereas for Level 4, which does not have unplanned takeovers, the driver may be allowed to adjust their seat so long as the driver is not handed back control of the vehicle when the seat is not confirmed as being in the driving/original position. Another factor to consider is driving glasses, as evidence suggests that a driver may remove these when the ADS is engaged and may switch these for reading glasses if engaged in a secondary task. For road safety purposes, the driver should not be allowed to take back control of the vehicle if they are not wearing their prescribed driving glasses. Whether or not technology is sufficiently robust to monitor this and ensure the driver is wearing their prescribed glasses prior to the resumption of control is currently unknown and requires further research and engagements.

4.5 Takeover manoeuvres

The majority of papers report the mean reaction time to a takeover request. Basing the time for the transition phase off this data is risky as it excludes a large portion of the driving population. It is recommended that the minimum time for the transition phase is based on the 95th percentile reaction time instead (i.e. includes the wider driving population). However, there are limited papers that report this data making it challenging to establish this minimum performance requirement.

From the literature reviewed, it appears that on average drivers are able to respond to a takeover request in less than 10 s, even when performing a secondary task. Generally, a driver is able to react quickest when not performing a secondary task, which is followed by performing an auditory task and then by a visual task, where a visual-manual task seems to elicit the slowest reaction times. Although limited, the evidence suggests that the 95th percentile driving population engaged in a visual-manual task using a handheld item, such as reading a book or using a mobile phone, may need more than 10 s to respond safely. Thus, if the ADS is unable to provide the driver with more than 10 s to respond, for safety reasons, it is recommended that the driver is prohibited from performing visual-manual tasks on or with handheld items. If the system is able to provide the driver with 10s, handsfree secondary tasks may be able to be performed by the driver. If the ADS is able to provide the driver with a very long transition time such as one minute (i.e. planned takeovers), a number of secondary tasks may be allowed. It is also recommended that manufacturers adhere to the framework developed by the Global Forum for Road Safety (WP.1) UNECE working group for secondary activities whilst the ADS is engaged (see Section 3.3).

There is substantial evidence suggesting that driving performance is likely to be impaired after the takeover. This has been attributed to the driver being OOTL and having reduced situation awareness: drivers are able to respond to a takeover request relatively quickly but require more time to become situationally aware. The likelihood of this occurring is increased with the engagement in secondary tasks, specifically those requiring the driver's visual attention, and even more so if the task comprises of a handheld device or item. TRL believes, along with Thatcham, that for road safety purposes, irrespective of whether the driver is performing a secondary task or not, the ADS should support the driver post-handover until they have regained situation awareness and have reached full stable control of the vehicle (i.e. lateral and longitudinal stability). This is especially the case for unplanned takeover which provide minimal warning.

The stakeholders suggested that vehicles are equipped with ADAS, and as such, in their opinion, will assist the driver whilst they regain situation awareness and full manual control of the vehicle. TRL investigated this further by engaging with internal experts who stated that, based on the minimum requirements of some ADAS, this is not a feasible option. For example, the minimum requirements for ELKS states that the system will intervene if the vehicle were to exit over a solid white line, but only provide a warning to the driver if they were to exit the lane over a dashed white line. The evidence from this study suggests, that after the handover of control, the driver is at higher risk of lane excursions. If these excursions occur on the motorway, the minimum requirements of ELKS will not stop the driver from exiting the lane.

4.6 Interaction between DAMS specification and ADS specification

The type of secondary task that the driver can or cannot engage in whilst the ADS is engaged is dependent on the transition phase of the system. For example, if the ADS is able to provide a 15 s transition phase, the driver can perform secondary tasks on handheld items / devices, whereas if the ADS is able to provide a 10 s transition phase, the driver can only perform handsfree secondary tasks. Thus, the DAMS specifications for Secondary Task Engagement is dependent on the ADS specification for the Transition Phase.

4.7 HMI

HMI strategies for conventional vehicles are not sufficient and always applicable for the HMI for ADS. This is because the HMI of ADS must account for a higher and more complex level of interaction and communication between the driver and the system. The HMI is a vital component of the ADS. If the system is not interacting with the driver in an appropriate manner or not informing them of relevant information effectively, the driver may not respond appropriately or efficiently.

Operator errors were highlighted as a great concern in the literature. To mitigate these errors, it is recommended that there is commonality amongst manufacturers HMIs. This includes the standardisation of functional logic (how the ADS interacts with the user), the transitions of control elements (drivers' understanding of the allocation of control) and the control elements (deactivating the ADS through physical input). The ALKS regulation and ISO standards state that the symbol for a transition demand shall compromise a steering wheel and hands, where the ISO recommends keeping coherence with other symbols that are already published (i.e. ALKS regulation).

ALKS regulation states the following information should be provided to the driver whilst the ADS is engaged: status of the system, any system failures, a transition demand, a minimum risk manoeuvre and an emergency manoeuvre. The literature confirms the importance of displaying automation status, as this has proven to mitigate mode confusion. Thatcham adds that the status of the driver should be displayed, and strong visual cues of driver role should also be provided. ALKS and ISO recommend that the interface should be easily perceivable from the driver's peripheral field of view and located near to the driver's direct line of sight to outside the front of the vehicle. Further, the ALKS regulation, Thatcham and ISO all state that the interface shall be intuitive and unambiguous.

Thatcham and ISO also state that the display should be distinguishable from other displays in the vehicle (e.g. driving assistance).

It is clear from the ALKS, ISO, Thatcham, stakeholders and literature that during a takeover, the warning should escalate to reflect the urgency. Further, ALKS and ISO state that the alert type should change characteristics at the start of a minimum risk manoeuvre to indicate an urgent action to the driver (e.g. red flashing). According to the literature a staged warning with escalating tones to highlight urgency should be used to assist the driver in recognising and responding to a warning. Thatcham recommend that for a planned takeover, the driver should be presented with information about the warning prior to the handover warning, where a countdown warning is recommended.

Multi-modal warnings are recommended for a transition demand in the literature and in the ALKS regulation. The literature recommends a minimum of visual feedback (to communicate automation status and display information to help drivers regain situation awareness e.g. highlighting hazards or important areas such as mirrors) and audio feedback (to alert the driver to a warning using tones or messages), where ALKS recommends at least an optical and an acoustic and/or haptic warning signal. Stakeholders suggest that a unimodal or multimodal warning should be used depending on the information being provided to the driver, while the literature indicates that the type of modality should depend on the environment and the urgency of the message. The ALKS regulation also requires a multimodal warning for a minimum risk manoeuvre, whereas at least an optical warning is required for system failures and emergency manoeuvres. Depending on the type of optical warning (this includes tone or verbal audio warnings), the latter may be insufficient for the driver to understand what the ADS is alerting or doing, which may result in confusion and panic. This emphasises the need for the HMI to display the role of the driver via strong visual cues as suggested by Thatcham.

It is recommended that when a takeover request is issued, secondary tasks that are displayed via the infotainment system should be suspended or deactivated to improve takeover performance. This advice from the UNECE working group: 'The World Forum for Harmonization of Vehicle Regulation (W.29)', is more stringent for Level 3 than Level 4 Automated Vehicles due to Level 3 comprising of unplanned takeovers. According to the literature, an adaptive HMI should also be considered to adjust the level of information a driver receives from the system based on the degree of trust the driver has in the ADS.

As stated in the first interim report, the ADS and DAMS system requirements need to be established before HMI requirements can be established, as these requirements dictate the design and behaviour of the interface (e.g. the information and types of warnings that could be presented). While there have been some design principles and recommendations proposed in the literature and standards, further research is required to understand the key design characteristics for Level 3 and Level 4 Automated vehicles.

4.8 Developing system requirements and type-approval test considerations

The sections below discuss and highlight some of the potential system requirements for DAMS. These, along with aspects that should be considered for the validation testing, were included into the 'Preliminary list of items that should be covered by requirements and tests in the future DAMS regulation', created in the first DAMS interim report (Annex 1).

4.8.1 Driver monitoring

The DAMS shall detect whether the driver is present in the driver's seat, sufficiently alert to perform the driving task, ready and willing to take over control of the vehicle and engaged in a task unrelated to driving.

4.8.1.1 Driver presence

In order to activate a Level 3 or 4 ADS, the driver needs to be in the driver's seat. Due to road safety rules, once the system is activated, the driver is not allowed to remove themselves from the driving seat or unbuckle their safety belt. To ensure compliance with these rules, the DAMS should monitor these aspects whilst the ADS is engaged and if the driver does not comply (e.g. remove their safety belt), the system should take appropriate action. Moreover, the DAMS should also monitor the driver's seat position. There is evidence to suggest that when the ADS is engaged, drivers may adjust or reposition their seating position to be more comfortable or to accommodate a secondary task (e.g. moving the seat backwards) (Burnett *et al*., 2019). This is a concern for Level 3 Automated Vehicles due to the limited takeover time. For example, if the driver is unable to move the seat back to its original position in time, the ADS will perform a minimum risk manoeuvre. To avoid this, rather than moving the seat back to the original position, the driver may bring themselves forward to the edge of the seat, which is unsafe. Alternatively, they may be able to respond in time, but lack the situation awareness to resume control safely. Therefore, TRL believes the driver's seat position should not be altered in anyway whilst a Level 3 ADS is engaged. For a Level 4 automated vehicle, this may not be the case as takeovers are planned. However, the system should still be able to determine if the seating position has been adjusted and ensure that it is returned to its original position prior to the driver taking back control of the vehicle.

Taking the above into account, TRL recommends the following three requirements be established for Driver Presence:

- The driver shall be present in the driver's seat throughout the engagement of a Level 3 or 4 ADS.
- The driver's seatbelt shall remain buckled throughout the engagement of a Level 3 or 4 ADS.
- Seat position:
    - Level 3: The driver's seat position shall not be significantly altered or adjusted throughout the engagement of the ADS.
    - Level 4: The driver's seat position can be significantly altered or adjusted whilst the ADS is engaged. If this occurs, the ADS shall ensure the driver's seat position is returned to the driving position prior to the manual resumption of control.

Each of these requirements needs to be met for the driver to be deemed present and in a position to take back control of the vehicle safely. If any one of these requirements is not met, the system should take appropriate action, such as:

- Level 3:
    - If the driver is no longer seated in the driver seat, the system should perform a minimum risk manoeuvre.
    - If the driver's seatbelt is unbuckled or the position of the seat adjusted to an unacceptable position, the system may initially alert the driver to correct this. If this is not corrected in a yet-to-be-determined time frame, the system should perform a minimum risk manoeuvre.
    - If the driver significantly alters or adjusts their seat position, the system should warn the driver that this is unacceptable and request them to return the seat to an acceptable position. If the driver does not respond appropriately to the warning, the ADS should perform a minimum risk manoeuvre.

- Level 4:
  - If the driver is no longer seated in the driver seat, the system shall perform the automated DDT fallback and automated minimum risk manoeuvre[1].
  - If the driver's seatbelt is unbuckled, the system may initially alert the driver to correct this. If this is not corrected in a yet-to-be-determined time frame, the system shall perform the automated DDT fallback and automated minimum risk manoeuvre.
  - If the driver does not adhere to the request from the system to return the driver's seat position back to the driving position, the system should not allow the driver to take back manual control and the ADS should either:
    - Continue with the DDT, or
    - Perform the automated fallback and minimum risk manoeuvre if it is reaching the limits of its ODDs.

4.8.1.2 Wakefulness

TRL believes that the driver's level of drowsiness should be continuously monitored throughout the duration of Level 3 or 4 ADS engagement, where the system should not hand back control of the vehicle to the driver if they are too drowsy to drive safely. As agreed with the customer, sleeping is not permitted when a Level 3 or 4 ADS is engaged.

TRL recently supported the European Commission with the development of a draft technical annex defining requirements and test procedures for a secondary type-approval act for Driver Drowsiness and Attention Warning (DDAW) systems. DDAW systems aim to prevent fatigue-related crashes by assessing the driver's alertness through vehicle system analysis and warning the driver when they are too drowsy to drive. For this project, TRL recommended a Karolinska Sleepiness Scale (KSS) level of 7 as the DDAW drowsiness threshold level (i.e. the system must alert the driver they are drowsy at or before this level on the KSS) (Huysamen and Pistak, 2020). This was because:

- The literature has shown that drowsy driving behaviour is present at a KSS level of 7 or above;
- The literature suggests that majority of fatigue-related accidents occur at a KSS level of 8 or above;
- The literature suggests that high risk driving instances happen on average above a KSS level of 8;
- Fatigue experts recommend that DDAW systems should alert drivers that they are drowsy at a KSS level of 7.

The findings highlighted by Huysamen and Pistak (2020) are directly applicable to the Wakefulness requirement, and as such, TRL recommends a KSS level of 7 as the wakefulness threshold for DAMS.

The Working Group on Motor Vehicles (MVWG), who assist the customer in the preparation of delegated acts and, legislative policy and proposals, suggested a KSS level of 8 as the DDAW drowsiness threshold. This threshold was adopted for the DDAW regulation, and as such, to maintain alignment, the customer may choose to use this threshold for the wakefulness threshold for DAMS.

TRL proposes two options for Level 3. The first option consists of handing back control of the vehicle to the driver before they exceed the wakefulness threshold. Once the driver

[1] The automated DDT fallback and automated minimum risk manoeuvre are not discrete actions. These actions are linked and follow after one another (i.e. when the ADS of a Level 4 automated vehicle performs the DDT fallback, it is subsequently followed by the ADS performing the automated minimum risk condition).

has resumed manual control of the vehicle, the DDAW system will be activated monitoring the driver's level of drowsiness and informing them when they are too drowsy to drive safely, encouraging them to take a break. Whether the driver continues with the DDT after the DDAW alert has been presented will be their choice. If the driver does not respond to the system to intervene, the ADS should initially warn the driver. If appropriate action is not taken, the ADS should perform a minimal risk manoeuvre.

The second option is slightly different, where the driver may exceed the wakefulness threshold. However, if this occurs, the ADS should warn the driver that they are too drowsy and will not be handed back control of the vehicle until their drowsiness level is within safe limits. If the ADS reaches the end of its ODDs and the driver is still exceeding the wakefulness threshold, the ADS should perform a minimum risk manoeuvre.

For a Level 4, it is recommended that the ADS inform the driver when they are approaching the Wakefulness Threshold, providing them with the option to take back manual control. The driver should be informed that they will not be able to take back manual control of the vehicle until their drowsiness level is within safe limits. If the driver exceeds the wakefulness threshold, the ADS should not send an intervention request or should delay manual disengagement until the driver's level of drowsiness is within safe limits. If the ADS is reaching the end of its ODDs and the driver's level of drowsiness is above the wakefulness threshold, the ADS should perform the DDT fallback and transition automatically into a minimum risk manoeuvre.

If the driver falls asleep when the ADS of a Level 4 (as well as Level 3) automated vehicles is engaged, the system should attempt to wake the driver up, and if the driver is unresponsive or is unable to stay awake, should then perform the automated DDT fallback and automated minimum risk manoeuvre. Importantly, the driver should not be sent a request to intervene as the driver will be in an extremely dangerous driving state, placing themselves and others at risk. In future research, the way in which sleeping is detected by DAMS (i.e. sleeping threshold) should be determined and add to the system requirements.

4.8.1.3 Attentiveness

In order for the driver to resume control of the vehicle, the driver needs to be deemed attentive during the transition phase (i.e. ready and willing to take back control). TRL developed an Attentiveness Criteria, where the driver needs to meet each of the criterion below to be deemed attentive:

1. The driver's eyes need to be confirmed as being directed to the road in front of the vehicle, unless switching to an automation level which does not require this.
2. Both of the driver's hands need to be confirmed as on the steering column.
3. One foot needs to be confirmed as on the accelerator or brake pedal, unless the vehicle is still in control of the speed (e.g. Adaptive Cruise Control (ACC)).

The three criteria proposed are further explained below.

If the driver does meet one of the criteria, the system should take appropriate action, such as:

- For Level 3:
    - Unplanned takeover: If the driver is not deemed attentive during the transition phase, the system should perform a minimum risk manoeuvre.
    - Manual disengagement: If the driver requests manual disengagement, but is not deemed attentive, the system should disallow it and continue with the DDT.
- For Level 4:

- Planned takeover: If the driver is not deemed attentive during a transition phase, the system should perform the automated DDT fallback and automated minimum risk manoeuvre.
- Manual disengagement: If the driver requests manual disengagement, but is not deemed attentive, the system should delay manual disengagement.

Attentiveness Criteria explained

Criterion 1

TRL believes, that when a transition demand is initiated, the driver should direct their visual attention towards the DDT in order to regain situation awareness and come back into the loop (i.e. gazing at forward road scene, traffic, mirrors and/or pedals etc.). However, for the system to deactivate, the driver's eyes need to be directed at the road scene in front of them. This is due to ensure safe takeover. There is substantial evidence to suggest that driving performance after a takeover is significantly impaired (e.g. lateral instability, speed variability and collisions). To mitigate this impairment, the driver's attention should be focused on controlling the lateral and longitudinal position of the vehicle, which they would not be able to do, if, for example, their eyes are directed at the passenger wing mirror.

Criterion 2

TRL recommends that one of the requirements to be deemed attentive is for the driver to have both hands on the steering wheel. This is due to traffic rules which require the driver to have both hands on the steering wheel whilst driving, as well as to ensure the driver's hands are empty when taking back control of the vehicle. There has been some evidence to suggest that not all drivers place their hand-held secondary tasks down during the takeover manoeuvre (i.e. keeping devices in their hand) (Burnett *et al.*, 2019).

Criterion 3

Due to being OOTL during automated driving and the evidence of impaired driving performance after a takeover, it is recommended that the driver gets themselves into the correct driving position before resuming control, which includes placing a foot on either the brake or accelerator pedal (i.e. pedal type). This action, along with eyes on the road and hands on the steering wheel, will assist with the driver's preparedness to resume manual control of the vehicle. Moreover, some studies reveal that drivers gaze at their feet during a takeover request due to deficiencies in proprioception[2]. This is caused by being OOTL, whereby the driver loses sense of where their feet/legs are in relation to the pedals. This phenomenon has been linked to pedal confusion[3], and as such, requiring the driver to place one foot on the pedal reduces the risk of such an incident from occurring. The pedal type which the driver chooses to place their foot on will depend on the driving environment and action needed by the driver.

4.8.1.4 Secondary task engagement

Drivers must be made aware of what secondary tasks, if any, they can perform when the ADS is engaged. Whether or not this is permitted or what type of secondary tasks can be performed is dependent on the traffic laws of the country and on the systems capabilities and limitations: ODDs (Refer to Section 4.4 for more details).

If a country does not permit secondary tasks, the DAMS should ensure that the driver is not engaged in a secondary task whilst the ADS is engaged. If the country permits a certain number of secondary tasks, such as those on the entertainment consoles, the DAMS should ensure that only these secondary tasks are performed. If the driver does not adhere to these rules, the DAMS should take appropriate action such as warning the driver that they

[2] Proprioception: driver's awareness or perception of the position and movement of their body

[3] Pedal confusion: pressing the accelerator instead of the brake pedal, and vice versa

are distracted or performing an unacceptable task, and if they do not stop engaging in the task, the vehicle should perform a minimum risk manoeuvre(Level 3) or automated DDT fallback and automated minimum risk manoeuvre (Level 4).

Performing a secondary task should not interfere with the monitoring of the driver’s level of drowsiness when the ADS is engaged. Depending on the system, this may restrict the types of secondary tasks the driver can perform or may even prohibit the engagement in all secondary tasks. Moreover, the type of secondary task that can be performed by the driver is also dependent on the transition phase provided by the system. It appears drivers are able to respond to a takeover request within 10 s when performing handsfree tasks but may require more time when performing secondary tasks on handheld devices or items (e.g. mobile phone use and reading a book). Thus, if a system can only provide a transition phase of 10 s, only hands-free secondary tasks should be permitted. Similarly to above, if the driver performs a secondary task outside of the systems ODDs (i.e. beyond its capabilities), the DAMS should recognise this and warn the driver. If the driver does not respond to the warning the system should perform a minimal risk manoeuvre (Level 3) or automated DDT fallback and automated minimum risk manoeuvre (Level 4). The initiation of a transition demand is not recommended because the driver may have exceeded the drowsiness threshold, or the transition phase may not be designed to accommodate the secondary task being performed (e.g. working on a laptop and the transition phase is 10 s), and as such the driver will not be in a state or position to resume the vehicle or drive safely.

It should be noted that current systems are not yet capable of monitoring secondary task engagement, especially to the extent highlighted above, where some stakeholders have not yet considered developing this function as part of their DAMS.

4.8.1.5 Sudden sickness

DAMS for Level 3 and 4 Automated Vehicles are required to monitor the driver for sudden sickness. If the driver experiences a sudden sickness which affects their ability to drive safely, or at all, the DAMS must detect this and take appropriate action. Currently, it is unknown which types of sickness should be monitored by DAMS. This needs to be determined and specified in order to establish the sudden sickness requirements. Moreover, to establish the trigger behaviours, thresholds and validation testing requirements for sudden sickness, the behaviours and characteristics of the specified sicknesses needs to be determined. In the next phase of the research project, TRL recommends that further research is conducted in this area where stakeholder developing these types of systems are engaged to understand the functionality, capabilities and limitations of these systems.

With regards to appropriate action, TRL recommends that if the driver is deemed to be too unwell to drive safely:

- Level 3: The ADS should perform a minimal risk manoeuvre.
- Level 4:
  - The ADS should not send an intervention request or should delay manual disengagement until the driver’s is in a fit state to drive.
  - The ADS should perform the automated DDT fallback and automated minimum risk manoeuvre if the system is reaching the end of its ODDs.

For both Level 3 and 4, if the driver is needing medical attention, the DAMS should alert emergency personnel (e.g. via E-call).

4.8.2 Takeover manoeuvres

4.8.2.1 Transition phase

It is clear that the length of the transition phase and the traffic rules of a country will dictate what secondary tasks can be performed by the driver. It appears that drivers not performing a secondary task prior to a transition demand generally can respond within 10 s. Similar findings were found when drivers were engaged in handsfree secondary tasks. This suggests that a minimum transition phase for these two examples could be [10 s], which is in alignment with the ALKS regulation and capabilities of current DAMS. For secondary tasks requiring a handheld device or item, drivers appear to need more than 10 s to react safely, where 15 s appears to be sufficient. However, research was limited, and further investigation is needed to ensure 15 s is enough time for these types of secondary tasks. It should be noted that handheld devices do not include laptops.

Based on the findings, TRL proposes the following requirements:

- No secondary tasks: The system should provide a minimum transition phase of [10] s.
- Hands-free secondary tasks (e.g. entertainment console): The system should provide a minimum transition phase of [10] s.
- Secondary tasks on handheld items / devices (e.g. reading a book or mobile phone use): The system should provide a minimum transition phase of [15] s.
- Other types of secondary tasks: the manufacturer should provide evidence that their transition phase is sufficient for the driver to respond in time and safely to the transition demand.

If the driver is unable to respond appropriately within the specified transition phase of the system, the system shall take the appropriate action. The appropriate action will be the same as that detailed for Attentiveness (Section 4.8.1.3).

4.8.2.2 Post-takeover support

As stated above in Section 4.5, TRL recommends that the system must continue to monitor and support the driver after the transition phase is completed until the driver has regained situation awareness and achieved full longitudinal and lateral control of the vehicle. The manufacture must provide details on how they will measure this along with evidence on the effectiveness of their method. A system merely equipped with ADAS will be insufficient to obtain type-approval due to the minimum performance requirements established for some systems such as ELKS (i.e. support is only required when exiting over a solid white line). If the manufacturer were to use ADAS, evidence of their ADAS effectiveness in supporting the longitudinal and lateral control of the vehicle when exiting the ODDs should be provided.

4.8.3 HMI

TRL reviewed the academic research on the HMI for DAMS and collated the findings with those found in the standards review. The aim of the analysis was to identify facets of the HMI that should be regulated in a technology-agnostic manner and, if possible, establish some of the minimum performance requirements. This includes the following:

- It is recommended that the following features of the HMI for DAMS are standardised amongst manufacturers systems:
  - The functional logic: This refers to how the ADS interacts with the user.
  - The transition of control elements: This refers to the drivers understanding of the allocation of control.

    - The control elements: This refers to factors such as deactivating and activating the system through physical input. Some of these factors, such as deactivation, are covered by the system requirements (i.e. Attentiveness requirements).
- The interface should be easily perceivable from the driver's peripheral field of view and located near to the driver's direct line to outside the front of the vehicle.
- The interface should be intuitive, unambiguous and easily distinguishable from other displays in the vehicle.
- The following information should be displayed to the driver whilst the ADS is engaged:
    - The status of the system (i.e. the automation status)
    - The status of the driver
    - The role of the driver
- The driver should be informed of a transition demand or minimum risk manoeuvre (Level 3), or the automated DDT fallback and automated minimum risk manoeuvre (Level 4).
- The driver should be informed of any system failures and emergency manoeuvres.
- Takeover manoeuvres:
    - The symbol for the transition demand should be in accordance with the ALKS regulation and comprise of a steering wheel and hands.
    - The warning should escalate during the transition phase to reflect urgency.
    - The alert type should change characteristics at the start of a minimum risk manoeuvre or automated DDT fallback.
    - For Level 4, it is recommended to inform the driver of a transition demand prior to it being initiated.
    - At a minimum, a visual and auditory warning signal should be provided to the driver.
- It is recommended that for all warning types, a visual and auditory warning signal is presented.
- Detailed visual and audio HMI requirements have been outlined in the DDAW draft technical annex (Huysamen and Pistak, 2020), such as the frequency and tonality of tonal alerts, and the frequency of flashing/blinking elements of a visual warning.
- Secondary tasks:
    - Secondary tasks which are displayed on the entertainment console should be suspended or deactivated when a transition demand is initiated.
    - It is recommended that secondary tasks which are displayed on the infotainment console should be suspended when the ADS is communicating with the driver whilst the ADS is engaged.

4.8.4 Validation testing

The validation testing requirements were not established in this piece of work. As highlighted in the DAMS first interim report, the validation testing requirements can only be established once the system requirements are specified and when more systems are brought to market. TRL aimed to establish as many of the system requirements as possible in this piece of work, placing us one step closer to being able to establish the validation testing requirements in the future. Annex 1.7 highlights some recommendations and considerations for the validation testing requirements.

5 CONCLUSION

It is currently challenging to develop a robust, technology neutral and universally applicable regulation. This is because of the limited information regarding DAMS, the lack of consensus surrounding the requirements and acceptable states for drivers using SAE Level 3 and Level 4 DAMS, the technological challenges to monitor certain driver states and the limited number of systems on the market. It is expected that over time and when more systems are brought to market, the factors preventing the creation of the regulation will be overcome.

TRL established as many of the DAMS system requirements as possible in this piece of work. Only once these requirements have been finalised, can the validation testing and documentation package requirements be established. TRL suggests that DAMS monitor the following five driver states: Driver Presence, Wakefulness, Attentiveness, Secondary Task Engagement and Sudden Sickness, where performance requirements for most of these were proposed. From the research conducted, it became evident that the engagement in secondary task is dependent on two factors: the traffic rules of the country and the capabilities and limitations of the Driver Availability Monitoring Systems. Moreover, a relationship between secondary task type and the transition phase was identified. From this information, TRL was able to propose performance requirements for the engagement in secondary tasks and for the transition phase. There were some design principles and guidance on the HMI for DAMS identified in the literature and standards, but further research is required to understand the key design characteristics for Level 3 and Level 4 automated vehicles for the performance requirements to be established.

For the requirements which could not be established in this study, TRL recommends conducting further research (i.e. literature, theory, standards) and engaging with stakeholder or experts on specific topics (e.g. sudden sickness). Moreover, TRL recommends reengaging with stakeholders when more systems are brought to market on topics such as the identified technological limitations and validation testing methods. Once these outstanding requirements are established and more information is gathered on DAMS validation testing and techniques, the assessment method for DAMS can be developed.

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Annex 1 PROPOSED ITEMS FOR FUTURE DAMS REGULATION

This section provides a summary of proposed items, and where possible, the proposed requirements, for the future DAMS for SAE Level 3 and 4 Automated Vehicles regulation.

Annex 1.1 Scope

The regulation applies to the approval for automated vehicles of category M_1, M_2, M_3, N_1, N_2 and N_3 with regards to an on-board system:

- Capable of monitoring the driver to ensure that they are available, ready, willing and able to take back control from automated mode safely, and
- Interact with and warn the driver when needed.

Annex 1.2 Definitions

Once the regulation has been finalised, definitions for the DAMS regulation need to be established. This can be achieved by collating information from the European Commission, existing standards and regulations such as the ALKS regulation, literature and stakeholders, or drafted by the consultant finalising the regulation.

Example definitions:

- 'Driver Availability Monitoring Systems (DAMS)' means …
- 'Driver presence' means …
- 'Wakefulness' means …
- 'Attentiveness' means …
- 'Minimum risk manoeuvre means …
- 'Dynamic driving task (DDT)' means
- 'Operational Design Domain (ODD)' means …
- 'Human Machine Interface' means …
- 'Transition demand' means …
- 'Transition time' means …
- Etc.

Annex 1.3 System requirements

[The DAMS for Level 3 and 4 Automated Vehicles shall adhere to the following system performance requirements.]

The minimum system requirements for DAMS for Level 3 and 4 Automated Vehicles which manufacturers must adhere to need to be established and specified in the regulation. Some of these requirements can only be finalised and established when more systems have been brought to market, more research in the field has been conducted and there is more consensus surrounding certain topics related to DAMS for SAE Level 3 and 4 Automated Vehicles.

Annex 1.3.1 System

[For both Level 3 and 4 ADS, the system shall directly and continuously monitor the driver to ensure they are available, ready, willing and able to take over control of the vehicle from automated mode safely.

Level 3 and 4 are defined in accordance to the SAE J3016 defined levels of automation.

Takeover manoeuvres:

- Level 3 ADS includes user-in-charge, unplanned, planned, manual disengagement and emergency takeovers
- Level 4 ADS includes user-in-charge, planned and manual disengagement takeovers]

Annex 1.3.1.1 Driver presence

[The driver's presence shall be monitored throughout the engagement of a Level 3 and 4 ADS. Each of the requirements in **Presence Criteria** needs to be met for the driver to be deemed present and in a position to take back control of the vehicle safely. If one of these are not met, the system shall take appropriate action as specified below.

Presence criteria:

1. The driver shall be present in the driver's seat throughout the engagement of a Level 3 and 4 ADS.
2. The driver's seatbelt shall remain buckled throughout the engagement of a Level 3 and 4 ADS.
3. Seat position:
    - Level 3: The driver's seat position shall not be significantly altered or adjusted throughout the engagement of the ADS.
    - Level 4: The driver's seat position can be significantly altered or adjusted whilst the ADS is engaged. If this occurs, the ADS shall ensure the driver's seat position is returned to the driving position prior to the manual resumption of control.

Appropriate action:

- Level 3:
    - Criterion 1: If the driver is no longer seated in the driver's seat, the system shall perform a minimum risk manoeuvre.
    - Criterion 2: If the driver's seatbelt is unbuckled or the position of the seat adjusted to an unacceptable position, the system may initially alert the driver to correct this. If this is not corrected in a yet-to-be-determined time frame, a minimum risk manoeuvre should be performed.
    - Criterion 3: If the driver significantly alters or adjusts their seat position, the system should warn the driver that this is unacceptable and request them to return the seat to an acceptable position. If the driver does not adhere to the request from the system to return the driver's seat position back to the driving position in a yet-to-be-determined time frame, the ADS should perform a minimum risk manoeuvre.
- Level 4:
    - Criterion 1: If the driver is no longer seated in the driver seat, the system should perform the automated DDT fallback and automated minimum risk manoeuvre.
    - Criterion 2: If the driver's seatbelt is unbuckled, the system may initially alert the driver to correct this. If this is not corrected in a yet-to-be-determined time frame, the system should perform the automated DDT fallback and automated minimum risk manoeuvre.
    - Criterion 3: If the driver does not adhere to the request from the system to return the driver's seat position back to the driving position, the system shall

not allow the driver to take back manual control of the vehicle and the ADS shall either:

- Continue with the DDT, or
- Perform the automated fallback and minimum risk manoeuvre if it is reaching the limits of its ODDs.

Annex 1.3.1.2 Wakefulness

[The wakefulness state of the driver shall be monitored throughout the engagement of a Level 3 and 4 ADS.

Thresholds:

Wakefulness threshold:

- TRL recommendation: KSS level of [7]
- Alignment with DDAW regulation: KSS level of [8]

Sleeping threshold: yet-to-be-determined threshold (e.g. eyes are not detected for 4 s; ALKS regulation)

Appropriate action:

- Level 3:
    - There are two options available for the Wakefulness threshold, where manufacturers shall choose and adhere to one of these.
        - Option 1: The ADS shall hand back control of the vehicle to the driver before the driver exceeds the **Wakefulness Threshold**. If the driver does not respond to the request to intervene, the ADS shall initially warn the driver. If appropriate action is not taken within a yet-to-be-determined timeframe, the system shall perform a minimum risk manoeuvre.
        - Option 2: If the driver exceeds the **Wakefulness Threshold**, the ADS shall warn the driver that they are too drowsy and will not be handed back control of the vehicle until their level of drowsiness is within safe limits. If the ADS is reaching the end of its ODDs and the **Wakefulness Threshold** is still being exceeded by the driver, the ADS shall perform a minimum risk manoeuvre.
    - If the driver exceeds the **Sleeping Threshold**, the system shall either:
        - Perform a minimum risk manoeuvre, or
        - Wake the driver up, and if unresponsive or sleep reoccurs, perform a minimum risk manoeuvre.
- Level 4:
    - Wakefulness threshold:
        - Recommendation:
            - Inform the driver that they are approaching the **Wakefulness Threshold.**
            - Inform the driver that if they exceed the threshold, they will be unable to resume manual control until their level of drowsiness is within safe limits.
            - Provide the driver with the option to resume manual control of the vehicle.
        - If the driver exceeds the **Wakefulness Threshold**,

        - The ADS shall not send an intervention request or shall delay manual disengagement until the driver’s level of drowsiness is within safe limits.
        - The ADS should perform the automated DDT fallback and automated minimum risk manoeuvre if the ADS is reaching the limits of its ODDs.
    - If the driver exceeds the **Sleeping Threshold**, the system must either:
        - Perform the automated DDT fallback and automated minimum risk manoeuvre, or
        - Wake the driver up, and if unresponsive or sleep reoccurs, perform the automated DDT fallback and automated minimum risk manoeuvre.]

Annex 1.3.1.3 Attentiveness

[The attentiveness state of the driver shall be monitored throughout the transition phase for both Level 3 and 4 Automated Vehicles. The handover shall only occur if the driver is confirmed as being ready and willing to take back control of the vehicle. The driver is confirmed as ready and willing if all the requirements of the **Attentiveness Criteria** is met. If one of the criteria is not met, the ADS shall take appropriate action as defined below.

<u>Attentiveness criteria:</u>

1. The driver’s eyes are directed to the road in front of the vehicle, unless switching to an automation level which does not require this (e.g. switching from a Level 4 to Level 3 ADS)
2. Both of the driver’s hands are on the steering column.
3. One of the driver feet is on the accelerator or brake pedal, unless the vehicle is still in control of the speed (e.g. Adaptive Cruise Control)

<u>Appropriate action:</u>

- Level 3:
    - Unplanned and planned takeovers: If the driver is not deemed attentive during the transition phase, the system shall perform a minimum risk manoeuvre.
    - Manual disengagement: If the driver requests manual disengagement, but is not deemed attentive, the system shall disallow manual disengagement and continue with the DDT.
- Level 4:
    - Planned takeover: If the driver is not deemed attentive during a transition phase, the system should perform the automated DDT fallback and automated minimum risk manoeuvre.
    - Manual disengagement: If the driver requests manual disengagement, but is not deemed attentive, the system shall delay manual disengagement.]

Annex 1.3.1.4 Secondary task engagement

[The driver’s engagement in secondary tasks shall be monitored throughout the engagement of a Level 3 and 4 ADS. If the driver performs a prohibited task, the ADS shall take appropriate action, as defined below.

The manufacturer shall adhere to the framework developed by the UNECE working group ‘The Global Forum for Road Traffic’ on the engagement in tasks unrelated to driving when the ADS is engaged, where evidence on the adherence shall be provided in the documentation package.

The engagement in a task unrelated to driving shall not interfere with the monitoring of the driver’s level of drowsiness.

Acceptable or prohibited tasks:

This is dependent on two factors: the traffic rules of the country and the capabilities and limitations of the system, specifically the transition phase (Refer to Section Annex 1.3.3.1) and the field of view of the DAMS. Evidence shall be provided by the manufacturer in the documentation of the acceptable and prohibited tasks and their adherence to the requirements set out in the DAMS regulation.

Appropriate action:

- Level 3:
    - The system shall warn the driver they are distracted or performing a prohibited task and request them to change their behaviour. If the driver does not change their behaviour immediately, the system shall perform a minimum risk manoeuvre.
- Level 4:
    - The system shall warn the driver they are performing a prohibited task and request them to correct their behaviour. If the driver does not comply, the system shall perform the automated DDT-fallback and minimum risk manoeuvre.]

Annex 1.3.1.5 Sudden sickness

[The driver shall be monitored for sudden sickness throughout the engagement of a Level 3 and 4 ADS. If the driver displays behaviours or characteristics indicative of ill health, the system shall take appropriate action, as defined below.

Sudden sickness criteria:

At a minimum, the DAMS should monitor yet-to-be-determined sudden sicknesses.

DAMS that are able to monitor more than the required sudden sicknesses, should detail this in the documentation package.

Appropriate action:

- Level 3:
    - The ADS shall perform a minimum risk manoeuvre
- Level 4:
    - The ADS shall not send an intervention request or shall delay manual disengagement until the driver’s is in a fit state to drive.
    - The ADS shall perform the automated DDT fallback and minimum risk manoeuvre if the system is reaching its ODDs.

For both Level 3 and 4, if the driver requires medical attention, the DAMS should contact emergency service (e.g. using E-call).]

Annex 1.3.2 Occlusion factors

[The system shall perform effectively or respond appropriately to yet-to-be-determined occlusion factors (e.g. spoofing, glasses etc.)]

Annex 1.3.3 Takeover manoeuvres

Annex 1.3.3.1 Transition phase

[To take back control of a Level 3 and 4 Automated Vehicle, the driver shall meet the attentiveness criteria detailed in Section Annex 1.3.1.3 within the transition phase specified by the system. If this not achieved by the driver, the ADS shall take appropriate action, as defined below.

<u>Transition phase:</u>

- The system shall provide a minimum transition phase of [10] s.
- Engagement in secondary tasks:
    - For the driver to engage in hands-free secondary tasks via the vehicle's systems (e.g. entertainment console), the system shall provide a minimum transition phase of [10] s.
    - For the driver to engage in secondary tasks on a handheld device or item (e.g. reading a book or mobile phone use), the system shall provide a minimum transition phase of [15] s.
    - For the driver to engage in other types of secondary tasks (e.g. laptops), the manufacturer shall provide evidence that the transition phase is sufficient for the driver to respond in time and safely to the transition demand.

<u>Appropriate action:</u>

- For Level 3:
    - Unplanned and planned takeovers: The system shall perform a minimum risk manoeuvre.
    - Manual disengagement: The system shall delay manual disengagement.
- For Level 4:
    - Planned takeover: The system shall perform the automated DDT fallback and automated minimum risk manoeuvre.
    - Manual disengagement: The system shall delay manual disengagement.]

Annex 1.3.3.2 Post-takeover support

[The system shall continue to monitor and support the driver after the transition phase is completed until the driver has regained situation awareness and achieved full longitudinal and lateral control of the vehicle.

- The manufacture shall provide details on how they will measure this along with evidence on the effectiveness of their method.
- A system merely equipped with ADAS will be insufficient to obtain type-approval due to the minimum performance requirements established for some systems such as ELKS (i.e. support is only required when exiting over a solid white line). If the manufacturer were to use ADAS, evidence on the effectiveness of their ADAS at supporting, for example, the longitudinal and lateral control of the vehicle after the transition phase should be provided. This includes its ability to support the driver in different road conditions when exiting its ODDs, for example, different lane line types and traffic flows.]

Annex 1.3.4 Activation and deactivation

[The DAMS shall confirm the driver is in an acceptable state to activate or deactivate the system. This information in conjunction with other system information (e.g. the ODD information of the system) shall be used to determine whether the system can or cannot be activated or deactivated.

[To activate the ADS:

- Level 3:
  - The driver presence and sudden sickness criteria shall be met, and the driver shall be below the wakefulness threshold.
- Level 4:
  - The driver presence and sudden sickness criteria shall be met.

To deactivate the ADS:

- The driver presence, attentiveness and sudden sickness criteria shall be met,
- The driver shall not be engaged in a secondary task
- The driver shall be below the wakefulness threshold, and
- The driver shall respond within the specified transition phase of the system.]

Annex 1.3.5 System override

Annex 1.3.5.1 ADS override

- [The system shall be completely overridden only if the following criteria are met:
  - The driver provides yet-to-be-determined input or feedback to the system (e.g. pressing a button),
  - The driver presence, attentiveness and sudden sickness criteria are met,
  - The driver is below the wakefulness threshold, and
  - The driver is not engaged in a secondary task.
- The input or feedback shall be designed to prevent unintentional override.
- The driver shall be supported after the takeover as per Annex 1.3.3.2.]

Annex 1.3.5.2 Lateral control override

- [The lateral control of the vehicle shall be overridden by input to the steering column by the driver.
- The input shall exceed a reasonable threshold designed to prevent unintentional override.
- The driver shall only be able to override lateral control if the driver presence and sudden sickness criteria is met, the driver is below the wakefulness threshold and fulfils criterion 1 and 2 of the attentiveness criteria.]

Annex 1.3.5.3 Longitudinal control

- [The longitudinal control of the vehicle shall be overridden by either:
  - The driver applying input to the braking control resulting in a higher deceleration than that induced by the system
  - The driver applying input to the braking control to maintain a standstill vehicle position.

  - The driver applying input to the accelerator pedal.
- The system shall ensure that input to the accelerator or brake pedal was not unintentional.
- The driver shall only be able to override longitudinal control if the driver presence, attentiveness and sudden sickness criteria is met and the driver is below the wakefulness threshold.]

Annex 1.4 HMI requirements

Minimum performance requirements for the HMI of the ADS need to be established. This should include standardising the functional logic, transition control elements and control elements. Some potential requirements are highlighted below:

- [The following information shall be displayed to the driver whilst the ADS is engaged:
  - The status of the system (i.e. automation status)
  - The status of the driver
  - The role of the driver
- The driver shall be informed of a transition demand, a minimum risk manoeuvre (Level 3) or automated DDT fallback and minimum risk manoeuvre (Level 4).
- The driver shall be informed of any system failures and emergency manoeuvres.
- Takeover manoeuvres:
  - The symbol for a transition demand shall comprise a steering wheel and hands and will be in accordance with the ALKS regulation.
  - The warning shall escalate during the transition phase to reflect urgency.
  - At a minimum, a visual and auditory warning signal shall be presented.
  - The alert type shall change characteristics at the start of a minimum risk manoeuvre or automated DDT fallback.
  - For planned takeover, it is recommended to inform the driver about a transition demand prior to it being initiated.
- For all warning types, a minimum of a visual and auditory warning signal shall be presented.
- Secondary tasks:
  - Secondary tasks displayed on the entertainment console shall be suspended or deactivated when a transition demand is initiated.
  - It is recommended that secondary task displayed on the entertainment console are suspended when the ADS is communicating with the driver whilst the ADS is engaged.
- The interface shall be easily perceivable from the driver's peripheral field of view and located near to the driver's direct line to outside the front of the vehicle.
- The interface shall be intuitive and unambiguous, and the display should be distinguishable from other displays in the vehicle.
- Etc.]

Annex 1.5 Data management

[DAMS shall be designed in such a way that they shall only continuously record and retain data necessary for the system to function and operate within the closed loop system.

Furthermore, this data shall not be accessible or made available to any third parties and shall only be held for the length of time for which it holds direct relevance to assessing the driver's availability, readiness, willingness and ability to take back control from automated mode.]

Annex 1.6 Verification and tests

[The technical service employed to verify the DAMS on behalf of the European Commission shall verify the information provided in the documentation package by testing a selection of aspects of the declared function of the system. The elements audited will be chosen at the discretion of the technical service. If possible, the minimum number of elements to be audited should be determined and specified in the regulation.]

Annex 1.7 Validation testing requirements

It is recommended that guidelines and minimum requirements are established for the validation testing which manufacturers need to adhere to. These can be established after the system requirements have been finalised and once more systems are on the market (i.e. re-engagement with manufacturers). Below highlights some of the things that should be considered for the validation testing requirements:

- The validation testing should be done with human participants (i.e. user trials), where a safety back-up (e.g. safety driver) is required for all testing completed in a non-simulated environment.
- The validation testing should assess whether the system is able to effectively:
    - Monitor the required driver states,
    - Detect when a requirement is not being met, and
    - Respond as planned.

  For wakefulness, it is recommended that the validation testing requirements are to be similar to the established for DDAW.
- The validation testing should assess the effectiveness of the system performance for the yet-to-be-determined occlusion factors.
- The validation testing should assess whether the DAMS is able to effectively perform in different environmental conditions (e.g. day and night, weather conditions). These conditions will be dependent on the ODDs of the system.
- The validation testing should assess the effectiveness for the other functions of the ADS that utilises the DAMS to make executive decisions (e.g. activation and deactivation of the ADS).
- The HMI of the DAMS and ADS should be reviewed and validated.
- It is recommended that validation testing is conducted on a closed test track.
- An acceptance criterion to determine whether the system is effective or acceptable needs to be developed.

Annex 1.8 Documentation requirements

Evidence of the effectiveness of the system shall be provided in the form of a documentation package. The requirements for the documentation package need to be established after the system and validation requirements are established. The documentation requirements should include system functionality and system validation.

Annex 2 Method

Annex 2.1 Expert engagement

Expert engagements were carried out to gather additional information on the topics covered in the literature review, standards review and stakeholder engagement from the DAMS first interim report. The experts were approached and offered the opportunity to feed their knowledge into the creation of the DAMS regulation. Most of the experts sit within the research field, and as such, were assumed to have good working knowledge of the current developments in the field and have a strong understanding of ongoing and un-published research. The experts were engaged using a standardised set of questions to guide the conversations and ensure that information relevant to the topic of DAMS and Automated Vehicle was gathered in a consistent manner. The topic guide includes (Annex 4):

- Defining an Automated Driving System (ADS),
- Human states and/or behaviours,
- Take-overs,
- Physiological indicators of drowsiness, and
- Validation testing.

The topic guide was sent to all experts ahead of the meetings to allow them time to prepare for the discussion, where they were requested to only respond to the topics which they had expertise in. Experts were engaged via teleconference.

Annex 2.2 Literature review

A literature review was conducted with four objectives:

1. To identify the effects of automation on driver drowsiness and the concerns surrounding this, if any.
2. To understand the effect of secondary task engagement on driver drowsiness during automated driving.
3. To understand the effect of secondary task engagement on takeover time and driving performance.
4. To understand the effect of HMI design on human performance and interaction with the ADS.

The literature search gave priority to recent, high quality (peer-reviewed) research that was considered to be of most direct relevance to the objectives of the current study. The review used the databases and search terms documented in Table 1, Table 2, Table 3 and Table 4.

Table 1 Search terms for the effects of automation on driver drowsiness

Search terms	Databases
(“automated driving”) AND (“drows*” OR “fatigue” OR “alert*”) AND (“cognitive underload” OR “out-of-the loop”)	Google Scholar TRID

Table 2 Search terms for the effect of secondary task engagement on driver drowsiness during automated driving

Search terms	Databases
("automated driving") AND ("secondary task") OR ("non-driving related task") AND ("drows*" OR "fatigue" OR "alert*") AND ("cognitive underload" OR "out-of-the loop")	Google Scholar TRID

Table 3 Search terms for the effect of secondary task engagement on takeover time and driving performance

Search terms	Databases
("Driv*") AND ("takeover performance" OR "takeover time*" OR "reaction time*" OR "driving performance" OR "impair*") AND ("secondary task*" OR "secondary activit*" OR "non-driving task")	Google Scholar TRID

Table 4 Search terms for the effect of HMI design on human performance and interaction with the ADS

Search terms	Databases
("automated driving") AND ("HMI" OR "human-machine interface") AND ("design") ("automated driving") AND ("HMI" OR "human-machine interface") AND ("design") AND ("situation awareness")	Google Scholar TRID

Annex 2.3 UNECE guidelines review

A review of current UNECE guidelines was conducted to identify if any guidance exists on the engagement of secondary tasks whilst the ADS is engaged for Level 3 and 4 Automated Vehicles, with specific focus on acceptable and unacceptable secondary tasks.

Annex 2.4 Chronogram

TRL developed a chronogram Annex 5) on the takeover manoeuvres from the literature reviewed in the DAMS first interim report and current study. Each study which reported takeover times (i.e. reaction time to a takeover request) was added to the chronogram, where factors such as lead time, driving performance after the takeover, secondary task engagement and takeover type were also included for analysis purposes.

Annex 3 RESULTS

Annex 3.1 Expert engagements

Annex 3.1.1 Defining an Automated Driving System (ADS)

Annex 3.1.1.1 SAE definitions

Most of the experts recognise the SAE definitions as the most well used industry standard for automated vehicles but suggest that more detail is required with regards to defining ADS. This included more information outlining the responsibility of the driver and the system, and the capabilities and limitations of the system within the SAE levels of automation. Specifically, it is suggested that more clarification around takeovers and responsibility between the driver and a Level 3 ADS is required.

Annex 3.1.1.2 Role of the driver when a Level 3 ADS is engaged

There was a lack of consensus between experts when considering the responsibility of the driver when a Level 3 ADS is engaged. Experts agree that the driver must be capable of resuming control at any point. However, there are conflicting opinions as to the monitoring role required by the driver:

- Some experts believe the driver must remain engaged in the driving task and take on an 'active monitoring' role; meaning the only secondary tasks that can be conducted whilst the ADS is engaged are those that are currently allowed during manual driving.
- Some experts believe the driver must be ready to take back control, but constant monitoring of the driving task is not required, and drivers may engage in non-driving related tasks. These acceptable secondary tasks were defined in a number of ways: tasks that do not distract the driver from monitoring the road environment for long durations of time; tasks that do not prevent the driver from taking back control in a timely manner; or tasks that allow drivers to keep one hand on the wheel.

Some experts suggest that secondary tasks, rather than having a negative impact on drivers' ability to takeback control, can help drivers stay in the loop, improve situation awareness and increase workload and therefore improve the quality of a takeover.

Experts have defined unacceptable tasks as: tasks that require moving out of the normal driving position; tasks that exceed safe levels of visual and/or cognitive distraction; tasks that negatively affect attention or fatigue; and sleeping or intoxication.

Annex 3.1.1.3 Role of the driver when a Level 4 ADS is engaged

There is a lack of consensus among experts as to the responsibility of the driver when a Level 4 ADS is engaged. Some experts state that the ADS is responsible for the DDT, and as such, the driver is not required to monitor the vehicle and may engage in any non-driving related task, including sleeping. Other experts believe that while the ADS is responsible for the DDT, the driver may be expected to have some awareness of vehicle state and situation awareness. Therefore, some levels of non-driving related tasks may be permissible that takes the driver's attention off the roadway for extended periods of time, but sleeping is not acceptable. However, drivers would still be expected to takeover following suitable notice before a planned takeover. Contrasting opinions also question whether the driver is allowed to move in the cabin, or if the driver has any driving responsibilities at all.

Annex 3.1.1.4 Human states and/or behaviours

The majority of experts mentioned the following driver states as unacceptable when a Level 3 ADS is engaged:

- Drowsy
- Fatigued
- Low levels of attentiveness and alertness
- Impairments from drugs or alcohol

Most experts agreed that drivers must have a reasonable level of alertness and attentiveness for both Level 3 and 4. However, some experts commented that certain levels of visual or cognitive distraction could be acceptable (situation dependent), or even beneficial in enabling the driver to avoid cognitive underload during automated mode. There was a lack of consensus among experts as to whether drowsiness and sleeping are acceptable driver states when a Level 4 ADS is engaged. The majority of experts suggest if the DAMS can no longer detect the drivers' eyes and/or face and no response is received from the driver then escalated warnings should be issued. This could be in the form of visual, audio or haptic feedback, or a combination as the severity of warning is escalated to the driver. If the driver does not respond, the majority of the experts also suggest that the system should take appropriate action such as pulling over to a 'safe spot'.

There was no consensus amongst experts on what an **available** driver looks or behaves like, as well as a **ready** driver**,** an **able** driver or a **willing** driver. It was evident that the characteristics used to describe these four states were dependent on what the experts perceived as acceptable and unacceptable driver states that the driver can be in when the ADS is engaged. Some experts used similar characteristics to describe different states. Therefore, the most commonly reported characteristics to describe an available, ready, able and willing driver were combined and are highlighted below:

- The driver is alert (i.e. not drowsy) and/or awake (i.e. not sleeping) during the engagement of the ADS.
- The driver is situationally aware of the driving task and environment, and/or attentive to the driving task during the takeover, where some also stated when the ADS is engaged.
- The driver is present in the driver's seat throughout the DDT.
- The driver is not engaged in a secondary task or is not distracted during a takeover, where some also stated when the ADS is engaged.
- The driver is able to fulfil the reengagement actions of the system (e.g. hands on wheel and engaging the pedals) or provide input by, for example, pressing a button to confirm they are willing to resume control.

Annex 3.1.1.5 Take-overs

Many of the experts commented on the lack of evidence towards minimum timeframes for safe takeovers. The majority of the responses were based from experts specialised knowledge within the topic area rather than research projects conducted. Timeframes varied from 5 seconds to 20 seconds. Most of the experts suggested variable takeovers[4] would be most suitable, where factors, such as the driver state prior to the takeover, situation awareness and the environment, would influence the timeframe for a safe takeover. Most experts also stated that the type of secondary task would have an effect on takeover time based on the physical and cognitive demand of the task.

[4] Variable takeover: the takeover time changes for each takeover depending on driver state and/or the state of the road environment

While no experts believe the minimum takeover time should be based on the mean, there is contrast in opinion between whether 95th percentile is safe enough or if 99th percentile would cause frustration for drivers in the lower percentiles. The human factors that are believed to have an impact on driver reaction time to takeover requests are prominently referenced as experience and age. Other factors mentioned by experts were fatigue, trust and driver behaviour.

The majority of experts believe the quality of driving performance (i.e. manual driving quality) after a takeover situation will be better when the takeover is accomplished at the drivers own speed (i.e. self-paced) rather than being specified by the system. Majority of the experts commented that continuous monitoring of the driver is important, specifically before and after the transitional takeover period to ensure the driver is in a safe state to take over control of the vehicle. There are a number of factors cited by experts that affect the quality of driving performance after a takeover. For example, the type of secondary task, specifically high visual or cognitive inattention, how much situation awareness the driver has before the takeover and if the driving environment has changed after the takeover, could have negative effects on the quality of a takeover, driving performance after a takeover, and time of the takeover.

Annex 3.1.2 Physiological indicators of drowsiness

Annex 3.1.2.1 Eye measures

Camera-based systems that measure eye movements and blink rates are described by experts as one of the most effective non-invasive physiological indicators to detect driver drowsiness. Experts commented on a substantial amount of research supporting the use of ocular methods to detect varying levels of drowsiness within variable driving conditions. According to the experts the following factors negatively impact the data collection of eye measures: different light conditions, specifically low light, different ethnicities (i.e. harder to measure PERCLOS) and eye occlusion (e.g. from glasses). Experts also commented on the variation in required time frames to accurately calculate different ocular indicators of drowsiness, with research ranging from 20 seconds to 20 minutes.

Annex 3.1.2.2 Wearable heart rate monitoring

Experts were largely in agreement that heart rate monitoring technology, while having potential to become an effective non-invasive measure, requires more development. Monitoring heart rate variability can detect early stages of drowsiness by measuring beats per minute. However, there is currently considerable variability in research findings towards the current effectiveness of HR monitoring as a non-invasive measure.

Annex 3.1.2.3 Wearable respiration rate monitoring

Few experts had any knowledge around the effectiveness of non-invasive wearable respiration rate monitors for detecting drowsiness. An expert suggested a correlation between respiration rate and HR, however, to the best of their knowledge, research is yet to be carried out to explore this. Another expert suggested that indications of sleepiness through respiration rate monitoring occurs too late in the drowsiness process (i.e. driver is already falling asleep), while another expert commented on the challenges facing respiration rate as a method of detecting drowsiness.

Annex 3.1.2.4 Cognitive attention

Some experts commented that cognitive attention can be measured directly, using ocular measures and visual behaviour to identify if a driver is cognitively distracted (e.g. scanning or gaze duration). An expert stated that cognitive load can be measured indirectly when a driver is controlling the vehicle or inferred based on what the driver is doing when not attending the driving environment. Some experts suggest that cognitive attention may be detected using a variety of measures such as Heart Rate Variability (HRV), but challenges lie with separating drowsiness from cognitive attention. A lack of consensus amongst the experts suggests that more research is required in this area, or that technology is not mature enough to measure cognitive attention reliably or accurately.

Annex 3.1.3 DAMS validation testing

Annex 3.1.3.1 Demographics

A range of ethnicities, nationalities and genders was recommended by most experts. Specific reference to an inclusive and broad spectrum was mentioned, alongside considered specific use cases such as older drivers and novice drivers.

Annex 3.1.3.2 Testing environment

According to experts, simulators are effective at monitoring certain human states such as drowsiness in a controlled and safe environment, while real-road or test track environments allow for high fidelity testing. Most of the experts recommended a combination of simulation and real-world or test track testing environments. There was concern expressed between some experts over the different driver behaviours and lower levels of risk perception experienced by driver's in a simulator versus on real roads or on a test track.

Annex 3.1.3.3 Statistical methods

Testing the system sensitivity and specificity was recommended by a number of experts. Further recommendations mentioned by other experts were independent variables including measures of visual distraction, cognitive distraction, drowsiness, trust and microsleeps. Dependent variables suggested were hazard perception, hazard mitigation, situation awareness and reaction times to scenarios.

Annex 3.2 Literature review

Annex 3.2.1 A review of automated driving and driver drowsiness

Annex 3.2.1.1 The effect of automation on driver drowsiness

It is considered that Automated Driving Systems (ADS) will bring significant road safety benefits in terms of reduced collisions and road casualties (Thatcham Research, 2019). One of the reasons for this is that is reduces the risk of the driver experiencing cognitive overload. This is because automated driving reduces the driving demands and cognitive load of the driver (Stanton and Young 1998 as cited in (Cunningham and Regan, 2017)). In saying that, there are concerns that cognitive underload may not improve road safety and should be as much of a concern as cognitive overload (Stanton and Young 2002 as cited in (Cunningham and Regan, 2017)).

During semi-automated driving, the role of the driver changes from being in control of the driving task to monitoring the driving task. As such, there is an associated reduction in effort required of the driver. It is suggested that this reduction in effort may lead to a cognitive underload, which can induce driver fatigue and inattention. Desmond and Hancock, as cited in Saxby *et al.* (2013), propose two types of cognitive fatigue: 'active' and 'passive' fatigue, where active fatigue is a result of high cognitive workload (i.e. task demands a high level of attention; associated with cognitive overload) and passive fatigue is the result of low cognitive workload (i.e. task demands a low level of attention; associated with cognitive underload) (Saxby *et al.*, 2013;May and Baldwin, 2019).

A study by Kaduk *et al.* (2020) found that participants were sleepier, more fatigued and had a lower mental workload after an automated driving phase compared to manual driving. The results suggest that manual driving performance after an automated driving phase may deteriorate, and the driver may not be able to accurately assess whether they are in a safe state to accept a takeover request. This is in line with similar research that found driver's levels of drowsiness to be higher and task engagement to be lower during automated driving compared to manual driving (Kudinger *et al.*, 2018;Saxby *et al.*, 2013;Schömig *et al.*, 2015). A study by Goncalves *et al.* (2016) revealed that most participants reported a high level of drowsiness within 15 minutes of semi-automated driving. This was followed by a reduction in the quality of lateral vehicle control during a takeover request.

The Malleable Attentional Resources Theory[5] suggests a driver experiencing passive fatigue induced by automation is likely to have impaired driving performance after a takeover request because they are not able to meet the substantial increase in cognitive workload required to take over from automation safely (Stanton and Young 2002 as cited in (Cunningham and Regan, 2017)). While automated driving will reduce the cognitive load on drivers, if the reduction is too large, passive fatigue is likely to occur as a consequence (Cunningham and Regan, 2017) which could lead to a negative effect on the driver's ability to take back control from automated mode.

Annex 3.2.1.2 The effect of secondary task engagement on driver drowsiness

Schomig *et al.* (2015) recognise that automated driving may have negative effects on the driver state such as arousal level and driving performance. While there is limited research on this topic, some authors suggest secondary tasks could act as a countermeasure against the monotony of automation by increasing the driver's arousal and situation awareness, and providing feedback on the system state (Schömig *et al.*, 2015;Vogelpohl *et al.*, 2019). A study by Schomig et al (2015) reviewed the effect of automated driving and how driver fatigue levels may be affected by completing a secondary task. The results from the simulator study revealed that during highly automated driving (15-minute test phase), drowsiness levels increased without secondary task engagement and remained low and constant when engaging in a secondary task. Similarly, Miller *et al.* (2015) found that drivers were less likely to experience drowsiness when engaged in a reading task or a video watching task when a Level 3 ADS was engaged (simulator study; 40 minute test phase) and Naujoks *et al.* (2018) found that driver drowsiness levels during a long drive in partial automation were kept relatively low when drivers were engaged in a variety of non-driving tasks such as reading and social media. Neubauer *et al*.(2012) found that drivers braked quicker to an event after the takeover from automated to manual driving when engaged in a cell phone task compared no task, and Gold *et al.* (2018) found that the increased cognitive load from engaging in NDRT decreased the time-to-collision after a takeover.

Similar research into the use of secondary tasks to alleviate driver fatigue when the ADS is engaged revealed that the use of media devices helped minimise the loss of task engagement and improve driving performance after the takeover (Neubauer *et al.*, 2014). However, the use of the media devices did not have an effect on the driver's braking reaction times to an emergency event. This was likely attributed to the driver being out-of-the-loop for 45 minutes and either being unable to obtain sufficient situation awareness due to secondary task engagement or the alertness derived from the use of the devices did not have a lasting or transferrable effect. Saxby *et al.* (2017) conducted similar research and concluded that cell phone conversation is not a counter for automation induced fatigue and may impair the driver's awareness of their performance deficits. It is suggested that motivating and engaging tasks may be more effective to maintain driver alertness such as trivia (Oron-Gilad *et al.*, 2008;Gershon *et al.*, 2009). However, both

[5] Malleable Attentional Resources Theory: a person's attentional resource varies (is malleable) based on the demands of the task being completed.

studies highlighted that the effect of an interactive cognitive task like trivia has a localised effect, in the sense that when the task is finished the physiological effects decrease.

While there is some evidence that supports the use of secondary tasks as a countermeasure to automation induced passive fatigue, the area is under-researched and further research is required to identify the type of secondary tasks that could increase arousal levels.

Annex 3.2.2 The effect of secondary task engagement on takeover and driving performance

The DAMS first interim report highlighted the fact that there is no consensus in the literature and amongst stakeholders surrounding a safe transition time (Huysamen *et al.*, 2020). The report mentioned that drivers appear to be "able to respond to a request within 10 s, but would need more time to become situationally aware, and even more time to obtain safe lateral and longitudinal control of the vehicle (i.e. driving performance after the takeover)". There was also evidence to suggest that secondary task engagement increased transition time and further impaired driving performance after a takeover. In this phase of the research project, TRL investigated the latter findings further to assist in understanding the effect of secondary task engagement on the driver's behaviour and takeover manoeuvres.

Evidence from the literature suggests that drivers are more likely to engage in non-driving tasks with increasing levels of automation. Driver's may choose to do this to fight boredom or increase their arousal levels (Carsten *et al.*, 2012). Burnett *et al.* (2019) conducted a simulator study (n=49) investigating driver behaviour and secondary task engagement during automated driving (30-minute drive; Level 3) over 5 consecutive days. Drivers were presented with several planned and one unplanned (emergency takeover request) during the automated driving. For the planned takeover requests, drivers were provided with a 60 s preparation warning which was followed by a takeover request of 10 s. For the unplanned takeover, drivers were only presented with a 10 s takeover request. The participants could choose what to do when the ADS was engaged. The key findings from the study include:

- Driver behaviour:
  - The most common behaviour was the use of a smartphone; this was used by over 80% of the participants. The second most common behaviour was performing a reading task such as reading a book, magazine or printed paper. This was performed by 25% of the participants at some point over the five days. Other tasks included using a tablet, working on a laptop, applying cosmetics and sleeping.
  - By the end of the week, drivers were looking at the road for less than 20% of the conditional automation drive time.
  - Some drivers changed the environment to fit their chosen task such as moving the driver's seat backwards (i.e. further away from the steering wheel) to relax or to accommodate a laptop or tablet, and swapping their driving glasses for glasses they use for reading or watching TV.
  - Approximately half of the drivers gazed at their feet when preparing take over control of the vehicle (Day 1: 57%; Day 5: 44%). This was attributed to impairment of the driver's proprioception due to being out-of-the-loop.
  - Some drivers continued to engage in the secondary task after the handover had been completed. In this study, readiness was defined as one hand on the steering wheel and first glance directed towards the road scene.
- Driving performance:
  - Even with a 60 second preparation time (i.e. lead time), driving performance after the takeover was significantly impaired as evidence by high levels of

lateral instability and speed variability, particularly during the 10 s after the takeover.

- After the takeover, majority of the drivers chose to accelerate instead of brake.
- Driving performance after an emergency handover appeared to be better than after a planned takeover. This was attributed to the "heightened driver arousal associated with the event notification"
- Automated driving experience improved driving performance after the takeover (i.e. fewer lane excursions); however, on Day 5, driving performance was still significantly impaired following the takeover.

The findings of Burnett *et al*. (2019) regarding impaired driving performance after a takeover was corroborated by the findings in the DAMS first interim report. Moreover, it appears that engaging in a secondary task impairs driving performance after a takeover more than when not engaging in a secondary task. Zeeb *et al*. (2015) and Radlmavr *et al.* (2014) found that drivers were more likely to have a collision with surrounding traffic when engaging in a secondary task. Louw *et al.* (2019) found that when drivers were engaged in a secondary task, significantly more lane excursions were observed after the takeover. The reason for poorer driving performance after a takeover when engaging in a secondary task is assumed to be because the driver's level of attention to the DDT and road scene (i.e. situation awareness) is low.

As noted in the DAMS first interim report, the literature also suggests that takeover performance is worse when engaging in a secondary task compared to not engaging a secondary task. This was further corroborated by Lin *et al.* (2020) who found drivers to take longer to respond to a takeover request and Zeeb *et al.* (2015) who found drivers to react slower and incorrectly in sudden emergency take-over situations. Evidence suggests that takeover performance is dependent on the type of non-driving task being performed, where takeover time is strongly related to the manual load of the task. For example:

- Yoon and Ji (2019) found the takeover time and the first road glance after a takeover request to be longest when watching a video on a smartphone (mean = 1.8 s and 0.7 s) compared to searching a radio station (mean = 1.62 s and 0.52 s) on the entertainment console or playing a game on a smartphone (mean = 1.6 s and 0.66 s).
- Vogelpohl *et al.* (2018) found that it took drivers longer to look at the road, place their hands on the steering wheel and turn off the automation when performing a gaming task (mean = 1.9 s, 3.9 s and 5.07 s) compared to a reading task (mean: 1.14 s, 3.28 s and 4.59 s) or engaging in no task (mean = 0.12 s, 1.62 s and 2.37 s).
- Naujoks *et al.* (2019) found takeover time to be approximately 5.5 s when performing a search or reading task, 4 s when playing tetris, 3.5 s when listening to an audio book and 3 s when performing no task after a 15 min automated driver.
- Zeeb *et al.* (2016) found that when drivers were watching a video they took longer to deactivate the automated system after a takeover request (mean = 3.02 s) compared to when they were responding to an email, reading the news or not performing any task (mean ranged approximately between 1.8 and 2.1 s).
- Wandtner *et al.* (2018) found that a visual-manual version of a driving task had a slower takeover time (mean = 1.8 s) compared to an auditory-vocal (mean = 1.2 s) and visual-vocal versions (mean = 1.35 s), with the auditory-vocal version have the least detrimental effect on takeover performance.
- Roche *et al.* (2019) found visual tasks to have more of a negative effect on takeover performance and attention to the roadway compared to auditory tasks.

Secondary tasks using handheld devices have shown to increase takeover time by as much as 1.6 s (Zhang *et al.*, 2018). One theory behind this effect is that before drivers can engage in the driving task, they are required to put down the device initiating eye and body movements to find and move the device into a safe place (Zeeb *et al.*, 2017;Wandtner *et al.*, 2018). It should be noted that there are some studies that have found no significant effect of secondary task engagement on takeover time. These studies are highlighted in a review conducted by MacDonald *et al*. (2019).

Vogelpohl *et al.* (2018) found that reaction times to a takeover request were unaffected by secondary task engagement; however, the length of time to look at the mirrors and speedometer was affected, where drivers engaging in secondary tasks took longer. This suggests that drivers engaging in a secondary task prior to a takeover take longer to regain situation awareness. Findings from Burnett *et al.* (2019) and Roche *et al.* (2019) suggest that drivers gaze less at the road when engaged in a secondary task, especially if the task is visually demanding, resulting in reduced situation awareness. The theory that situation awareness is impaired due to secondary task engagement negatively affecting the takeover performance and/or driving performance is corroborated by Zeeb *et al.* (2015), Burnett *et al.* (2019), Mc Donald et al. (2019) and Louw *et al*. (2019). Zeeb *et al*. (2015) states:

"Drivers who distribute their visual attention appropriately between the driving and secondary task and regularly monitor the roadway should be able to acquire and maintain high situation awareness. This allows rapid orientation and quick reaction in unexpected takeover situations. In contrast, a driver who is more focused on the secondary task will have a less complete and presumably less adequate mental model of the driving situation and thus will take more-sometimes too much-time to update the model before reactions can be generated".

Gold et al. (2016) suggest that longer takeover times could result in better takeover quality as it allows driver's more time to regain situation awareness before resuming control of the vehicle. It has been suggested in the literature that automated vehicles should implement strategies that support time sharing between non-driving and driving tasks (Kanaan *et al.*, 2020;He and Donmez, 2019). This strategy would not prevent distraction but help manage the degree of it in certain situations. For example, if the driver were required to intervene immediately (i.e. takeover request), the ADS could lock or interrupt the non-driving task. This was demonstrated by Wandtner *et al.* (2018) who found drivers to respond quicker (i.e. hands on wheel) when the non-driving task was stopped during the takeover compared to when it was not stopped. Köhn *et al.* (2019) found improvements in takeover performance and situation awareness when frequently interrupting a video being watched by the driver. This interruption provided the driver with an image of the driving scene.

Annex 3.2.3 Chronogram: Review of takeover manoeuvres

TRL developed a chronogram on the takeover manoeuvres from the literature reviewed in the DAMS first interim report and current study. The chronogram, which can be found in Annex 5, details the reaction time to a takeover request for several studies, as well as driving performance after the resumption of control, if reported. The chronograms also detail whether the takeover was self-paced, an emergency (indicated by a lead time in the chronogram – the amount of time before a critical event) or unplanned (indicated by a time budget in the chronogram – the amount of time before the system reaches its ODDs). Whether the study investigated secondary tasks is also reported, along with the type of secondary task performed. For all studies, the mean reaction time was reported. Some studies also reported the standard deviation (represented by the boundaries of the rectangle) and the 5th and 95th percentile (represented by the whiskers of the rectangle). One study was conducted on real roads (Naujoks *et al.*, 2019), while the rest of the studies were carried out using driving simulators.

The key findings are highlighted below:

- The mean reaction time to a takeover request was less than 10 s for all papers reviewed in this study. Seven papers reported the 95th percentile reaction time, where four of these found the reaction time to be greater than 10s. This could be attributed to the following factors:

- Alert type: Naujoks et al. (2014) found the 95th percentile reaction time to be greater than 20 s when participants were presented with a visual takeover request alert, however this was less than 10 s when a visual-auditory alert was presented.
- Planned takeover: Payre et al. (2016) provided drivers with 30 s to respond to a planned takeover request. The 95th percentile reaction time to this request was greater than 15 s. However, when presented with an emergency takeover request, the 95th percentile reaction time was below 10 s.
- Takeover urgency: Erikson and Stanton (2019) informed drivers to adhere to instructions of a takeover request "only when they felt safe to do so". The aim of this was to 1) reduce the pressure on the driver to respond immediately and 2) ensure the driver is aware that they are the ones responsible for the safe operation of the vehicle. This reduction in urgency to takeover (i.e. self-paced takeover) could explain the long reaction times reported in this study (No secondary task: Median = 4.57 s, Maximum = 25.75 s; Reading task: Median = 6.06 s, Maximum = 20.99 s).
- Secondary task type: Naujoks et al. (2019) investigated the effect of several secondary tasks on takeover time, where the 95th percentile reaction time reported for the reading task was 10.91 s. The 95th percentile reaction times for the search, tetris, audio book and reference task was below 10 s. Evidence suggests that visual-manual tasks elicit longer reaction times compared to auditory tasks.

- Most of the studies comparing the effect of secondary task engagement on reaction time to a takeover request found the reaction times to be longer when engaged in a secondary task compared to not being engaged in a secondary task
- From the limited data, it appears visual-manual and visual demanding tasks elicit a longer reaction time to a takeover request compared to auditory tasks, but more data is required to confirm this statement.
- From the studies reviewed, some reported impaired driving performance after the takeover request when no secondary task was performed, where others did not report impairment.
- Most of the studies reported impaired driving performance when a secondary task was performed prior to the takeover request, especially for visual and visual-manual tasks.

Annex 3.2.4 A review of HMI design for automated vehicles

The human-machine interface (HMI) of an ADS is of vital importance as it acts as the point of communication between the ADS and the driver. Information on vehicle functions and status has commonly been presented to the driver through the use of an HMI. However, the HMI design of an ADS must account for a higher level of interaction between the driver and the system than that of other driver assistance or warning systems. This interaction is more complex with ADS due to the changing responsibilities of the driver between partial or full control of the vehicle and the required two-way communication. The HMI must be designed to provide adaptable and relevant information to the driver to ensure appropriate and safe control of the vehicle during different levels of automation.

Annex 3.2.4.1 Automation status

A number of authors state the importance of ensuring mode awareness. As the complexity of automation increases, it becomes increasingly important to ensure that the driver is aware of the current system mode. This requires clear differentiation between manual and automated modes communicated to the driver through strong feedback to ensure predictability and understanding of the driver's role within the dynamic driving task (DDT) (Montalvo *et al.*, 2020;Sheridan and Parasuraman, 2005;Carsten, and Martens, 2019;Beggiato *et al.*, 2015;Thatcham Research, 2019). Bengler *et al.* (2020) state that to ensure mode awareness, transparency of automation to the driver, communicated by a HMI, is vital to ensure safe transitions between automation levels. Automation status can maintain driver's situation awareness, communicate if a driver's request has been received by the system and update the driver about the systems performance and any problems (Toffetti *et al.*, 2009). In a study by Beggiato *et al.* (2015) the status of the system and the degree of certainty that the ADS can handle the current scenario were deemed the two most essential information needs for HMI design. An adaptable HMI is suggested by Montalvo *et al.* (2020)) to provide optimum support for the driver and avoid known operators errors such as mode confusion that come from inadequate information. Feldhütter *et al.* (Anon., 2017), conducted a study to investigate if adaptive HMI could improve driver mode awareness. The adaptive HMI, which had additional mode awareness features and a time bar to highlight takeover time, did not lead to improved mode awareness in comparison to an acoustic and heads-up HMI display. However, the results revealed that a number of participants did not notice the adaptive HMI, concluding that the conspicuity of the HMI is crucial to improve mode awareness. Further results from Burnett (2019) found no correlation between system status feedback and the number of mirror checks undertaken by the driver during and shortly after a takeover and as such had no effect on situation awareness. However, providing a HMI that presented the automation status reduced the time to driver readiness (defined as at least one hand being on the steering wheel and a first glance directed towards the road scene) during an emergency takeover (Burnett *et al.*, 2019).

While a number of studies recommend several principles to consider for HMI, it is clear that more research is required to understand the key design characteristics. In a study prepared for the European Commission by Montalvo *et al.* (2020), it is stated that operator errors such as mode confusion are a result of a lack of adequate or sufficient information. As such, 'commonality' of an HMI is recommended. This suggests the functional logic (the way in which the ADS interacts with the user), the transitions of control (driver's understanding of the allocation of control), control elements (deactivating and activating the ADS through braking, steering, accelerating or decelerating) needs to be standardised across OEMs to promote user understanding and trust.

Annex 3.2.4.2 Takeover guidance

HMI has been highlighted as a critical feature to enable drivers to safely and efficiently take back control of the vehicle from automated mode. Studies have highlighted that the design of the HMI can influence drivers takeover time and quality of driving after the takeover. The type of modality should depend on the driving environment, the urgency of the message and location of visual displays (Fisher *et al.*, 2020). In general, it is believed that a multimodal HMI strategy of audio and visual takeover information is essential for takeover requests (Melcher *et al.*, 2015;Bengler *et al.*, 2020). Further, audio feedback through tones and spoken messages are more effective as warnings, while visual feedback through text and images are more effective at monitoring and communicating the status of the ADS and other non-critical information (Montalvo *et al.*, 2020;Burnett *et al.*, 2019;Fisher *et al.*, 2020). Results from a study by Burnett (2019) found that multimodal warnings result in shorter reaction times to takeover requests and faster perceptions of high amounts of information. A study by Toffetti *et al.* ((2009) compared a combination of multimodal warnings: a visual-audio HMI and a HMI that had visual, audio and vocal modalities (i.e. spoken words). The HMI with vocal modality increased general levels of awareness and was perceived as safer than the visual-audio. Vocal modality can be considered more appropriate for initial information, especially information around system failures, and resulted in quicker reaction times. Naujoks *et al.* (Anon., 2014) conclude that just visual HMI is unlikely to be enough to ensure safe takeovers. Multimodal warnings result in shorter reaction times and safer takeovers (Bengler *et al.*, 2020;Naujoks *et al.*, 2014). Alongside auditory and visual modalities, haptic/tactile messages are also considered to be capable in capturing the driver's attention quickly. Fisher *et al*. (2020) highlight two forms: vibrotactile interfaces and kinaesthetic interfaces. Vibrotactile interfaces provide vibrations which may be included in seat belts, seats, foot pedals and steering wheel, whereas kinaesthetic interfaces create limb or body motion from foot pedal counterforce or brake jerks. Haptic or tactile messages are suggested to be beneficial in alerting drivers to takeover requests by sufficiently alerting them and regaining their attention (Fisher *et al.*, 2020). Burnett et al. (2019) trialled top-down HMI feedback (visual guidance highlighting important areas such as mirrors and a countdown timer to highlight lead time) with a bottom-up feedback (simple 'take control' request). While it is suggested that a top-down HMI approach increases situation awareness, results indicate that drivers were using the prepare-to-drive time to stop their secondary task, rather than re-engaging with the driving task. Burnett et al. (2019) suggests that greater clarity and training is required when providing a top-down HMI such as a countdown timer.

Fisher *et al.* (2020) discuss the wide range of research that supports staged warnings in assisting a driver in recognising and responding to a hazard. Staged warnings involve two or more levels of warnings, which escalate in urgency. Fisher et al. highlight the benefit of a staged warning by creating more time for the driver to recognise and respond to a hazard and improving the driver's awareness of the systems ODD. Escalating tones to highlight the urgency by increasing proportionally in terms of timings and modality is widely stated as an effective HMI measure to support the driver in a takeover scenario (Fisher *et al.*, 2020;Thatcham Research, 2019;Flemisch *et al.*, 2011).

Design features such as a heads up display with augmented reality have the potential to improve drivers situation awareness by providing key, time-critical information (Fisher et al., 2010) and to display confidence in the system's ability to handle a scenario (Guo *et al.*, 2017).

Annex 3.2.4.3 Driving performance

Situation awareness

During automated phases, the driver may lose situation awareness to the driving task from a lack of active control in the driving task or from involvement in a secondary task. Research suggests that HMI design can help drivers maintain situation awareness, and therefore improve safety and driver performance. Fisher *et al.* (2020) state that a visual HMI that displays information such as the location of potential hazards or information about surrounding vehicles can help drivers regain situation awareness. Future design may be able to use this information and combine it with information about the driver state (e.g. eye glance history) to help direct the driver towards specific elements of the environment. Burnett's top-down HMI approach found similar results. Drivers were encouraged to check for hazards prior to taking back control, which resulted in increased mirror checks to the simple bottom-down HMI takeover request. Nevertheless, several drivers did not check their mirrors despite the HMI prompt; Burnett et al. (2019) reflected this could be a result of low traffic density and recommended further research into the effect this type of HMI may have on situation awareness (Burnett *et al.*, 2019).

Even if drivers have enough situation awareness through the support of an informative HMI, results from Burnett et al. (2019) suggest that driving performance may still be affected after a takeover until drivers have become re-accustomed with steering and pedal inputs.

Trust

A lack of trust in the ADS can have a negative effect on driving performance, specifically the takeover time, while, too much trust in the automated system could lead to over-reliance and risk adaption (Mahr and Müller, 2011). HMI is considered a key element to ensure acceptance, trust and safety of the ADS from the driver (Bengler *et al.*, 2020). Results from a study by Beggiato *et al.* (2015) found that information needs correlate with the level of trust in the system. The more trust the driver has in the system, the less information is demanded. Experts and users both suggest that less information will be required over time as higher trust and familiarity in the system grows. Adaptive HMI displays are considered as a solution to support the driver as they build trust in the system; however, future research is required to validate this.

Annex 3.3 UNECE guidance on secondary tasks

The UNECE have two working groups which address secondary tasks and automated driving:

1. The Global Forum for Road Traffic Safety (WP.1)
2. The World Forum for Harmonization of Vehicle Regulations (WP.29)

The work conducted and guidance provided by these two working groups are discussed below. The three main documents of interest include:

1. ECE/TRANS/WP.1/2019/3/Rev.1 (2020): Revised safety considerations for activities other than driving undertaken by the driver in a vehicle when its automated driving system is engaged.
2. Informal document No.4 (UNECE, 2017): Discussion paper on possible driver's "other activities" while an automated driving system is engaged.
3. ECE/TRANS/WP.29/1140 (2018): Reference document with definitions of Automated Driving under WP.29 and the General Principles for developing a UN Regulation on automated vehicles.

Annex 3.3.1 Global Forum for Road Traffic Safety (WP.1)

Annex 3.3.1.1 ECE/TRANS/WP.1/2019/3/Rev.1

The Global Forum for Road Traffic Safety (WP.1) recommend a framework comprising four criteria for drivers to engage in non-driving related activities whilst the ADS is engaged. The criteria were developed as the organisation does not believe it is feasible to develop a complete list of acceptable non-driving related activities or tasks. According to the Global Forum for Road Traffic Safety, drivers are permitted to engage in activities not related to driving, so long as the following criteria are met:

a) The activities conducted must not prevent the driver from being able to respond to any manual take-over demand that is received from the vehicle;

b) The activities must align with the prescribed use of vehicle systems and their pre-defined functions;

c) The driver must continue to abide by any traffic laws that apply including the secondary activities that are permitted; and

d) The driver must still have the required capabilities to meet their duties during automated and manual driving.

Each of the criterion proposed are further expanded and explained below.

The Global Forum for Road Traffic Safety also highlights the importance to manage the driver's attention, to ensure they are alert enough to be able to safely resume manual control from the automated system. It is suggested that activities which are integrated into the vehicle could be automatically suspended when a take-over request is issued, stating this as an effective measure to allow non-driving related activities, as well as ensuring the cessation of the activity when a take-over request is initiated.

Annex 3.3.1.2 Criterion a

The activities conducted must not prevent the driver from being able to respond to any manual take-over demand that is received from the vehicle.

- In the event of a take-over request, the driver is expected to be able to resume control of the vehicle in a timely, safe and proper manner.
- Whilst the ADS is engaged, secondary activities that the driver engages with should not compromise the *ability, readiness, and willingness* of the driver to resume full safe manual control, in planned and unplanned take-over requests.
- Level 4 automated vehicles do not have unplanned takeovers. Therefore, in these vehicles, the driver must ensure the non-driving related activity being performed does not impair their ability to safely continue with their journey.
- During take-over requests the ADS must maintain control of the vehicle until there is confirmation that the driver has safely resumed control. If the driver fails to do so, the vehicle must use an appropriate minimum risk manoeuvre.
- The non-driving related activity is prohibited to interfere with any part of the ADS which could jeopardise safety.

Annex 3.3.1.3 Criterion b

The activities must align with the prescribed use of vehicle systems and their pre-defined functions.

- When designing the ADS' Human-Machine Interface (HMI), Criterion 1 must be considered by the manufacturer. This includes the take-over scenario and a safe take-over timeframe.
- Manufacturers must include a driver monitoring system in vehicles to monitor the driver's availability. This should also detect that the driver has safely resumed control before the vehicle deactivates the ADS.
- If the driver is unable to driver safely after a takeover request, the system should take all adequate steps to ensure road safety and endeavour not to obstruct traffic flow.
- The manufacturer is responsible for "providing the driver with clear descriptions of the intended use of the vehicle's systems and the driver must be aware of these before using the system in order to ensure safe use". This should include the driver role and responsibilities, as well as their expected behaviour during the takeover. The information provided must not use "misleading names, descriptions or promotional material" which may lead to unsafe use of the system.
- The communication from the system to the driver must be clear so that the driver is able to understand any information provided to them by the system.

Annex 3.3.1.4 Criterion c

The driver must continue to abide by any traffic laws that apply including the secondary activities that are permitted.

- Contracting parties are recommended to develop regulations and/or measures surrounding the engagement in non-driving related activities whilst the ADS is engaged.
- Drivers should familiarise themselves with the non-driving related activity requirements of the country they are in before they begin their journey to ensure they comply with them.

Annex 3.3.1.5 Criterion d

The driver must still have the required capabilities to meet their duties during automated and manual driving.

- Throughout the DDT, the driver must have the "required physical and mental capabilities and skills to manually driver the vehicle".
- Prior to engaging in a non-driving related activity, the driver should consider their capability to resume the DDT safely. Some people may not have the mental or physical capabilities required to safely engage in specific non-driving related activities.

Annex 3.3.2 Informal document No. 4/WP1/2017

This document was published by Global Forum for Road Traffic Safety (WP.1); it is a discussion paper following on from the 75th WP.1 session.

Annex 3.3.2.1 Views of vehicle manufacturers on "other activities"?

Manufacturers think that while ADS is engaged, a driver may be able to engage in other activities if it does not compromise their ability to resume manual control when required. It is believed that secondary activities could possibly prevent undesirable driver states, such as the negative effects of underload caused by automated driving.

The automotive industry proposes to use the description 'secondary activities' during automated driving (Level 3 to 5); which means any activity that is not something generally accepted to occur during manual driving, for example, activities that go beyond using the radio or adjusting the heating.

The general approach of manufacturers for secondary activities (for Level 3 and Level 4 systems) is to focus on vehicle-integrated 'infotainment systems' operable from the driver's seat. This can be fully developed by the manufacturer and controlled by the automated system (e.g. during a take-over request the activity can be terminated, and the system can ensure sufficient and safe take over time). It is suggested that complex secondary activities that would prevent the driver from safely reacting to take-over demands should not be allowed in conditional automation.

Manufacturers' classification of acceptable secondary tasks during Level 3 ADS engagement includes those which are simple and do not require a high level of physical or cognitive engagement. This includes:

- Use of infotainment system which is located 'perceptually upright' to the driver for uses such as video calls, streaming video and using the internet.
- Use of electronic handheld devices such as smartphone or tablet that are connected to the vehicle so that they can be controlled through the vehicle's HMI.
- Potential use of handheld devices and books etc. providing there are studies to prove they are safe.

It is suggested that studies should be done to prove which secondary tasks influence driver capability to resume control of the vehicle.

Manufacturers state that drivers should be able to engage in any secondary task when the ADS of a Level 4 Automated Vehicle is engaged (until it reaches the end of its ODD) because this level of automation does not include unplanned takeovers.

Manufacturers can help to decide what activities a 'driver' can do when the ADS is engaged although the final regulatory decision will lie with public authorities. However, the manufacturers expect to be responsible for proving the efficacy of engaging in secondary activities integrated into their infotainment systems whilst demonstrating and independently verifying the safety of this approach.

It is also noted that there should be a standardised interface between the driver and the vehicle. A clearly defined HMI requires a harmonised approach to reduce the chance of human confusion or error because the system delivers safety critical information.

Annex 3.3.2.2 The views of the contracting parties on "other activities"

Contracting parties, part of IGEAD, include representatives from Spain, UK, Japan, Finland, Sweden, Belgium, Switzerland, Germany, Netherlands, France and CLEPA.

Spain say that the definitions should remain high level to ensure that they are technology agnostic. They suggest that the most important thing to focus on is driver monitoring. Spain will allow mobile phone use in Level 3 Automated Vehicles.

In the UK there are currently no plans to lift the ban on using mobile phones whilst driving due to the negative behaviour this induces in drivers of conventional vehicles.

Japan agree with Spain that the definitions need to remain high level for the purpose of technology development. They also acknowledge that national rules need to be adhered to as Japan already has rules with regard to secondary activities. They also discuss the need for driver monitoring and recognition of driving mode from the exterior so that law enforcement can enforce these rules.

Finland say that even when allowing secondary activities that are connected to the in-vehicle systems there should be caution. The definition of driver responsibility should be clearly defined, and the system should be able to account for misbehaviour and human error to ensure road safety.

Sweden state that manufacturers should prove what is safe in relation to their systems. There need to be more definitions about what is permitted in Level 3 compared to Level 4 Automated Vehicles.

Belgium supports Finland and Sweden and agrees that the differences between Level 3 and 4 Automated Vehicles need to be made clearer.

The Swiss representative wanted clarification on the amount of time that a driver engaged in a secondary task had to take-over control of the vehicle and what the risks of not responding would be, along with the consequences of a MRM, in order to determine safe secondary tasks that could be allowed.

Germany hesitate to name 'reading a book' or 'sleeping' in their list of appropriate tasks.

The Netherlands state that it is urgent to create a list of acceptable secondary tasks as the first Level 3 and 4 Automated Vehicles are appearing on the market and it may result in national decisions contradicting one another. The ability to perform secondary activities depends on the role and responsibilities of the driver and the amount of distraction that is deemed as acceptable. Similarly to Japan, Netherlands considers implementing a different coloured light for law enforcement to identify vehicles in automated mode.

France believe that some activities should be permitted as drivers will break rules regardless. For this reason, they suggest that a regulation is used instead of guidelines.

CLEPA believe broad categories of other activities would be appropriate.

Annex 3.3.3 World Forum for Harmonization of Vehicle Regulations (WP.29)

According to the World Forum for Harmonization of Vehicle Regulations, for Level 1 and 2, the driver may not perform secondary activities, whereas for Level 3 to 5, the driver may perform secondary activities. The sections below summarise WP.29 recommendations and guidelines for Level 3 and 4 Automated Vehicles.

Annex 3.3.3.1 Level 3

- When the ADS is engaged, the driver may turn their attention away from the driving task within the system’s ODD.
- The driver can only perform secondary activities with appropriate reaction times; these activities, as well as appropriate reaction times are unspecified by WP.29.
- It is recommended that the vehicle displays are used for secondary activities, because they could be used to improve the take-over process in a Level 3 Automated Vehicle (i.e. the allowed activities can be controlled by the ADS in the event of a take-over demand).
- The secondary tasks shown on the infotainment system should be deactivated in the event of a takeover request.
- The driver is not expected to intervene as quickly as with Level 1 and 2 due to the system being able to perform emergency manoeuvres (i.e. the minimal risk manoeuvre will be initiated if safe take-over is not detected).
- The system must be able to accomplish emergency braking so that it is not expected from the driver since they could be engaged in secondary activities.

Annex 3.3.3.2 Level 4

- When a Level 4 ADS is engaged, the driver may perform a wide variety of secondary activities within the system’s ODD.
- The system must be able to accomplish emergency braking so that it is not expected from the driver since they could be engaged in secondary activities.

Annex 3.3.4 Conclusion

According to the Organisation Internationale des Constructeurs d'Automobiles (OICA) there is currently no formal legislation regarding secondary activities that are permitted. To ensure alignment and harmonisation, there needs to be good collaboration between UNECE WP.29 and WP.1 to avoid ‘any legal gap(s) between the driver’s requirements and the vehicle’s construction requirements’ and exchange of knowledge and methods chosen whilst regulating automated driving functions.

Annex 4 EXPERT ENGAGEMENT TOPIC GUIDE

	Topic 1: Defining an Automated Driving System (ADS)
1	The SAE defines six levels of driving automation. This is the most widely recognised way of classifying and distinguishing between different Automated Driving Systems (ADS). Do you believe that an ADS should be classified based on the SAE six levels of automation? If not, how would you recommend doing this?
2	What do you consider the role of the driver to be when a Level 3 ADS is engaged and what do you believe the driver is allowed and not allowed to do? What do you consider the role of the driver to be when a Level 4 ADS is engaged and what do you believe the driver is allowed and not allowed to do?

	Topic 2: Human states and/or behaviours
1	In order to determine what human states, characteristics or behaviours the DAMS should be monitoring, we must consider what driver states or behaviours are acceptable and unacceptable when a Level 3 and 4 ADS is engaged. What driver states or behaviours do you consider as acceptable (e.g. alert/awake) and unacceptable (e.g. drowsy/asleep) when a • Level 3 ADS is engaged? • Level 4 ADS is engaged?
2	For a driver to take back control they need to be deemed available, ready, able and willing to take back control of the vehicle. • What do you consider an **available** driver look or behave like? • What do you consider a **ready** driver look or behave like? • What do you consider an **able** driver look or behave like? • What do you consider a **willing** driver look or behave like?
3	What do you believe should happen when the DAMS can no longer detect the drivers' eyes and/or face?

	Topic 3: Take-overs
1	What do you consider as the minimum timeframe for takeovers ensuring majority of drivers are able to safely take back control of the vehicle after the ADS is disengaged?
2	Should drivers be allowed to engage in secondary tasks when a: • Level 3 ADS is engaged? • Level 4 ADS is engaged? What limitations, if any, should be placed on drivers in terms of the type of secondary tasks they are allowed to engage in for: • Level 3? • Level 4?
3	If the driver was performing a secondary task (e.g. texting, reading, eating, working on laptop etc.), to what extent would this impact the timeframe required to ensure a safe takeover? To what extent is this dependent on the *type* of secondary task being performed?
4	Should the takeover time be different for unplanned and planned takeover requests?
5	For the regulation, the minimum takeover time needs to be established. Do you think this timeframe should be based off the mean, 95^{th} percentile or 99^{th} percentile takeover time?
8	What human factors are likely to have the greatest impact on driver reaction times to a takeover request (e.g. age, gender, level of experience)? What level of variability in reaction times should we expect to see across the driver populations?
9	Do you think the quality of driving performance (i.e. manual driving quality) after a takeover situation is better when the takeover is accomplished at the drivers own speed (i.e. self-paced) rather than being specified by the system?
10	Do you believe the driver should be supported / monitored during (and shortly after) the takeover to manual driving? If yes, why? If you believe the driver should be supported, how would you suggest doing this? If you believe the driver should be monitored, what driver states or behaviours should be monitored?
11	Do you believe the DAMS should switch off as soon as the driver has completed the takeover or for a period time after the takeover has been completed?

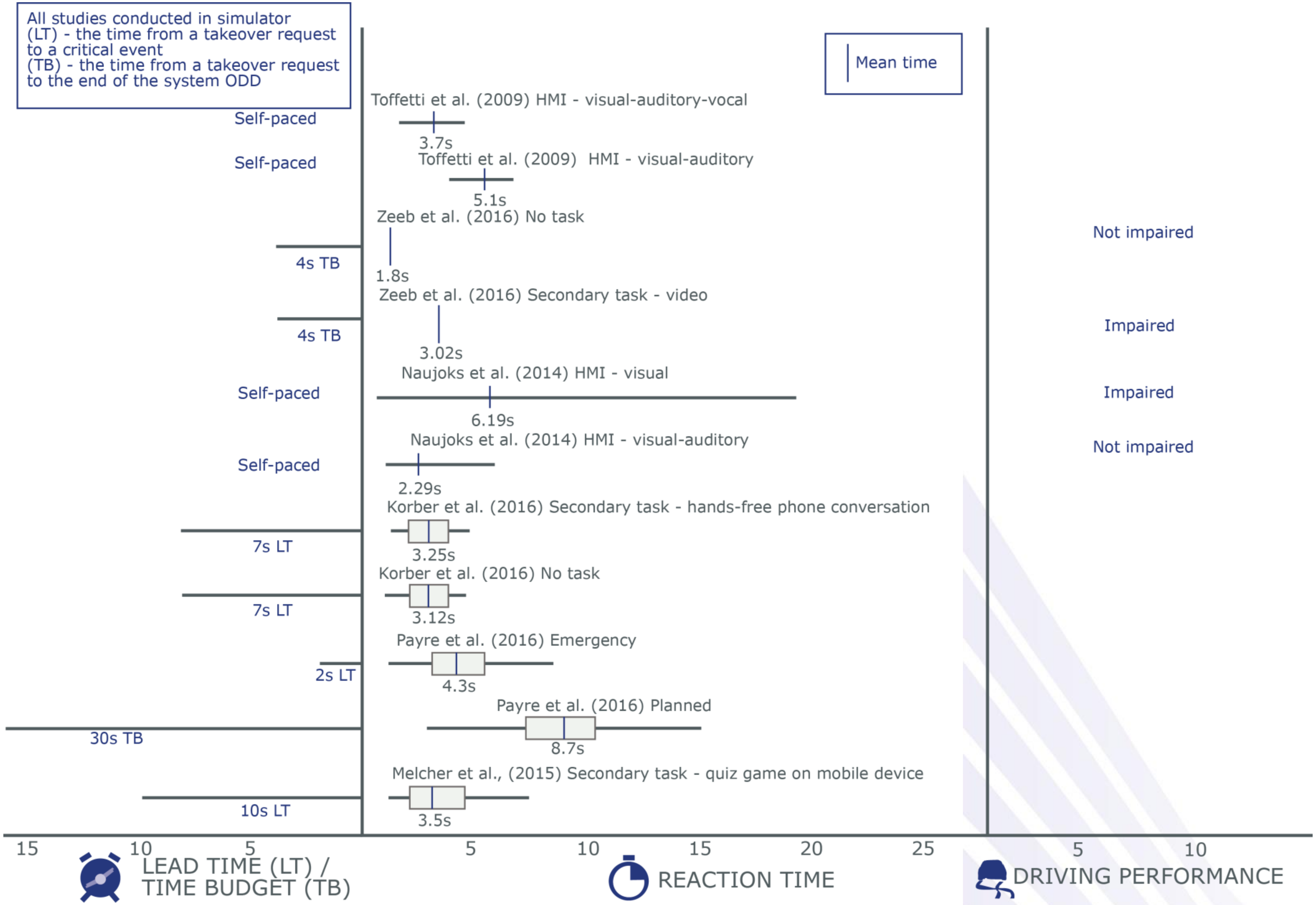
12	Do you have insight into the quality of driving performance after a takeover situation? If so, • Is the quality dependent on the type of takeover (i.e. unplanned and planned)? • Is the quality dependent on whether the driver was engaging in a secondary task prior to takeover? If yes, is it dependent on the type of secondary task?

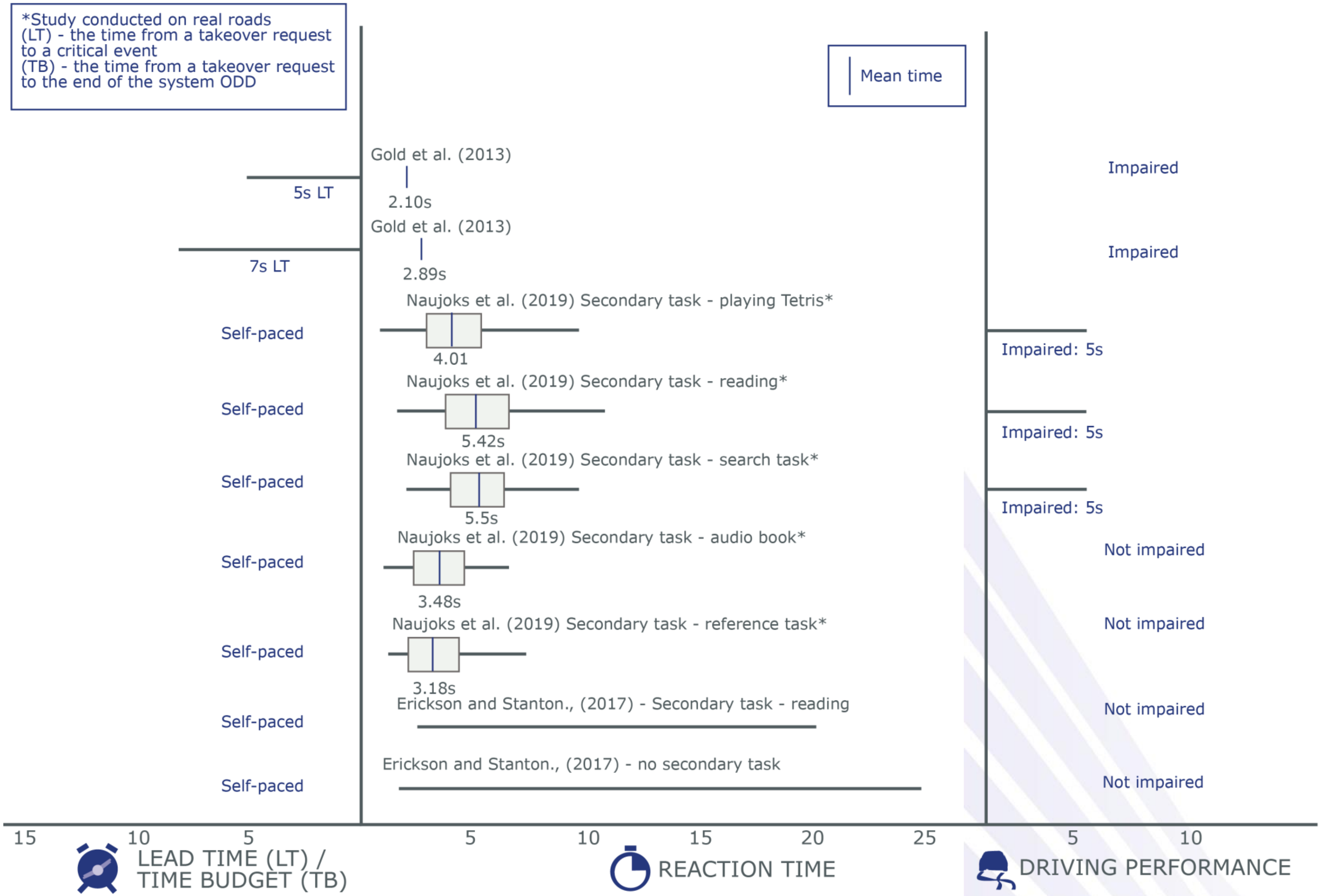
	Topic 4: Physiological Indicators of Drowsiness
1	What are the most effective non-invasive physiological indicators to detect driver drowsiness in early stages in a non-controlled environment (e.g. whilst driving a vehicle on real roads)?
2	What are the data collection requirements for eye measures to ensure valid and reliable results? Does the time interval in which an eye measure is calculated influence its effectiveness in detecting drowsiness? In which intervals should eye measures be calculated to detect drowsiness accurately?
3	How effective or ineffective is a non-invasive wearable heart rate monitor for detecting drowsiness? Is it possible to use a HR monitor to detect early stages of drowsiness? What level of variability should be expected in HR measures? Are there appropriate HR thresholds for classifying a driver's levels of drowsiness?
4	How effective or ineffective is a non-invasive wearable respiration rate monitor for detecting drowsiness? Is it possible to use a wearable respiration rate monitor to detect early stages of drowsiness? What level of variability should be expected in respiration rate measures? Are there appropriate respiration rate thresholds for classifying a driver's levels of drowsiness?
5	Do you believe it is possible to directly or indirectly measure cognitive attention? If so, can this be done non-intrusively and effectively in a real-world driving environment?

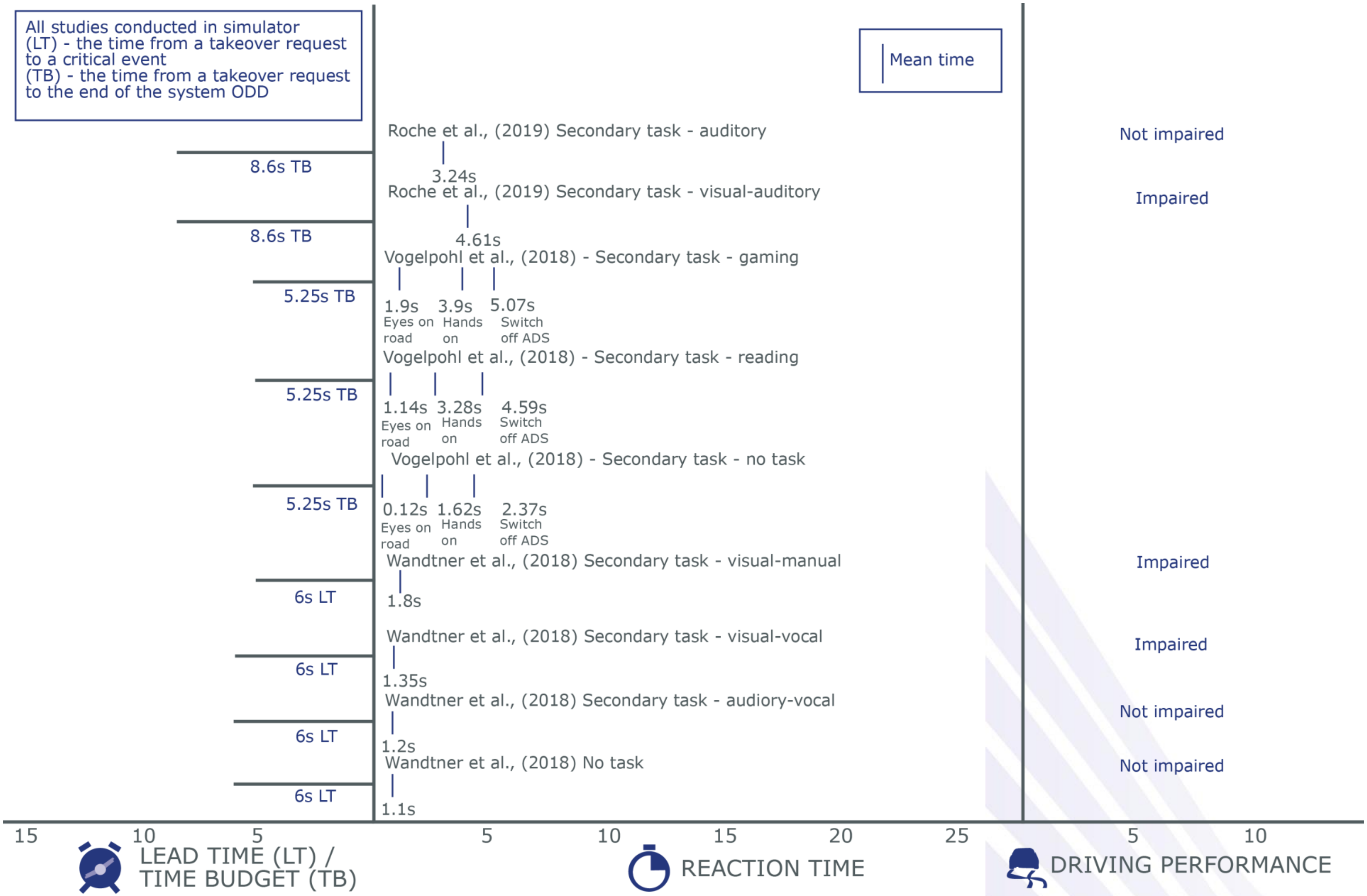
	Topic 5: Validation testing
1	What demographics (i.e. sample requirements) should be used to test the effectiveness of a DAMS?
2	How do you think the effectiveness of a DAMS should be tested? This includes factors such as the testing environment (e.g. simulator, test track, real-roads), the testing protocol, the factors and conditions to be tested, the dependent and independent variables and the statistical methods used to validate the system etc.

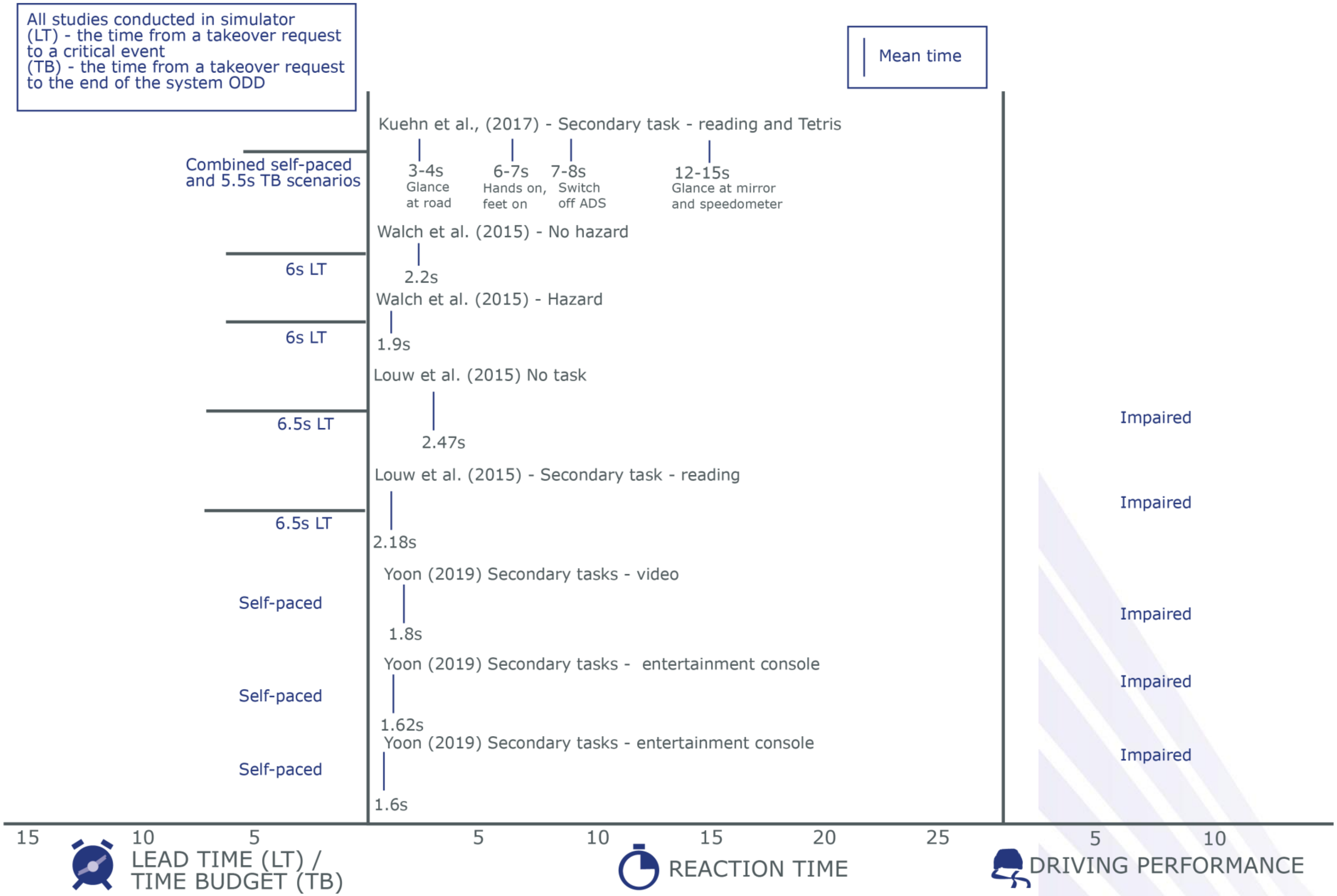
Annex 5 CHRONOGRAMS ON TAKEOVER MANOEUVRES

The chronogram details the reaction time to a takeover request for several studies, as well as driving performance after the resumption of control, if reported. The chronograms also detail whether the takeover was self-paced, an emergency (indicated by a lead time in the chronogram – the amount of time before a critical event) or unplanned (indicated by a time budget in the chronogram – the amount of time before the system reaches its ODDs). Whether the study investigated secondary tasks is also reported, along with the type of secondary task performed. For all studies, the mean reaction time was reported. Some studies also reported the standard deviation (represented by the boundaries of the rectangle) and the 5th and 95th percentile (represented by the whiskers of the rectangle). One study was conducted on real roads, while the rest of the studies were carried out using driving simulators.


All studies conducted in simulator
(LT) - the time from a takeover request to a critical event
(TB) - the time from a takeover request to the end of the system ODD
Mean time
Toffetti et al. (2009) HMI - visual-auditory-vocal
Self-paced
3.7s
Toffetti et al. (2009) HMI - visual-auditory
Self-paced
5.1s
Zeeb et al. (2016) No task
4s TB
1.8s
Not impaired
Zeeb et al. (2016) Secondary task - video
4s TB
3.02s
Impaired
Naujoks et al. (2014) HMI - visual
Self-paced
6.19s
Impaired
Naujoks et al. (2014) HMI - visual-auditory
Self-paced
2.29s
Not impaired
Korber et al. (2016) Secondary task - hands-free phone conversation
7s LT
3.25s
Korber et al. (2016) No task
7s LT
3.12s
Payre et al. (2016) Emergency
2s LT
4.3s
Payre et al. (2016) Planned
30s TB
8.7s
Melcher et al., (2015) Secondary task - quiz game on mobile device
10s LT
3.5s
15
10
5
5
10
15
20
25
5
10
LEAD TIME (LT) / TIME BUDGET (TB)
REACTION TIME
DRIVING PERFORMANCE


*Study conducted on real roads
(LT) - the time from a takeover request to a critical event
(TB) - the time from a takeover request to the end of the system ODD
Mean time
Gold et al. (2013)
2.10s
5s LT
Impaired
Gold et al. (2013)
2.89s
7s LT
Impaired
Naujoks et al. (2019) Secondary task - playing Tetris*
Self-paced
4.01
Impaired: 5s
Naujoks et al. (2019) Secondary task - reading*
Self-paced
5.42s
Impaired: 5s
Naujoks et al. (2019) Secondary task - search task*
Self-paced
5.5s
Impaired: 5s
Naujoks et al. (2019) Secondary task - audio book*
Self-paced
3.48s
Not impaired
Naujoks et al. (2019) Secondary task - reference task*
Self-paced
3.18s
Not impaired
Erickson and Stanton., (2017) - Secondary task - reading
Self-paced
Not impaired
Erickson and Stanton., (2017) - no secondary task
Self-paced
Not impaired
15
10
5
5
10
15
20
25
5
10
LEAD TIME (LT) / TIME BUDGET (TB)
REACTION TIME
DRIVING PERFORMANCE


All studies conducted in simulator
(LT) - the time from a takeover request to a critical event
(TB) - the time from a takeover request to the end of the system ODD
Mean time
Roche et al., (2019) Secondary task - auditory
8.6s TB
3.24s
Not impaired
Roche et al., (2019) Secondary task - visual-auditory
8.6s TB
4.61s
Impaired
Vogelpohl et al., (2018) - Secondary task - gaming
5.25s TB
1.9s Eyes on road
3.9s Hands on
5.07s Switch off ADS
Vogelpohl et al., (2018) - Secondary task - reading
5.25s TB
1.14s Eyes on road
3.28s Hands on
4.59s Switch off ADS
Vogelpohl et al., (2018) - Secondary task - no task
5.25s TB
0.12s Eyes on road
1.62s Hands on
2.37s Switch off ADS
Wandtner et al., (2018) Secondary task - visual-manual
6s LT
1.8s
Impaired
Wandtner et al., (2018) Secondary task - visual-vocal
6s LT
1.35s
Impaired
Wandtner et al., (2018) Secondary task - audiory-vocal
6s LT
1.2s
Not impaired
Wandtner et al., (2018) No task
6s LT
1.1s
Not impaired
15 10 5
LEAD TIME (LT) / TIME BUDGET (TB)
5 10 15 20 25
REACTION TIME
5 10
DRIVING PERFORMANCE


All studies conducted in simulator
(LT) - the time from a takeover request to a critical event
(TB) - the time from a takeover request to the end of the system ODD
Mean time
Kuehn et al., (2017) - Secondary task - reading and Tetris
Combined self-paced and 5.5s TB scenarios
3-4s Glance at road
6-7s Hands on, feet on
7-8s Switch off ADS
12-15s Glance at mirror and speedometer
Walch et al. (2015) - No hazard
6s LT
2.2s
Walch et al. (2015) - Hazard
6s LT
1.9s
Louw et al. (2015) No task
6.5s LT
2.47s
Impaired
Louw et al. (2015) - Secondary task - reading
6.5s LT
2.18s
Impaired
Yoon (2019) Secondary tasks - video
Self-paced
1.8s
Impaired
Yoon (2019) Secondary tasks - entertainment console
Self-paced
1.62s
Impaired
Yoon (2019) Secondary tasks - entertainment console
Self-paced
1.6s
Impaired
15
10
5
5
10
15
20
25
5
10
LEAD TIME (LT) / TIME BUDGET (TB)
REACTION TIME
DRIVING PERFORMANCE

Annex 6 HIGH-LEVEL COMPARISON BETWEEN DAMS AND ALKS REGULATIONS

<table>
<tr><th colspan="2">Topic</th><th>DAMS</th><th>ALKS</th></tr>
<tr><td colspan="2">Level of Automation</td><td>Level 3 and Level 4</td><td>Level 3</td></tr>
<tr><td colspan="2" rowspan="5">Monitored human states</td><td colspan="2">Driver Presence</td></tr>
<tr><td colspan="2">Consciousness</td></tr>
<tr><td colspan="2">Attentiveness</td></tr>
<tr><td>Secondary Task Engagement</td><td>Not required</td></tr>
<tr><td>Sudden Sickness</td><td>Not required</td></tr>
<tr><td colspan="2" rowspan="3">Driver presence criteria</td><td colspan="2">The driver shall be present in the driver’s seat</td></tr>
<tr><td colspan="2">The driver’s seat belt shall be fastened</td></tr>
<tr><td>Seat position:
• Level 3 – the driver’s seat position shall not be significantly altered.
• Level 4 – the driver’s seat position can be significantly altered but must be returned prior to the resumption of manual control.</td><td>Not required</td></tr>
<tr><td rowspan="3">Consciousness</td><td rowspan="2">Sleeping</td><td colspan="2">Sleeping prohibited</td></tr>
<tr><td>If sleeping, the ADS shall either perform a minimum risk manoeuvre or warn the driver and if unresponsive or sleep reoccurs, perform a minimum risk manoeuvre.</td><td>If sleeping, the ADS shall warn the driver. If appropriate action is not taken within 15 s, the system shall perform a minimum risk manoeuvre.</td></tr>
<tr><td>Wakefulness</td><td>Resumption of manual control is not allowed if the driver is too drowsy to drive safely

The system shall either hand back control to the driver prior to them exceeding the wakefulness threshold OR only allow the driver to resume manual control when their drowsiness level is back within safe limits.</td><td>Not required</td></tr>
</table>

Topic	DAMS	ALKS
Attentiveness criteria	The attentiveness state of the driver shall be monitored throughout the transition phase	
	The driver will be deemed attentive (i.e. ready and willing) if their eyes are on the road, both hands are on the steering wheel and foot on either the accelerator brake pedal	The driver will be deemed attentive if their eyes or head are directed towards the road, rear-view mirror or driving task
Transition phase	Dependent on secondary task. • No secondary task: 10s • Handsfree secondary task: 10s • Handheld secondary task: 15s	Minimum requirement: 10 s
Post takeover support	Required	Not required
Deactivation	The system will deactivate if: • The driver presence, attentiveness and sudden sickness criteria are met, • The driver is not engaged in a secondary task and is below the wakefulness threshold. • The driver is able to respond with the specified transition phase of the system	Dependent on reason for deactivation. Four types specified. • Deactivation by driving controls (i.e. override; see below) • Deactivation during transition demand. Driver shall be holding the steering column and met the attentiveness criteria. • Deactivation during on emergency manoeuvre. This may be delayed until collision risk has disappeared. • Deactivation due to severe vehicle failure. Manufacture shall declare their strategy in these instances.

Topic	DAMS	ALKS
System override	ADS override	Not specified
	Lateral control override by input to steering column. The driver shall only be able to override if the driver presence and sudden sickness criteria are met, the driver is below the wakefulness threshold and fulfils Criterion 1 (eyes) and 2 (hands) of the attentiveness criteria.	Lateral control override by input to steering control. The driver shall only be able to override if their hands are on the steering control and the attentiveness criteria is fulfilled.
	Longitudinal control override by applying force the brake or accelerator pedal. The driver shall only be able to override if the driver presence, attentiveness and sudden sickness criteria is met and the driver is below the wakefulness threshold.	Longitudinal control override by applying force the brake or accelerator control. The driver shall only be able to override if their hands are on the steering control.
	Mechanisms required to prevent unintentional override	
HMI: Information presented to the driver	The driver shall be informed of the status of the system, any system failures, a transition demand, a minimum risk manoeuvre and an emergency manoeuvre	
	The driver will be informed their status and role whilst the ADS is engaged	Not required
HMI: Takeover manoeuvres	• Symbol for a transition demand shall compromise of a steering wheel and hands • The warning shall escalate to reflect urgency • The alert type shall change characteristics at the start of minimum risk manoeuvre (or automated DDT fallback)	
	Planned takeovers: its recommended to inform the driver about a transition demand prior to it being initiated	Not recommended

Topic	DAMS	ALKS
HMI: Interface	The interface should be easily perceivable from the driver's peripheral field of view and located near to the driver's direct line of sight to outside the front of the vehicle	
	The interface shall be intuitive and unambiguous	
	The display should be distinguishable from other displays in the vehicle.	Not required
HMI: Warning type	For all warning types, a minimum of a visual and auditory warning shall be presented	For a transition demand and minimum risk manoeuvre, at least an optical and an acoustic and/or haptic warning signal shall be presented. For a system failure or emergency manoeuvre, at least an optical warning shall be presented
HMI: Secondary tasks	Secondary tasks displayed on the entertainment console shall be suspended or deactivated when a transition demand is initiated. It is recommended that secondary task displayed on the entertainment console are suspended when the ADS is communicating with the driver whilst the ADS is engaged.	Not required

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