THE FUTURE OF TRANSPORT

PUBLISHED PROJECT REPORT PPR979

Safe performance of other activities in conditionally automated vehicles

Automated Lane Keeping System

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Report details

Report prepared for:	Department for Transport		
Project/customer reference:	1-1160		
Copyright:	© TRL Limited		
Report date:	4th December 2020		
Report status/version:	Final		
Quality approval:			
Yorgos Voukas (Project Manager)		Shaun Helman (Technical Reviewer)	

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Executive Summary

Background

Automated Lane Keeping System (ALKS) is a vehicle technology that keeps the vehicle within its lane and controls its speed for extended periods without further driver input. It is a 'conditionally automated' system, meaning that it controls all aspects of the dynamic driving task with the expectation that the human driver will respond to a request to intervene. At present, the system is intended for use at low speeds on motorways. This shift in primary responsibility will, for the first time, provide a driver with the potential to engage in activities other than driving while a car is in motion on a public highway. This has implications for both Government and industry policy.

This research

This report details the findings from a review of the literature that sought to understand which activities could be safely performed by a driver in a conditionally automated vehicle using ALKS. The aim was to understand the kinds of task that might be safely performed by a driver when ALKS is in control of the vehicle, so as to not materially impact the safe resumption of control when a transition demand for manual control is enacted by the system.

The findings

What is the current state of the literature?

While there is a sizeable literature examining automation and driver behaviour, there is no clear evidence or direct summary of tasks that can, and cannot, be safely performed while a vehicle is operating in conditional automation. Part of the reason for this is the lack of standardised testing protocols, resulting in studies testing a variety of systems and human-machine-interfaces against various forms of driver behaviour metrics. Other variations such as sampling further limit the ability to draw firm conclusions. Finally, the lack of real-world studies mean that conclusions are required to be largely based on simulator studies.

The volume and variety of research, nevertheless, allow for identification of the emergence of trends and directions of research findings. These can be appraised in the context of reasoned judgement and theory from broader knowledge of driver behaviour and psychology

What tasks are drivers likely to undertake during conditional automation?

Most studies plan tasks into the experiment, but one study allowed drivers to choose what they wanted to do when the vehicle was in control. This study found that the majority (80%) of drivers primarily chose to engage with their smartphone. Other popular tasks (typical of the commuting nature of the study) included reading books, magazines and newspapers. Laptop and tablet use, listening to podcasts and applying cosmetics were also recorded.

What does takeover involve?

Following a transition demand, drivers must mentally and physically re-engage with the driving task. Evidence suggests that drivers respond relatively quickly, and with initial visual and motor orientation occurring in parallel – the first glance at the roadway appears to occur concurrently with a motor movement to reposition hands on the wheel and feet on the pedals. However, drivers appear to require a period of recalibration with initial lateral and longitudinal control seeing the potential for drivers to drift across lane boundaries in the first few seconds following takeover.

There is also evidence that drivers use all the time available to them before taking full control, sometimes to complete the non-driving related task (NDRT) they were engaged with.

How is takeover impacted by non-driving related tasks?

It is consistently reported that takeover time and quality is negatively impacted by engagement with NDRTs. A meta-analysis found strong evidence that performing an NDRT with a handheld device increases total takeover time. Studies focused on near-crash emergency scenarios (e.g. broken-down vehicle in lane) suggest that NDRTs, particularly visually engaging ones, impact negatively on performance of takeover and collision avoidance.

The impact of the use of centre console devices (often tablets attached to the simulator vehicle) is unclear with task type possibly being more important. Tasks that allow the driver to occasionally glance at the road appear to offer the advantage of maintaining some level of situational awareness that more visually engaging tasks (e.g. watching a film) do not.

Will drivers trust ALKS?

Studies indicate that trust in automated systems is high, albeit most systems being tested are in a simulated, no-risk, environment. Trust is generally so high that there is concern drivers may require greater awareness or training in order to accurately develop mental models that appreciate the functionality, responsibility and limitations of conditionally automated systems such as ALKS. Undesirable behavioural adaptations, such as repositioning the seat to a more relaxed position, have been noted.

What does this mean for the use of ALKS?

Physical and sensory disengagement with the driving task, and adoption of NDRTs, has the potential to increase risk resulting from poor takeover performance. However, aspects of the ALKS system, as currently specified, should minimise some potential risks. For example, the driver availability recognition system should ensure that drivers remain in the driving position, with their seatbelt fastened. In addition, driver availability will be checked every 30 seconds using at least two criteria such as input to driver-exclusive vehicle controls, hand positioning, blink rate and eye closure. At 60 km/h, and with the driver availability recognition system, the system should naturally limit drivers' engagement with NDRTs. Consideration will need to be given to the use of handheld devices, with the obvious alternative ensuring all interaction is through the vehicle infotainment system. This has several benefits during transition and aligns with the approach to handheld devices during manual driving.

In summary, the literature review established a rather disparate body of evidence for establishing what tasks can be safely performed while a vehicle is operating in conditional automation. The clearest findings relate to the risk posed by handheld devices, and potentially related to this, tasks that demand considerable visual engagement. While some of these risks may be mitigated by existing legislation (e.g. handheld devices) and the current ALKS specification, it places an emphasis on manufacturers and software developers for what drivers can and cannot do using in-vehicle controls. The use of ALKS at higher speeds and as an Advanced Driver Assistance system is also considered, although significant risks with both scenarios are raised and further research would be needed to establish what would be safe in these contexts.

1 Introduction

Until recently automated technology in vehicles available in the UK were driver assistance systems only. While the vehicle could control longitudinal movement (such as with adaptive cruise control) or lateral movement (such as lane keeping assist), the driver always had to remain vigilant and in control. Automated Lane Keeping Systems (ALKS) allow the driver to hand over the dynamic driving task to the vehicle. The system controls the lateral and longitudinal position of the vehicle relative to other vehicles in certain settings where vulnerable road users are not present under normal circumstances, and carriageways are separated (e.g. motorways).

For the first time, a driver will potentially be able to engage in activities other than driving while a car is in motion on a public highway. This shift in responsibility has implications for both Government and industry policy. For Government policy, it is important to ensure that drivers understand both their responsibilities and are clear in how to use the new technology safely. The introduction of ALKS also has implications for the insurance industry: if the focus of responsibility shifts from drivers to an automated system this will need to be reflected in the way in which the insurance industry assesses risk and creates business models.

A change in government policy will need to be reflected directly into road policy and law within the UK, particularly with respect to driver responsibility. Changes in legislation may be needed, at the very least to clarify what the driving task will look like whilst ALKS is in control of the vehicle.

While drivers may be able to delegate the dynamic driving task to the system when it is engaged, this does not mean that they delegate all responsibility. Should the driver not respond to a request to take over by the system (and they are not unduly incapacitated) they may face the same ramifications as if they were operating a standard vehicle. For example, if a driver fails to resume control of the vehicle upon request, and the vehicle is automatically brought to a stop and another vehicle crashes into it, the driver of the vehicle with ALKS may still be seen as the cause of the collision. It is, therefore, important that drivers, industry and policy makers understand the extent and limitations of the ALKS system.

The system requirements for ALKS are set out in a new United Nations Economic Committee for Europe (UNECE) Regulation that was adopted on the 24th June. This regulation outlines what is required from the system in order to re-engage the driver in the driving task. The transition from non-driving related tasks to taking back control is considered critical for safety and is the focus of this review.

With the introduction of ALKS in the near future, the activities that a driver might legally engage in while an automated driving system which issues transition demands is in control of the vehicle remain undefined in the UK (aside from existing general driving regulations). The transition demand period is critical, as this presents a time period where the system requires the driver to take back control and the driver may be engaged in non-driving related tasks. The ability of the driver to take over control of the driving task within the required time constraints may be critical to the safe resumption of the driving task. Therefore, the focus of this review is system-initiated transition demand, that is, a transition demand which originates from the system, rather than the driver.

1.1 This report

The Department for Transport (DfT) commissioned TRL to conduct a review to understand which activities could be safely performed by a driver when engaging ALKS in a vehicle. Specifically, the aim is to understand the kinds of task that might be safely performed by a driver when ALKS is in control of the vehicle, so as to not materially impact the safe resumption of control when a transition demand for manual control is enacted by the system.

This report details a rapid review of literature that took a systematic approach. It considers the evidence available to inform the development of future regulation regarding non-driving related activities when an automated system is engaged.

Section 2 provides an overview of the method employed to collate the literature for the review. Further detail of the full approach can be seen in Appendix A.

Section 3 summarises the literature reviewed under sections that align with the focus of the project.

Section 4 summarises the key findings and considers the implications for regulation and policy.

2 Method

The research question that this work intended to answer was:

How do the various tasks that a driver can undertake whilst conditional automation is in control of the vehicle affect ability to regain safe control?

The literature review took a systematic approach consisting of three key tasks:

1. Definition of search terms
2. Assessment of quality and relevance
3. In-depth review of full text literature

A detailed breakdown of each of these tasks can be seen in Appendix A and a high level summary of the process and key findings can be seen in Figure 1.

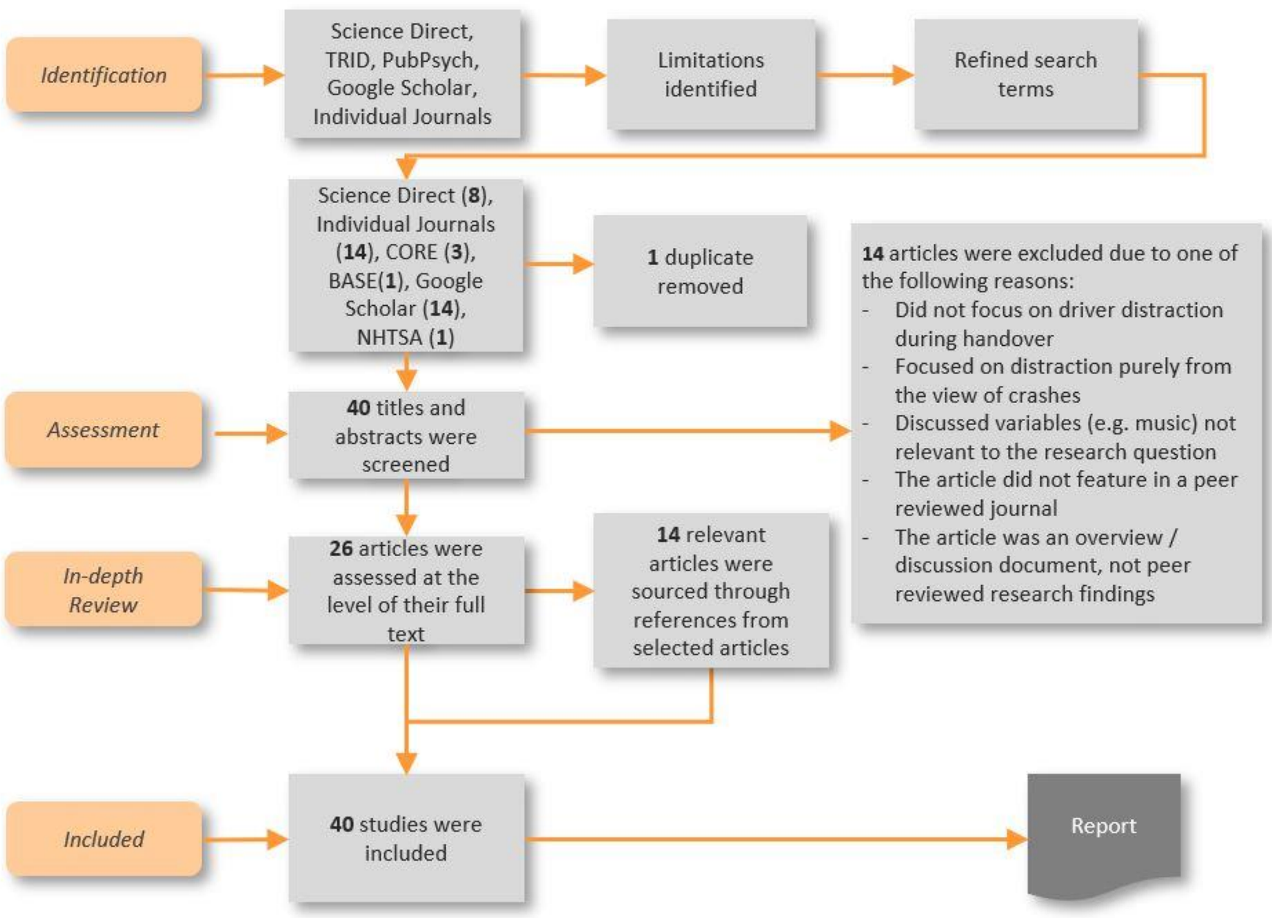

Figure 1: Flowchart illustrating the process of literature identification, assessment, and inclusion for the final review

TRL has access to a range of databases and sources that were used for undertaking this literature review. The sources that were used allowed us to obtain literature both specific to the transport sector (e.g. TRID) as well as other relevant sectors, such as behavioural psychology (e.g. ScienceDirect) and more general sources such as Google Scholar. The final review identified 40 relevant research papers.

2.1 Definition of search terms

Search terms were developed. These search terms were used in combination with each other and 'wildcard' searches were used to capture variations in terms (e.g. driv* would show results for 'drive', 'driving', 'driver' and 'driven'). In order to obtain relevant and timely literature, the date range of 2010 to 2020 was applied in all searches. Articles outside of this date range were considered if referenced by these articles and considered to provide research findings relevant for the review.

2.2 Assessment of quality and relevance

Once the final papers had been obtained, an assessment of quality and relevance was carried out. This process is outlined in detail in Appendix A. Briefly, specific criteria were used to assess the suitability of the identified literature, to ensure that only the most relevant literature was included. Appendix A also details the in-depth review process of the full text papers. Once one researcher had identified and conducted the in-depth review process, another researcher checked the process and findings, to ensure that relevant literature had not been excluded unnecessarily. Conflicts were resolved by NK and NS through discussion.

3 Literature review

3.1 Overview of Automated Lane Keeping System

The Automated Lane Keeping System (ALKS) is a vehicle technology activated by the driver that keeps the vehicle within its lane and controls the speed of the vehicle for extended periods within traffic without further driver input. It is designed to allow the driver to disengage from the driving task for the first time.

The ALKS system can be used on roads where pedestrians and cyclists are prohibited and where there is a physical separation that divides the traffic moving in opposite directions. These criteria essentially mean that in Great Britain the system can only be used on the motorway network. The current proposed ALKS regulations are restricted to passenger cars and has an operational speed limit of 60 km/h.

3.1.1 Transition demand

When the system is engaged, the driver will need to take back control at some point to complete their journey. The system can be manually disengaged if a driver decides to take back control (by deselecting the system through a button or by engaging with vehicle controls, like disengaging current cruise control systems). Transition demand is when the system places a request with the driver for them to take back control of the vehicle. The types of system-initiated transition demand include:

- Planned event – a situation which is known in advance (e.g. exiting at a junction)
- Unplanned event – a situation which is unknown in advance that creates uncertainty or affects the system's ability to perform the dynamic driving task (e.g. road works, inclement weather, missing lane marking, object in road)
- Driver unavailability – the system detects that the driver is unavailable (e.g. not in an appropriate driving position to respond to a transition demand)
- Driver not present or unbuckled – when the driver is detected not to be in the seat for a period of more than one second; or when the driver's safety belt is unbuckled.
- System failure – response to any electronic or sensor failure.

The driver will be made aware of the transition demand through manufacturer warning signals and the vehicle's user interfaces. When a transition demand is initiated, on-board displays will be automatically suspended and likely show a transition demand message. If no response has been detected from the driver, the system will escalate its warnings with a mixture of auditory and haptic (e.g. vibration of the driver's seat) inputs. This will occur no more than four seconds after the transition demand was initiated. The driver will have a minimum of 10 seconds to respond to a transition demand.

If the driver fails to resume control of the vehicle during the transition phase, the system will perform a minimum risk manoeuvre (MRM). A minimum risk manoeuvre is a procedure aimed at bringing the vehicle to a safe stop while minimising risk in traffic. It is automatically performed by the system after a transition demand without driver response or in the case of a severe ALKS or vehicle failure. During a minimum risk manoeuvre, the system will bring the vehicle to a safe stop in the lane of travel.

3.1.2 Driver availability recognition system

ALKS requires that a ‘driver availability recognition system’ be in place. The function of this system is to detect if the driver is present in a driving position with their safety belt fastened and is available to take over the driving task. Should any of these criteria not be present, a transition demand will be issued

In addition, the ALKS must have a specified system to detect if the driver is available to take over control of the driving task. Driver availability should be checked every 30 seconds using at least two criteria. Example criteria include input to driver-exclusive vehicle controls, hand positioning, blink rate and eye closure.

As soon as the driver is detected as unavailable, the system will provide a distinctive warning. If the driver fails to demonstrate that they are available within 15 seconds, the system will issue a transition demand. However, if the driver successfully demonstrates that they are available, based on criteria above, the ALKS will continue to operate.

3.1.3 Performance of other activities

When ALKS is engaged, drivers may be able to perform activities other than driving. It is important that performance of any other activities does not prevent the driver from responding to a transition demand and taking over control of the dynamic driving task. The requirement for safe transition has implications for what activities a driver might engage in whilst the car is in conditional automation.

3.2 Tasks drivers are likely to undertake

Allowing vehicles to operate under conditional automation does not necessarily imply that human intervention is no longer required. Drivers will be required to take control in either planned or unplanned circumstances. As a result, what drivers do when the vehicle is operating in conditional automation is anticipated to impact a driver’s ability to take back control.

It is possible to consider a spectrum of the amount of attention a driver has allocated to the road while the vehicle is controlled by conditional automation. At one end of this spectrum we can consider a driver who is continuing to pay full attention to the road; at the other we can consider a driver who has fallen asleep. Both of these extreme cases are unlikely. Falling asleep while the vehicle is in conditional automation should not be possible due to the requirement for driver monitoring technologies; it would also presumably be considered reckless or dangerous in the event of a collision. At the other end of the spectrum, it is unlikely that drivers will hand over control to the vehicle and then continue to pay full attention to the driving task. Tasks that drivers will likely engage in will sit somewhere in the middle of these extremes.

Burnett, Large and Salanitri (2019) provided the opportunity for drivers to experience conditional automation (using a system akin to ALKS, but without driver monitoring) in a simulator. Forty-nine drivers completed 30-minute commute style drives for five continuous days (Monday to Friday). Drivers could choose what to do when the vehicle was in conditional automation for approximately 23 minutes of each drive. This unique opportunity provides some insight into what tasks drivers might choose to do in such circumstances. The most common behaviour was to use a smartphone, with 80% of participants choosing to do this at some point in the week. The next most common behaviour was choosing to read a book, magazine or printed paper; 25% of participants did this at some point in the week. The proportion of participants doing these activities each day did not change throughout the week. Other tasks included using a tablet, working on a laptop, applying cosmetics and sleeping (one person did so on Wednesday, and two on Friday).

The range of tasks included some drivers choosing to listen to music or podcasts on their smartphones, which allowed them to visually monitor the road conditions. However, it is noteworthy that other drivers demonstrated behaviours to fit the environment to their chosen task. For example, some drivers moved their seat to relax or to accommodate using a laptop or tablet device. Some swapped glasses they wear for driving, to glasses they wear for reading or watching TV. Such behaviours were likely perceived as logical transitions to prepare for the (non-driving related) task being undertaken, but clearly raise concerns for preparedness if the driver was required to take back control of the driving task.

Resuming control of a vehicle from automation is commonly referred to as “takeover” (Walch, Langer, Baumann & Weber, 2015). The impact of various non-driving related tasks (NDRTs) on takeover has been the focus of several experimental studies in recent years. Table 1 summarises the types of NDRTs commonly tested in studies of takeover from automated driving. The tasks identified from the literature were classified into categories according to whether they tested use of a third-party device (e.g. smart phone or tablet), in-vehicle infotainment system, or used an experimental task as a proxy for distracting and high-workload conditions. The range of tasks suggests that researchers anticipate smartphone use, tablets and use of in-vehicle infotainment systems to be the predominant tasks when vehicles are operating under conditional automation.

The following sections discuss the impact that engaging in NDRTs during conditional automation has on drivers’ ability to safely regain control of the driving task.

Table 1: Non-driving related tasks tested during automation studies identified in the literature review

Task	Classification	Brief description
Smart phone use	Third party device engagement	Engaging in texting (reading and sending), conducting internet searches and performing transcription tasks
Interacting with a tablet	Third party device engagement and mimicking in-vehicle system	Using a tablet / iPad to conduct a task, for example playing a game, watching the news or a film, or composing an email
Interacting with an infotainment console	In-vehicle system	Using an infotainment system to search for a radio station, watch a video, compose email or play a simple game
Reading	Third party device engagement	Reading printed magazines, news or books
Paper based tasks	Experimental task	Solving anagrams and a labyrinth puzzle on a pad of paper. Used to create conditions or workload and distraction.
Monotonous monitoring task	Experimental task	The “pqpd” task is used in experimental conditions to replicate a monotonous task with the intention of provoking fatigue
N-back task/ Standardised visual Surrogate Reference (SuRT) Task	Experimental task	These are experimental tasks used to create high-workload conditions
Searching for an item within the vehicle	Experimental naturalistic task (internal distraction)	Searching for an item within the vehicle such as a magazine and adjusting seat

3.3 Takeover time

One of the most common ways to determine the effect of NDRTs on takeover from conditional automation is to measure the time taken to respond to a transition demand. Zhang, De Winter, Varotto, Happee and Martens (2019) note that the takeover process is made up of several information-process stages:

- Perception of visual, auditory and vibrotactile stimuli (transition demand warning)
- Cognitive processing of the information
- Response selection (decision making)
- Resuming motor readiness (repositioning of hands and feet)
- Action (e.g. steering and accelerator/braking input).

These stages are not necessarily exclusive. For example, Zeeb, Buchner & Schrauf (2015) summarise that reaction times are typically less than a second for the first gaze at the scenery, 1.5–1.8 seconds for the first contact with the steering wheel, and about 1.5 seconds until the foot is on the pedal. In line with 'threaded cognition theory' (Salvucci & Taatgen, 2008, 2011) – which states that discrete tasks can be completed simultaneously – it appears that the initial perceptual and cognitive processing of the takeover situation can be performed in parallel with the motor response. A basic overview of the transition process is shown in Figure 2.

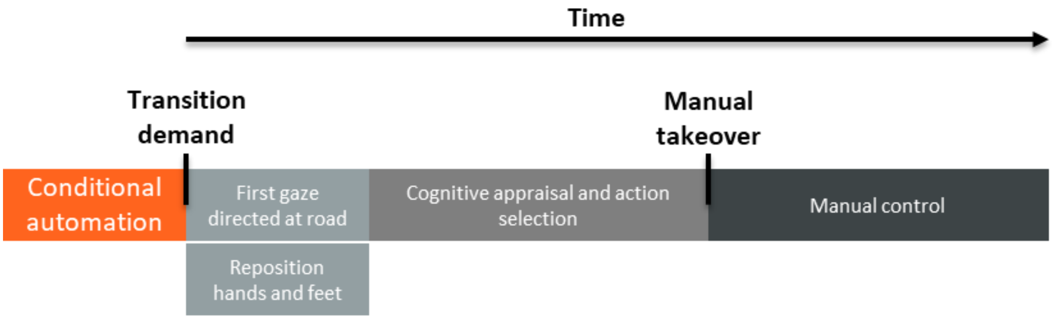

Figure 2: Overview of basic transition demand process

There is no single, accepted takeover time. Takeover is impacted by specific situational variables (e.g. traffic complexity, takeover demand warning, human-machine interface design, secondary task type) and individual variables (e.g. age, experience and skill) (Vogelpohl, Vollrath, Kühn, Hummel & Gehlert, 2016; Zhang et al., 2019). While all these variables can theoretically be controlled in experimental conditions, the reality is that only some are at any one time. The result is that a range of takeover times is reported in the literature. Further, the measure of takeover time also varies between studies, including time to first glance at the road, time to first touch of the controls, time to manual driving. Although different response time measures exist, total takeover time (TOT), defined as the time that drivers take to resume full control from automated driving after a critical event or after having received a transition demand, appears to be the most frequently used measure in the literature (Zhang et al., 2019).

Walch et al. (2017) conducted a review of 17 TOT studies, focusing on the effect of the time budget (the system's takeover time window), traffic complexity, non-driving task, and driver age. The review concluded that 10 seconds seems an adequate time budget, although noted that driver state and situational circumstances affect the driver's ability to take over control. Some studies have suggested that a request should be issued between 5.7 and 8.8 seconds prior to takeover (Petermann-Stock et al., 2013); others have suggested the mean time required to take control is between 2.1 seconds and 4.1 seconds (Gold & Bengler, 2014; Gold, Damböck, Lorenz & Bengler, 2013).

Reviews by Vogelpohl et al. (2016) and Walch et al. (2017) both note that outcomes are sometimes inconsistent between studies and that more evidence is required if we are to be able to quantify the factors and conditions that will impact TOT. For example, some studies (e.g. Gold, Berisha & Bengler, 2015); Petermann-Stock et al., 2013) report significantly longer TOTs when participants are engaged in visual-motor non-driving related tasks during conditional automation, compared with cognitive-auditory tasks. However, this effect was not statistically significant in a study by Radlmayr, Gold, Lorenz, Farid and Bengler (2014). Nevertheless, engagement in a non-driving related task (NDRT) when a transition demand is requested in an automated vehicle is widely considered to increase the time required to take control of the vehicle (Merat et al., 2012).

A meta-analysis of 129 studies by Zhang et al. (2019) resulted in several notable conclusions:

1. **Drivers will use the time they have available**: If a system allows a longer time window for transition demand (time budget), then drivers will use that time and take longer to take back manual control. For example, if drivers perceive there is more time, they are more likely to assess the situation for longer (e.g. checking mirrors), adjust their seat position or posture, and spend time performing the NDRT (Gold et al., 2013; Zhang et al., 2019; Burnett et al., 2019).

2. **Performing an NDRT with a handheld device strongly increases the mean TOT**: This was a reliable finding confirmed in three different models conducted in the analyses. It is also supported by recent studies such as Naujoks, Purucker and Wiedemann (2019).

3. **Among the studies without a handheld device, performing a visual NDRT yielded a moderate increase in mean TOT** as compared with not performing such a task: Engagement in a visually demanding NDRT increased mean TOTs, whereas auditory or cognitive demand alone did not show significant associations with increasing mean TOTs.

4. **A high level of automation (SAE L3 and above) showed higher mean TOTs than partial automation (SAE L2)**: This was possibly due to a combined effect of a longer time budget, lower urgency, and more involvement in handheld NDRTs in SAE L3 and above studies.

5. **Prior experience with transition demand from automated or assisted technologies (e.g. Adaptive Cruise Control) has a strong effect**: Drivers responded about 1 second faster during their second transition demand than in their first. Zhang et al.'s meta-analysis also showed that drivers responded about 0.5 seconds faster when the transition demand warning could be anticipated from task-related or environmental cues.

6. **Visual only transition demand warnings result in longer TOTs than audible or tactile warnings**: Audible or tactile warnings resulted in lower TOTs when compared with a visual warning only, or no warning.

The studies identified within the literature search reported various ways in which reaction time was gauged, but consistently show that engaging in tasks whilst conditional automation is in control of the vehicle increases a driver's response time when a takeover request is initiated. For example, Lin, Li, Ma and Lu (2020) examined drivers' responses to transition demands while reading the news, watching a video or not having any NDRT. The time budget, that is, how long the driver is given to respond to a takeover request, was three, four or five seconds. The results showed that engaging in either NDRT led to longer response times during a takeover situation compared with no NDRT. They also found that an NDRT allied with the shortest time budget resulted in a greater number of collisions than the other conditions. Similar findings are reported by Zeeb et al. (2015), who found that drivers who were engaged with an NDRT whilst conditional automation was in control of the vehicle reacted slower in sudden emergency takeover situations and were more likely to have a collision with surrounding traffic. Shen and Neyens (2017) meanwhile reported that drivers' responses to a safety critical event (the car 'drifting' due to a wind gust) were impaired when engaged with a demanding non-driving task (watching a film). Eriksson and Stanton (2017) also found longer transition times (how quickly the participants reacted to the control transition request) when participants engaged in an NDRT compared with when not doing so.

In their review of recent studies, Lin et al. (2020) summarise that handheld NDRTs have been shown to increase takeover time, but that the evidence of the effect of non-handheld NDRTs is not as clear. They note that the interaction between environmental complexity, time-criticality and cognitive demand is likely to mediate studies of takeover time and task type. Ultimately a comprehensive understanding of this issue requires a consideration of the impact of NDRTs on takeover quality, as well as takeover time.

3.4 Takeover quality

3.4.1 Driving performance

Transition to manual control from conditional automation can affect driving performance in several ways:

- **Lateral control**: The number of lane excursions or measure of drift from the centre lane position when taking control.
- **Longitudinal control**: Vehicle speed or acceleration/deceleration profile of the vehicle following takeover, demonstrating a level of vehicle control.
- **Collision avoidance**: The ability to avoid a collision in an emergency takeover scenario.

Findings from the literature suggest that driving performance following a transition demand is affected by periods of conditional automation, irrespective of the presence, or type, of an NDRT. For example, Large, Burnett, Salanitri, Lawson and Box (2019) found longitudinal and lateral instability of the vehicle was high immediately following takeover, suggesting that the procedure of taking over control of the vehicle from the automated system might prove difficult for drivers. Most variation appears to occur in the first three to five seconds following takeover before settling, although control appears to improve with experience. In Large et al.'s study, drivers experienced conditional automation on five continuous days. On day one, drivers moved up to two metres from the centre of their lane (peaking at 3 seconds following transition); this meant they were often outside of the lane markings. By the fifth day, drivers maintained the vehicle within the lane but still demonstrated notable lateral deviation (0.5-0.8 metres). The authors noted that the best takeover performance occurred on the fourth day when drivers had to take over in unplanned emergency circumstances (caused by fog); this suggests that drivers do not perform to their capabilities when there is no perceived need to do so. Based on the same study, Burnett et al. (2019) reported that in normal takeover conditions (i.e. a planned transition request) it was typical to see a slight increase in speed over the first five seconds following takeover, before drivers reduced to the speed limit again.

In general, experimental studies to date have shown that NDRTs deteriorate takeover quality compared with a no task condition. Louw et al. (2019) required drivers to engage with a road vigilance task (reading random words on variable message signs) and the same task but with the addition of a visually demanding NDRT (completing a workload task on a tablet) during simulated Level 2 automation. There were significantly more lane excursions during an unplanned takeover as a result of the additional NDRT. Several other Level 2 automation simulator and real-world studies reviewed by Louw et al. (2019) also demonstrate that reduced visual attention to the road ahead, exacerbated by engagement in visually demanding NDRTs, can result in poorer responses to critical incidents. While Level 3 automation removes the requirement for the driver to actively monitor the road ahead, the requirement to take back control at some point (planned or unplanned) is the same. It is therefore relevant to consider the results of the impact of NDRTs on takeover performance in studies of Level 2 automation.

Several studies have incorporated collision scenarios into their simulations. Louw, Merat and Jamson (2015) used a simulator setup to examine the effects of two automated conditions compared with a manual driving condition. At one point in the drive, participants had to respond by changing lanes to avoid a stationary vehicle in their lane. Drivers took significantly longer to generate their first avoidance manoeuvre during both engaged-automation (where drivers took their hands away from the steering wheel but observed the driving scene) and distracted-automation (drivers were asked to read aloud a selection of text that was displayed on an iPad), when compared with manual driving. In addition, higher maximum lateral accelerations for both engaged automation and distracted automation drivers were observed, compared with that of manual drivers. These results support the importance of the physical disconnect observed during transition in Burnett et al. (2019).

Similar findings were noted by Radlmayr et al. (2014) who found that when drivers are engaged in a high-workload task (Surrogate Reference Task) and are presented with a sudden transition demand, a higher total number of collisions are observed, compared with when the NDRT workload task was not present. Lin et al. (2020) also found that the addition of NDRTs increased the number of crashes when drivers were required to avoid a broken-down vehicle in their lane (in this case the automated system warned the driver with a time budget of 3, 4 or 5 seconds). Results found no difference between the two types of NDRT that were presented on a tablet attached to the centre console (reading the news and watching a video). The authors note that both non-handheld tasks were relatively simple visual tasks, which did not require higher cognitive demand, but they nevertheless impacted takeover performance.

The evidence reviewed suggests the importance of visual and motor disconnect from the driving task as being particularly important for the quality of transition. As drivers are not completing dual tasks during conditional automation, concerns of cognitive workload (overload) appear to be less important, although will clearly impact the intensity of the attention a driver pays to a NDRT. In fact, extended periods of conditional automation lead to the opposite concern – underload – where a lack of mental stimulation negatively impacts performance (see for example Neubauer, Matthews, Langheim & Saxby, 2012). The relationship between mental workload, task type and takeover performance requires further examination (Zeeb et al., 2015).

3.4.2 Mental models

The findings related to driver performance suggest that drivers need to time to become accustomed to the feel of the vehicle controls following conditional automation. However, there are no longitudinal studies (beyond five days) of conditionally automated driving to determine the long-term effect, and whether drivers learn to conduct smoother transitions over time. Nevertheless, the findings denote a need to consider awareness and training that could be required to ensure drivers become better accustomed to automated systems such as ALKS.

Researchers discuss this in terms of ‘mental models’. Mental models reflect a user’s understanding about a system’s purpose and functionality (Carroll & Olsen, 1987). Put simply, a mental model is how we expect a system to operate in any given environment; it is a simplified mental representation and expectation about what a system is for, and what it can do. Mental models are developed through experience and built up through numerous situational models; that is, use of the system in various environments. Mental models of a system are, therefore, continuously updating. However, relying on users to develop mental models without providing an initial framework for understanding the functionality and limitations of a system can lead to critical user errors and over-expectation (Pradhan et al., 2020; Shaw, Large & Burnett, 2020). Pradhan et al. reviewed various studies which suggest drivers are not accurately aware of the functionality and limitations of current driver assistance systems, such as adaptive cruise control. It is suggested that mismatches or inaccuracies in a driver’s mental model could result in errors, particularly in high-demand situations, such as emergency transition demands.

Shaw et al. (2020) reviewed literature from the aviation domain to highlight the need to consider the capabilities and responsibility of a human driver during conditional automation. The review identified the need for clear, consistent learning strategies and processes that underpin the development of accurate mental models. The value of focusing on the development of accurate mental models is that it avoids drivers creating their own (potentially inaccurate or incomplete) models (Merat et al., 2019) and reduces the chances of user error in critical circumstances. Shaw et al. go on to demonstrate a pilot study of driver training outlining drivers’ responsibilities during conditional automation. The provision of behavioural training around an easy-to-understand operating procedure appeared to be effective and resulted in more mirror checks during automation and a greater likelihood to notice a hazard during transition, compared with a group who were only given the user manual. While this was a small demonstration, it signifies the potential importance of the development of mental models for ALKS for supporting situational awareness.

The importance of providing training, or at least raising awareness, of system features, responsibilities and limitations has implications for industry and legislators. For example, who should be responsible for training drivers? Individual manufacturer operating systems may differ, requiring manufacturer responsibility for training drivers; although this may only be beneficial to the original owner of a vehicle. A centralised communication strategy to inform the public of the basic principles of automated systems could underpin such an approach, although there would be a critical role for evaluation of impact and efficacy of such a campaign. There may also be a need to train or educate new drivers about automated systems when learning to drive; few cars used for training would have such technology, although for some systems knowledge-based questions could be included in the driving test (ensuring that people at least seek information on them during the learning to drive process). There is a risk that while training may be an effective approach to developing drivers' mental models, the responsibility for it could fall between the gap between industry and policy.

3.4.3 Situational awareness

Situational awareness is another important measure of driver performance. Situational awareness refers to a driver's perception and comprehension of environmental elements and events, and their ability to project the future status of these items (Large et al., 2018, 2019). Like mental models, situational awareness is a psychological construct that can be difficult to operationalise and quantify. Studies operationalise situational awareness in different ways, but typically use measures of visual behaviour. For instance, Vogelpohl, Khun, Hummel and Vollrath (2019) measured situational awareness as the time taken to look at the side mirror and the speed display for the first time after a transition demand or warning signal was requested by the vehicle. In this study, participants were divided into either manual or automated drive groups and were required to complete several monotonous drives. Transition demands were interspersed into the automated drives and required drivers to react to a critical driving scenario; drivers in the manual driving condition experienced the same on-road events but heard warning signals that indicated the vehicle had identified a potential hazard. The results showed that drivers in the automation condition took significantly longer to glance at the speed display than drivers in the manual condition after a transition demand (or warning signal) and took longer to first look at the side mirror than did manual drivers.

Research conducted by Fleskes and Hurwitz (2019) highlights how situation awareness, in particular visual behaviour, can be affected by engaging in NDRTs. In this study, a driving simulator was used to evaluate drivers' visual attention and collision avoidance when operating a vehicle under Level 3 conditional automation. During the study, drivers repeatedly drove along a street, at the end of which was a stop line at a junction. A transition demand was initiated either 5, 10 or 15 seconds ahead of the stop line. A simulated cyclist was placed either close to, or further away from, the stop line, to induce different yielding or overtaking decisions by the driver. The cyclist only became visible to the driver 10 seconds before a transition demand; prior to the demand the cyclist was stationary behind a parked vehicle and obscured from the driver's view. The transition demand was initiated as a result of approaching the junction, but during approach the cyclist's trajectory meant that the driver had to take avoiding action. While participants were experiencing conditional automation, they were occasionally required to engage in an NDRT. The NDRT involved playing a pop the bubble game on a mounted touch screen device (simulating an in-vehicle display). The results showed that engaging in an NDRT led to decreased driver performance with respect to the time that it took a driver to first identify the cyclist on the road; drivers took around 4.5 seconds longer to identify the cyclist on the road when engaged in the NDRT compared with when they were not. Drivers engaged with the NDRT also fixated significantly less on the cyclist, suggesting their awareness of the cyclist's presence was impaired.

Research has also shown that there are differences between tasks, in terms of how they affect drivers' visual behaviour during transition. Yoon and Ji (2019) focussed on how the activities of interacting with an entertainment console, watching a video and using a smartphone affected takeover performance and workload, once a transition demand has been issued. The visual behaviour metrics measured in the study were gaze-on time (time taken to complete the first gaze reaction) and fixation time (how long it took to fixate on the road after the transition demand was issued). The results were similar to that of Fleskes and Hurwitz (2019); drivers' visual behaviour (both gaze-on time and time to first fixation) was significantly affected by engaging in a NDRT. While all NDRTs impacted visual behaviour and total takeover time, engaging with the entertainment console appeared have less impact than watching a video and interacting with a smartphone. This was evidenced by a reduced gaze-on and fixation time reported for the entertainment console task, compared with the other two tasks. These findings may be attributable to the nature of the tasks. It is suggested that interacting with the entertainment console allowed drivers to occasionally glance towards the road, allowing greater maintenance of awareness. The other two tasks were more visually demanding and required a continuous level of attention, not affording the same opportunities to occasionally monitor the road.

3.5 Trust and behavioural adaptation

For systems like ALKS to be used, they must be trusted by the operator. Studies have shown that improper use of a system, or repeated system failures, erode user trust in vehicle assistance systems (Pradhan et al., 2020). This relates to the importance of training and developing accurate mental models of system functionality and limitations. In theory, conditionally automated systems should take full control of the vehicle from the driver in the given use context (i.e. low-speed motorway driving). Drivers' trust in the system is likely to depend on their early experience and expectations of the system. Ultimately, it is not yet fully understood how trust in conditional automation is influenced by the long-term use of automated systems like ALKS and the frequency of transition demands. Nor can it be fully appreciated how trust in simulated environments translates into trust in the real-world.

Research has shown that trust in automated technologies is a strong predictor of both use and NDRT engagement by the driver whilst the car is in a state of conditional automation (Banks, Eriksson, O'Donoghue & Stanton, 2018). Burnett et al. (2019) collected subjective judgements of trust during participant's five-day series of automated drives. Results showed that trust following experience on day one was high, increasing throughout the week. All transition demands were planned events, although on day four, there was an unexpected, unplanned transition demand related to sudden heavy fog. Interestingly while trust was very slightly reduced on day four following this experience, trust on day five rebounded to its highest level during the week. This could suggest that drivers trust in the system increased following a correct handover request for entering inclement conditions. Trust was not tested against false transition demands in this study.

All participants within the study willingly, and almost immediately, engaged in NDRTs when the vehicle entered conditional automation, suggesting that participants trusted the system enough to relinquish control and supervision. Large et al. (2019) highlight the relationship between the trust and situational awareness, whereby an increase in trust creates a concomitant likelihood to disengage, resulting in a decrease in situational awareness. Examples of this included engaging in a range of activities that would distract a driver, were they required to monitor the road. Drivers commonly engaged with their smartphones, used a tablet or laptop in front of the steering wheel, relaxed the seating position or moved to accommodate devices and changed glasses to enable them to read rather than drive (Burnett et al. (2019). There were however some drivers who engaged in more 'vigilance-friendly' tasks such as listening to music or podcasts and holding devices to one side to allow them to occasionally glance at the road and be prepared for taking control.

Nevertheless, as the week progressed and drivers became more comfortable with the system, there was an increase in the number of drivers continuing to interact with their NDRTs (not just glancing) during the prepare-to-drive phase following a transition demand. Examples given include continuing to compose a smartphone message and actively packing away their devices. The number of drivers engaging in this behavioural adaptation increased throughout the week. Drivers with a countdown timer were more likely to use more of the transition time to continue their NDRT before resuming control.

The behavioural shift was also measured through drivers' eye glance behaviour as the week progressed. The amount of time spent looking out of the vehicle at the road during conditional automation reduced as the week progressed; 70% of visual attention was directed towards NDRTs on day one to 80% on day five (this was statistically significant).

Burnett et al. (2019) conclude that removal from physical and sensory engagement with the driving task and absorption into engaging NDRTs can leave drivers ill-prepared for transition demands and resumption of control. The findings from the study suggest that drivers easily enter a state that is focused on the NDRT, rather than driving. Such was the absorption of NDRTs and the unwillingness to change state and re-engage with driving, participants were found to continue to engage with NDRTs even after a transition demand was issued. Although the time budget for handover was long in this study (60 seconds), the fact that drivers took longer to take control of the steering wheel on day 5 than on day 1 suggests drivers are at risk of becoming complacent.

3.6 Fatigue

Fatigue refers to external factors, such as sleep loss and prolonged performance as well as to the psychophysiological state changes induced by those factors, such as tiredness (Saxby, Matthews, Warm, Hitchcock & Neubauer, 2013; Saxby, Matthews & Neubauer, 2017). In terms of automation, the greatest concern is around the monotony of merely monitoring the driving task (without physical engagement) or the complete disengagement from the monitoring task where the vehicle takes responsibility. This is known as passive fatigue.

Passive fatigue occurs when there is a requirement for system monitoring with either rare or even no overt perceptual motor requirements. Passive fatigue may be induced by driving in low workload conditions, requiring infrequent use of controls – for instance, if adaptive cruise control is in control of the car's speed and distance to the vehicle in front.

Vogelpohl et al. (2019) showed that when a driver is experiencing fatigue from monitoring the vehicle whilst it is under conditional automation, and is faced with a transition demand, there is a delay in the reactions of the driver, specifically their first glance to the speed display.

The authors highlight that drivers who are experiencing the effects of fatigue may require additional time during transition demands in order to obtain situational awareness. Matthews and Neubauer (2017) report similar findings; when passive fatigue was induced through drivers disengaging with the driving task, slower responses to the critical driving procedure (exiting the motorway) were observed.

The findings of Vogelpohl et al. (2019) have been replicated elsewhere, and validated in on-road conditions (Jarosch, Paradies, Feiner & Bengler, 2019). Jamson, Merat, Carsten and Lai (2013) compared drivers' fatigue levels in both manually controlled and automated driving, in conditions of both low and high traffic. Driver fatigue was measured using the Percentage of Eye Closure Over the Pupil Over Time (PERCLOS) scale, which is a standardised measure of fatigue. The scale reflects slow eyelid closures ("droops") rather than blinks. A PERCLOS drowsiness metric was established in a previous driving simulator study as the proportion of time in a minute that the eyes are at least 80 percent closed. The findings of Jamson et al. (2013) suggest that in conditions of automation, driver fatigue tended to rise, with greater scores on the (PERCLOS) scale in the automation condition (3.8%) than in the manual condition (1.8%). Conditions of traffic also appeared to affect fatigue levels, with increased fatigue observed when the vehicle was in low traffic under automation compared with in high traffic, suggesting some level of alertness is created by more complex conditions.

However, not all studies have demonstrated negative effects of fatigue on takeover, with some studies finding no difference between alert and fatigued drivers in response to a transition demand. Feldhütter, Kroll and Bengler (2018) looked at the impact of drowsiness and fatigue on takeover performance during the transition from conditionally automated driving to manual driving. Forty-seven participants were assigned to one of two conditions: fatigued or alert. In the alert condition, the desired driver state was promoted by specific measures (e.g. daytime, caffeinated beverages, physical exercise). In the fatigued condition, the transition demand was triggered once participants reached a certain level of drowsiness and fatigue. Two trained, independent observers assessed the state of drivers with the support of a technical fatigue assessment system based on objective eyelid-closure metrics. In the alert condition, participants experienced conditional automation for fixed 5-minute periods. As a transition request was issued only when a specific level of drowsiness and fatigue was reached in the fatigued group, actual periods of automation varied in duration. Results showed no significant difference between participants' take-over times in the two conditions. However, drivers in the fatigued condition showed more signs of stress and burden during takeover. In addition, their behaviour was assessed to be less confident, which could negatively affect the transition from conditionally automated driving to manual driving in more complex situations.

In a detailed review of drowsiness and fatigue in conditionally automated driving, Radlmayr et al. (2019) conclude that while studies have shown significant individual differences in the development of drowsiness and fatigue it appears to have little to no effect on takeover performance for the levels of fatigue tested. Nonetheless, extreme levels of drowsiness and fatigue should still be avoided to prevent impairment in critical takeover scenarios.

In this regard, NDRTs have shown a high potential to counter drowsiness and fatigue and potentially offer a way of prolonging periods of conditionally automated driving. For example, Weinbeer, Muhr, and Bengler (2018) investigated the effects of different NDRTs and their effects on drowsiness and fatigue during conditional automation. After a relaxation phase, the sample was split into three groups that were given different non-driving-related tasks (a dictation task, an activity and a relaxation task). No participant in the dictation or activity group exceeded a high level of self-reported drowsiness after the transition demand, demonstrating that some NDRTs have the potential to be suitable options for managing driver drowsiness and fatigue during prolonged use of conditional automation.

4 Summary and conclusions

The introduction of conditionally automated driving systems could fundamentally change the role of the driver if they are permitted to disengage from the driving task. For the first time, drivers may be allowed to divert their attention to non-driving related tasks (NDRTs).

Disengagement from the driving task could impair drivers' availability to safely resume control where the automated system reaches a functional limit and issues a transition demand. At the point of the system issuing a transition demand, the driver must already be prepared to re-engage while dumping any other task being undertaken that is not allowed for drivers of conventional vehicles.

The current review sought to explore published scientific literature to consider how the various tasks that a driver might undertake while conditional automation is in control of the vehicle might affect their ability to regain safe control. The direct application of this is to inform the implementation of Automated Lane Keeping Systems (ALKS) in Great Britain.

What is the current state of the literature?

The evidence base for appraising the research question is still developing. As such there is no clear evidence or direct summary of tasks that can, and cannot, be 'safely' completed while conditional automation is in control of the vehicle. Most of the research has been completed in the last 20 years, with the most relevant published research on conditional automation occurring in the last 5 years. Most studies have used simulators and tested specific aspects of automation, typically relying on timed response, driver performance metrics and visual behaviour as measures.

Zhang et al.'s (2019) meta-analysis of takeover times revealed a number of limitations in drawing firm conclusions from the literature. One is the vast array of mocked-up simulated systems and measurement protocols being used, making comparison of findings very difficult. Another is the variety of participants used in studies, ranging from typically younger volunteers at universities to middle-aged and older participants in studies completed by research companies with high-fidelity simulators. Low-fidelity simulator use is associated with greater sample sizes and younger ages, likely due to their use in populated university settings.

These limitations mean that it would be risky to attempt to draw firm conclusions based on the current state of the evidence. Nevertheless, the volume and variety of research do allow for the identification of the direction of research findings which can be appraised in the context of reasoned judgement and theoretical underpinnings from broader knowledge of driver behaviour and psychology.

What tasks are drivers likely to undertake during conditional automation?

While there is little evidence of free choice in the studies reviewed, where drivers had the opportunity to do what they wanted during conditional automation, most drivers reach for their smartphone. Clearly a variety of tasks can be conducted using a smartphone. Other than listening to music or a podcast, most tasks are highly visually engaging. Other tasks undertaken include reading from books, magazines and tablet devices. Laptop use and applying cosmetics were other activities recorded.

What does takeover involve?

Manual takeover from conditional automation involves a series of processes: perception of the transition demand warning; cognitive processing and decision making; resumption of motor readiness; physical engagement and driving action; and situational awareness. This is illustrated in Figure 3.

The evidence suggests that drivers' initial responses to a transition demand occur relatively quickly, and with visual and motor processes to 'reorient' occurring in parallel; the first glance at the roadway appears to occur concurrently with a motor movement to reposition hands on the wheel and feet on the pedals.

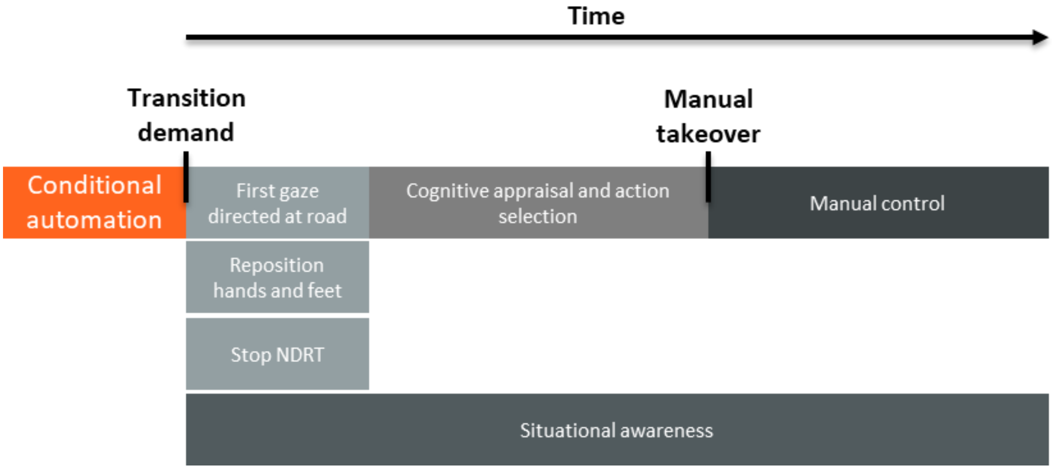

Figure 3: Enhanced overview of transition demand process

Evidence also suggests that drivers will typically use all the time they have available before taking back control, sometimes to finish and dump an NDRT. It is apparent that re-engagement with the physical and sensory aspects of the driving task requires some recalibration. Studies have reported both lateral and longitudinal movement variation immediately after manual takeover, which then settles. It appears that drivers improve with experience, as would be expected, and that those experienced with similar driver assist systems (such as adaptive cruise control) perform better. Nevertheless, while long-term effects are unclear, even after five days of experience, one study found drivers to require some recalibration when taking back control.

Situational awareness refers to the driver's perception and comprehension of their environment and is related to accurate anticipation and hazard perception. As it is a psychological construct, it is difficult to measure, but it is widely accepted that it is a critical requirement for safe transition. Compared with manual driving, measurement of gaze behaviour has been shown to be impacted by conditional automation when responding to an in-vehicle warning signal. This is largely to be expected, as a manual driver is still fully engaged with the driving task.

How is takeover impacted by non-driving related tasks?

It is widely evidenced that takeover time and quality is negatively impacted by engagement with NDRTs. A meta-analysis found strong evidence for the conclusion that performing an

NDRT with a handheld device increases total takeover time. It has also been repeatedly demonstrated in collision scenarios that emergency takeovers are negatively impacted by engagement in NDRTs, particularly visually engaging tasks which take eyes away from the road (and which are likely to be common in the use of handheld devices). The effect of the use of centre console devices (often tablets attached to the simulator vehicle) is unclear, with task type possibly being more important. For example, using the console for tasks that allow occasional glances at the road (e.g. general interaction and browsing) may be less damaging to performance than visually engaging tasks such as watching a film.

Further research is required on the specific aspects and characteristics of NDRTs that could have a significant influence on the takeover task, but it appears sensible to conclude that tasks which require significant visual attention will impact the ability of drivers to safely resume control of the vehicle. Visual inattention is one of the strongest predictors of crash-risk during manual control (Dingus et al., 2006), and theoretically aligns with an impairment of immediate situational awareness and hazard anticipation. It should be expected therefore that a driver who has been occasionally perceiving the road environment will be at an advantage to a driver who has been completely visually engaged in a NDRT, when required to take back control.

This has implications for how driving automation technologies work alongside driver monitoring technologies, such as the driver availability recognition system required for ALKS. The function of the proposed ALKS monitoring system is to detect if the driver is present in a driving position, with their safety belt fastened, and is available to take over the driving task. Driver engagement will be checked every 30-seconds via criteria such as input to driver-exclusive vehicle controls, hand positioning, blink rate and eye closure. If a driver is allowed to undertake secondary tasks only via the vehicle HMI – say, a screen directly in front of the driver or in the centre of the instrument panel – then the driver is likely to be looking in certain, known directions. This means that driver attention monitoring systems can be extended relatively easily (and cheaply) to monitor and ensure that the driver is in an appropriate state to take back control when a transition demand is issued. In this example, an additional camera mounted near a screen in the centre console would be able to detect that the driver's attention was focused on that screen and that they were not asleep. By contrast, it is much more difficult to ensure this sort of monitoring if the driver's gaze direction is unconstrained. For instance, they could be looking down at a phone or laptop screen, or sideways at someone in the passenger seat. A conventional attention monitoring system may not be able to determine whether the driver is engaged in that task. Careful consideration will therefore be required of the interplay between the driving automation system, driver monitoring technology and secondary tasks in order to ensure safe operation of different automation technologies.

The integration of automation technology and driver monitoring technologies is likely to be critical for the effective integration of systems to riskier driving situation such as at higher speeds or in mixed traffic.

Do drivers need to be trained?

"In simple terms, some drivers may not know exactly who is responsible, what they need to do, or how to do it." (Louw et al., 2019, p871). Mental models represent our understanding of a system's purpose and functionality in a given situation. It has been suggested that the significant variability in driver response to automated systems is due to a lack of awareness and understanding of the systems. Research into current driver assist systems suggests drivers have poor mental models and understanding of the functionality and limitations. Relying on drivers to read the user manual is unlikely to be enough to ensure understanding and there is suggestion that awareness and training may be required for new systems being introduced on the road. A recent pilot study of training designed to guide drivers to develop accurate mental models has shown some promise, although further validation is required.

Will drivers trust ALKS?

Studies indicate that trust in automated systems is high, albeit the systems being tested are in a simulated, no-risk, environment. Nevertheless, studies report drivers engaging with the systems as soon as they become available during a drive and are happy to almost immediately disengage from driving and turn to NDRTs. During Burnett et al's (2019) 5-day study, drivers' trust was already high after day one, and even higher on day five, despite an unplanned takeover being required on day four. Large et al. (2019) note that greater trust creates an associated likelihood to disengage and adopt NDRTs, resulting in a decrease in situational awareness.

Is there evidence of conditional automation leading to undesirable behaviours?

Burnett et al's (2019) 5-day study provided the opportunity to identify behavioural adaptations that may occur as drivers become more comfortable and trusting in conditional automation systems. Of note were situations where drivers adapted their environment to fit with their NDRT; moving the seat to use a laptop, reclining to relax and swapping glasses to read. It is unsurprising that from the user perspective, if the vehicle is in control and they are focused on another task, that drivers will adapt their environment to make that task comfortable. However, some drivers also engaged in more 'vigilance-friendly' tasks such as listening to music or podcasts via headphones and holding devices to one side to allow them to occasionally glance at the road and be prepared for taking control. A variety of behaviours might be expected, but it is those which lead to greater disengagement with the driving task that are likely to have a greater impact on safety.

What does this mean for the use of ALKS?

Physical and sensory disengagement with the driving task, and adoption of NDRTs might leave drivers ill-prepared for transition demands and resumption of control in certain circumstances. However, aspects of the ALKS system, as currently specified, should minimise some potential risks. For example, the driver availability recognition system should ensure that drivers remain in the driving position, with their seatbelt fastened, thereby making it difficult for them to adapt their environment to a NDRT (e.g. moving the seat back to rest or to accommodate a laptop). In addition, driver availability will be checked every 30 seconds using at least two criteria such as input to driver-exclusive vehicle controls, hand positioning, blink rate and eye closure. These systems have the potential to ensure a level of visual awareness of the road, thereby maintaining a certain level of situational awareness. It remains to be seen how manufacturers will design and integrate the driver availability recognition system into vehicles.

At present, the ALKS operational design criteria limits it to use in passenger cars on motorways, and has an operational speed limit of 60 km/h. This means use of the system in congested motorway traffic scenarios. Assuming systems operate as specified, at this speed drivers should have sufficient time to safely respond to transition demands in most cases, meanwhile the driver availability recognition system should naturally limit drivers' engagement with NDRTs.

When considering the types of task that could be safely performed, the literature reviewed suggests that tasks that are visually demanding or require manual manipulation of a device are related to longer takeover times and more likely to impact takeover quality. The evidence of specific task effects is not yet clear enough, but the evidence to date can be used to appraise typical behaviours based on a wider understanding of driver inattention. For example, driver inattention is not only manual and visual but can also be cognitive (mental) and auditory. The relationship that these different forms of distraction have on safety will be influenced by the task and such things as the timing, intensity, frequency and duration (Kinnear & Stevens, 2015). Table 2 provides an example of how various tasks might impact on driver resources, highlighting that some tasks (even with the same device) are more likely than others to impact takeover safety and quality. For example, hand-held texting is likely to be cognitively, visually and manually demanding, and therefore is likely to impact on takeover time following a transition demand. Alternatively, browsing, reading or viewing short-content material on a centrally placed infotainment system may not be as demanding on these same resources, in addition to encouraging glances at the roadway to maintain situational awareness. Such a breakdown of individual tasks may be necessary to really understand the potential for safe use when operating ALKS. This requires further research and a consistent research protocol to facilitate comparison of findings across studies.

Table 2: Example of how various NDRTs might be considered to impact on driver resources

Task example	Cognitive	Visual	Manual	Audible
Mobile phone – Texting etc. (hand-held)	H	H	H	L
Mobile phone – Dialling (hand-held)	M	H	H	L
Mobile phone – Conversation (hands-free)	H	L	L	H
Infotainment system – Watching video	M	H	L	M
Infotainment system – Playing game	H	M	M	M
Infotainment system – Browsing / short content material	M	M	M	L
Eating / smoking	L	M	H	L
Reading a book / newspaper / magazine	M	H	H	L

H= High; M=Medium; L=Low

Consideration might be given to only permitting tasks that can be completed through the vehicle infotainment system. The benefit of this is that transition warnings can immediately interrupt engagement with infotainment system NDRTs. This forces the driver to dump the NDRT before they might otherwise do with a third-party device such as a tablet or smartphone. There is not enough evidence to appraise the impact of use cases such as reading a book, newspaper or magazine where a driver would have to rely on auditory or vibrotactile warnings to indicate a transition demand. Inherently any task that cannot be interrupted directly by the vehicle's transition warning poses a risk to safe transition.

What if the ALKS maximum speed was increased to 70mph?

ALKS is the first automated driving system to be approved via a UN Regulation. It is likely that ALKS has become the first use case for SAE Level 3 conditional automation in type-approval because it has the most highly constrained operational design domain (ODD) available on the public road. It shall only be possible to activate the ALKS on roads where pedestrians and cyclists are prohibited, which considerably reduces the complexity of the traffic in which the system is operating. In the UK, this limits ALKS use to motorways. Furthermore, the road must be equipped with physical separation that divides the traffic moving in opposite directions, which further limits use of ALKS to sections of the motorway that have a median barrier. Finally, currently the Regulation limits the operational speed to 60 km/h and use in passenger cars (M_1 vehicles).

Increasing the speed range would maintain the infrastructure and other-vehicle constraints of the existing ODD, but is a very different challenge in terms of the capability of the automated driving system (including sensor range and technology and software required to identify hazards). It will require a different evidence base for safe operation, and requirements for testing, for example:

- Use in free-flowing traffic includes the requirement to move to the left-most lane where possible (Rule 264 of the Highway Code), so ALKS could only be engaged for a short period of time, before the human driver would have to take back control and overtake, or move back to the left-hand lane. This would considerably constrain the usefulness of the system, unless the driver was content to stay in the left-most lane with heavy goods vehicles limited to 90 km/h. Alternatively, the system will need to be capable of safe lane change manoeuvres.
- Rule 268 of the Highway Code allows undertaking in congested traffic, when lanes may be moving at similar speeds. This allows for undertaking in traffic jams while ALKS is active. However, undertaking is not otherwise permitted and the ALKS would have to behave differently in free-flowing traffic, e.g. reduce speed or hand control back to the human driver to avoid undertaking slower vehicles.
- If the ALKS were constrained to operate at a maximum speed of 112 km/h (the speed limit for M_1 vehicles on the UK motorway network unless otherwise signed), a proportion of other vehicles on the motorway may be expected to be travelling in excess of this speed (DfT, 2020). An ALKS system used in free-flowing traffic would have to be capable of dealing with this.

These points regarding technical capability are pertinent to how the vehicle operates and interacts with other vehicles. For example, overly cautious systems could by default leave large gaps to the vehicle ahead that manual drivers use to their advantage (e.g. to pull into when approaching motorway exits), causing the system to have to continually react. Whether this has any safety implications, like unexpected sharp braking, or merely causes frustration to the operator has yet to be ascertained.

Aside from any technological concerns regarding the use of ALKS at higher speeds on the road network, transition demands at higher speeds are clearly higher risk manoeuvres. The increasing complexity of transition at higher speeds places added demands on the driver when responding to a transition demand. In this more complex scenario, there may be more infrastructure elements and more complex traffic environments for the driver to perceive, understand and incorporate in planning during the transition phase. The consequences of making a mistake during the handover and initial driving phase will be greater if driving speeds are higher. This may mean that the time required for safe handover of control to the human driver is longer, while at the same time the distance travelled at 70mph over the current 10 second transition phase is much greater. The evidence to date suggests that certain NDRTs (e.g. visually-demanding or hand-held tasks) increase the time required to take back control of the dynamic driving task. Given that shorter transition demands may be required at higher speeds, the types of secondary tasks a driver can safely engage in may be more limited. For example, this might only include brief engagement with a centre console, or voice controlled auditory related tasks only.

What if ALKS requires drivers to monitor the driving situation at all times?

There are two related risks in this situation. One is that it affords drivers the opportunity to take on a NDRT, potentially resulting in the driver not maintaining sufficient attention to the road. The system may provide a sense that it has taken full responsibility of the driving task, when in fact it has not. In this use case, the accuracy of drivers' mental models of the operating functionality, responsibilities and limitations of the system are critical.

The second risk is that there was some evidence of 'underload' in the literature, whereby the monitoring task becomes monotonous if conducted for a long period of time. This might be controlled by limiting the time with which the system can be engaged, or as some have alluded, by allowing drivers to engage with cognitively engaging tasks such as simple games that maintain vigilance. It is clear that engagement in tasks, even where they are not driving related, can maintain vigilance and avoid fatigue, but it is unclear what specific tasks may offer benefits where the driver is still required to monitor the driving situation at all times.

If the driver is required to monitor the driving situation at all times to ensure safety and compliance with road traffic rules relating to the dynamic driving task, it is not considered feasible to permit drivers to undertake NDRTs beyond those which are already permitted during manual driving.

References

Banks VA, Eriksson A, O'Donoghue J and Stanton NA (2018). Is partially automated driving a bad idea? Observations from an on-road study. *Applied ergonomics*, 68 (4), 138-145, https://doi.org/10.1016/j.apergo.2017.11.010.

Burnett G, Large D and Salanitri D (2019). *How will drivers interact with vehicles of the future*? London: RAC Foundation

Carroll JM and Olson JR (1987). *Mental models in human-computer interaction: Research issues about what the user of software knows*. Committee on Human Factors, Commission on Behavioral and Social Sciences and Education, National Research Council. Washington, DC: National Academy Press.

DfT (2020). *Vehicle Speed Compliance Statistics, Great Britain: 2019*. Statistical Release. London: Department for Transport

Dingus TA, Klauer SG, Neale VL, Petersen A, Lee SE, Sudweeks J, ...and Bucher C (2006). The 100-car naturalistic driving study, Phase II-results of the 100-car field experiment (No. DOT-HS-810-593). United States. Department of Transportation. National Highway Traffic Safety Administration.

Eriksson A and Stanton N (2017). Takeover Time in Highly Automated Vehicles: Noncritical Transitions to and From Manual Control. *Human Factors*, 59(4), 689-705, 10.1177/0018720816685832.

Feldhütter A, Kroll D and Bengler K (2018). Wake Up and Take Over! The Effect of Fatigue on the Take-over Performance in Conditionally Automated Driving. *In, Proceedings of the 2018 IEEE 21st International Conference on Intelligent Transportation Systems (ITSC).*

Fleskes K and Hurowitz D (2019). Influence of bicyclist presence on driver performance during automated vehicle take-over requests. *Transportation Research Part F*, 64 (8), 495-508, https://doi.org/10.1016/j.trf.2019.06.007.

Gold C, Damböck D., Lorenz L and Bengler K (2013). "Take over!" How long does it take to get the driver back into the loop? *In: Proceedings of the human factors and ergonomics society annual meeting, 2013, Los Angeles.* Los Angeles, CA: Sage Publications, 1938-1942.

Gold C and Bengler K. (2014). Taking over control from highly automated vehicles. *In: the 5th international conference on applied human factors and ergonomics, 2014, Krakow, Poland*. Poland: AHFE, 3362-3367

Gold C, Berisha I and Bengler K (2015). Utilization of drivetime – Performing non-driving related tasks while driving highly automated. *In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 2015, Los Angeles*. Los Angeles, USA: Human Factors, 1666-1670.

Jamson A, Merat N, Carsten O and Lai F (2013). Behavioural changes in drivers experiencing highly automated vehicle control in varying traffic conditions. Transportation Research Part F, 30, 116-125, http://dx.doi.org/10.1016/j.trc.2013.02.008.

Jarosch O, Paradies S, Feiner D and Bengler K (2019). Effects of non-driving related tasks in prolonged conditional automated driving – A Wizard of Oz on-road approach in real traffic environment. *Transportation Research Part F*, 65, 292-305, https://doi.org/10.1016/j.trf.2019.07.023.

Large D, Burnett G, Salanitri D, Lawson A and Box, E (2019). A Longitudinal Simulator Study to Explore Drivers' Behaviour in Level 3 Automated Vehicles *In: Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, 2019, The Netherlands.* The Netherlands: Association for computing machinery, 222-232.

Large, D, Pampel S, Burnett G, Matthias R, Thompson S and Skrypchuk L (2018). Exploring Drivers' Visual Behaviour During Take-Over Requests. *In: Proceedings of the 6th International conference on Driver Distraction and Inattention*, 2018, Sweden. Sweden: Sweden MEETX AB.

Lin Q, Li S, Ma X and Lu G (2020). Understanding take-over performance of high crash risk drivers during conditionally automated driving. *Accident Analysis and Prevention*, 143, https://doi.org/10.1016/j.aap.2020.105543.

Louw T, Merat M and Jamson H (2015). Engaging with Highly Automated Driving: To be or Not to be in the Loop? *In, Proceedings of the Eighth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, 2015, Salt Lake City, Utah*. Iowa City, IA: Public Policy Center, University of Iowa, 190-196. https://doi.org/10.17077/drivingassessment.1570.

Louw T, Kuo J, Romano R, Radhakrishnan V, Lenne M and Merat N (2019). Engaging in NDRTs affects drivers' responses and glance patterns after silent automation failures. *Transportation Research Part F*, 62(4), 870-882, https://doi.org/10.1016/j.trf.2019.03.020.

Merat N, Jamson H, Lai F and Carsten O (2012). Highly automated driving, secondary task performance and driver state. *Human Factors*, 54, 762-771

Merat N, Seppelt B, Louw T, Engström J, Lee JD, Johansson E... & McGehee D (2019). The "out-of-the-loop" concept in automated driving: Proposed definition, measures and implications. *Cognition, Technology & Work*, 21(1), 87-98.

Naujoks F, Purucker C and Wiedemann, K (2019). Noncritical State Transitions During Conditionally Automated Driving on German Freeways: Effects of Non–Driving Related Tasks on Takeover Time and Takeover Quality. *Human Factors*, 61(4), 596-613.

Neubauer C, Matthews G, Langheim L and Saxby D (2012). Fatigue and voluntary utilization of automation in simulated driving. *Human factors*, 54(5), 734-746.

Payre W, Cestac J, Dang N-T, Vienne F and Delhomme P (2017). Impact of training and in-vehicle task performance on manual control recovery in an automated car. *Transportation Research Part F: Traffic Psychology and Behaviour*, 46, 216-227.

Petermann-Stock I, Hackenberg L, Muhr T and Mergl C (2013). How long does the driver need - an analysis of take-over times from various non-driving tasks during highly automated traffic jam driving. *Advanced driver assistance systems. The way to automatic driving*. TÜV SÜD Academy

Pradhan AK, Pai G, Radadiya J, Knodler Jr MA, Fitzpatrick C and Horrey WJ (2020). Proposed Framework for Identifying and Predicting Operator Errors When using Advanced Vehicle Technologies. *Transportation Research Record*, 0361198120938778.

Radlmayr J, Gold C, Lorenz L, Farid M and Bengler K (2014). How traffic situations and non-driving related tasks affect the take-over quality in high automated driving. *In: Proceedings of the human factors and ergonomics society annual meeting, 2014, Los Angeles, USA*. Los Angeles, CA: Sage Publications, 2063-2067.

Radlmayr J, Feldhütter A, Frey A, Jarosch O, Marberger C, Naujoks F, ... and Bengler K. (2019). Drowsiness and fatigue in conditionally automated driving – Towards an integrative framework. In, *D de Waard, K Brookhuis, D Coelho, S Fairclough, D Manzey, A Naumann, L Onnasch, S Röttger, A Toffetti and R Wiczorek (Eds.). Proceedings of the Human Factors and Ergonomics Society Europe 2018 Annual Conference*. ISSN 2333-4959

Salvucci D and Taatgen N (2008). Threaded cognition: An integrated theory of concurrent multitasking. *Psychological Review*, 115(1), 101–130, https://doi.org/10.1037/0033-295X.115.1.101.

Salvucci D and Taatgen N (2011). Toward a unified view of cognitive control. *Topics in cognitive* science, 3(2), 227-230, https://doi.org/10.1111/j.1756-8765.2011.01134.x.

Saxby D, Matthews G and Neubauer C (2017). The relationship between cell phone use and management of driver fatigue: It's complicated. *Journal of Safety Research*, 61 (6) , 129-140, http://dx.doi.org/10.1016/j.jsr.2017.02.016.

Saxby DJ, Matthews G, Warm JS, Hitchcock EM and Neubauer C (2013). Active and passive fatigue in simulated driving: discriminating styles of workload regulation and their safety impacts. *Journal of experimental psychology*, 19(4), 287-300, https://doi.org/10.1037/a0034386.

Shaw E, Large D and Burnett G (2020). *Driver Training for Future Automated Vehicles: Introducing CHAT (Check, Assess and Takeover).* London: RAC Foundation.

Shen S and Neyens D (2017). Assessing drivers' response during automated driver support system failures with non-driving tasks. *Journal of Safety Research*, 61, 149-155.

Vogelpohl, T., Vollrath, M., Kühn, M., Hummel, T., & Gehlert, T. (2016). *Übergabe von hochautomatisiertem Fahren zu manueller Steuerung*. Berlin: GDV. Cited in Zhang B, de Winter J, Varotto S, Happee R and Martens M (2019). Determinants of take-over time from automated driving: A meta-analysis of 129 studies. Transportation Research Part, 64 (7), 285-307.

Vogelpohl T, Kuhn M, Hummel T and Vollrath T (2019). Asleep at the automated wheel—Sleepiness and fatigue during highly automated driving. *Accident Analysis and Prevention*, 126, 70-84, https://doi.org/10.1016/j.aap.2018.03.013.

Walch M, Langer K, Baumann M and Weber M (2015). Autonomous driving: Investigating the feasibility of car-driver handover assistance. *In: Proceedings of the Automotive UI '15 Adjunct, 11–18, 2015, Nottingham, United Kingdom*: Association for Computing Machinery.

Walch M, Mühl K., Kraus J., Stoll T, Baumann M and Weber M (2017). From car-driver-handovers to cooperative interfaces: Visions for driver–vehicle interaction in automated driving. *In* G. Meixner & C. Müller (Eds.), *Automotive user interfaces: Creating interactive experiences in the car*. Cham, Switzerland: Springer International Publishing, 273-294, https://doi.org/10.1007/978-3-319-49448-7_10

Weinbeer V, Muhr T and Bengler K (2018). *Automated driving: The potential of non-driving-related tasks to manage driver drowsiness*. In Congress of the International Ergonomics Association (pp. 179-188). Springer, Cham.

Yoon S and Ji Y (2019). Non-driving-related tasks, workload, and takeover performance in highly automated driving contexts. *Transportation Research Part F*, 60, 620-631 https://doi.org/10.1016/j.trf.2018.11.015.

Zeeb K, Buchner A and Schrauf M (2015). What determines the take-over time? An integrated model approach of driver take-over after automated driving. *Accident Analysis and Prevention*, 78, https://doi.org/10.1016/j.aap.2015.02.023.

Zhang B, de Winter J, Varotto S, Happee R and Martens M (2019). Determinants of take-over time from automated driving: A meta-analysis of 129 studies. *Transportation Research Part*, 64 (7), 285-307, https://doi.org/10.1016/j.trf.2019.04.020.

Appendix A Detailed method

A.1 Search criteria

A list of search terms relevant to the research questions was generated to run the literature search. These search terms were tested and applied across the databases detailed in A.1.1. Multiple searches were conducted within each database through an iterative process, wherein search terms were tested individually and in combination with each other to identify which terms generated relevant results. Once the terms had been tested, those that generated relevant results were merged into a Boolean search expression. This allowed the output to be refined to the most manageable number of relevant texts. The final set of search terms can be seen in Table 3. These terms retrieved broad search results and revealed studies reporting the findings from various research methods including driving simulation, cognitive task setups and meta-analyses.

Table 3: List of search terms

(1st Level Search Terms)		**(2nd Level Search Terms)**		**3rd Level Search Terms**		**(4th Level Search Terms)**
"Driver"	A	"Automation	A	"Lane keep"	A	"Task"
"Driv*"	N	"Automated"	N		N	"Safe"
	D	"Self driving"	D		D	
		"Autonomous"				
		"Driverless"				

Additional search terms were also identified and compiled. These served to supplement the existing search terms identified in Table 3. The additional terms served to both narrow the focus of the search, and potentially identify new or niche literature that was not found in the broader search. These terms can be seen in Table 4.

Table 4: Additional search terms

(1st Level Search Terms)		(2nd Level Search Terms)		3rd Level Search Terms
"Drivers"	A	"Task"	A	"Respons*"
"Level 3"	N	"Activity"	N	"Reaction"
"Older driver"	D	"Behaviour"	D	"Control"
"Novice driver"		"Take over"		"Engagement"
"Control"		"Objects"		"Awareness"
"Lane keep"		"Type		"Failure"
"Lane keeping system"		"Hand over"		"Awareness"
"Driver assistance "		"Transition"		"Crash"
		"Emergency"		"Hazard perception"
		"Control"		"Engage"
		"Time"		"Error"
				"Switching"

A.1.1 Databases

The following databases and journals were searched. An asterisk * marks journals where the findings were collapsed together to form the group 'Individual journals'.

- Google Scholar
- ScienceDirect
- TRID
- CORE
- Transportation Research Part A: Policy and Practice *
- Transport Policy *
- Accident Analysis and Prevention (AAP) *
- Transportation Research Part E: Logistics and Transportation Review *
- National Highway Traffic Safety Administration (NHTSA)
- Journal of Safety Research *
- BASE
- PubPsych

A.2 Assessment of quality and relevance

In order to ensure that only literature of enough quality and relevance was included in the review, specific criteria were used to assess the suitability of the identified literature. The criteria were applied twice, once during an initial review of abstracts and again during the full-text review. A shortlist of papers was identified by reviewing abstracts and titles. The full texts were sourced for a full review following this. Each document identified was given a score for relevance (e.g. how useful it is to answer the research question), and quality (e.g. whether it details a robust scientific study). Documents published by commercial entity/organisation were used if they directly related to the research question. The timeliness of the evidence (e.g. does it reflect what is current) was also considered, although this was not formally scored. The proposed inclusion criteria can be seen in Table 5.

Table 5: Inclusion criteria

	Score = 0	Score = 1	Score = 2
Relevance	Not relevant to the objectives of the project	Some indirect relevance to the objectives of the review (e.g. research regarding transition demand) but does not describe the effect of tasks on driver awareness or take-over performance.	Directly relevant to the objectives of the review (e.g. research which directly describes the types of activities which can be completed by the driver when the system is in conditional automation)
Quality	Non-scientific study with demonstrably poor method	Non-peer reviewed scientific study lacking enough detail to demonstrate a fully robust method but appearing to have some credibility. This includes documents published by a commercial entity/ organisation or government agency.	Peer-reviewed scientific study accounting for confounding variables through appropriate methods

A.3 In depth review of full text

In addition to the shortlisted papers found through the review, the reference lists of these documents were examined to identify whether any further literature could be obtained. This technique is known as 'snowballing' and identified additional sources that were collated from existing databases or from contacting the authors.

Once the full texts of the shortlisted papers were obtained, the literature was reviewed in full and the key information was collated in a research matrix. Each source was represented in a row in the matrix, and the method, findings and conclusions of the research summarised in columns. The inclusion criteria presented in Table 5 were applied and only those scoring either 1 or 2 on both criteria were included in the full review and report. This resulted in further exclusions. The final list of evidence for inclusion in the review amounted to 40 publications.

Safe performance of other activities in conditionally automated vehicles

Automated Lane Keeping System (ALKS) is a vehicle technology that keeps the vehicle within its lane and controls its speed for extended periods without further driver input. At present, the system is intended for use at low speeds on motorways. The system will provide a driver with the potential to engage in activities other than driving while a car is in motion on a public highway. This report summarises the findings from a review of literature that sought to understand which activities could be safely performed by a driver in a conditionally automated vehicle using ALKS.

The review established a recent body of evidence largely based on simulator studies. Lack of a consistent testing protocol for measuring driver attention and performance makes comparison difficult but themes have emerged from the volume of literature. These include the increased risk (e.g. time required to take back control) posed by engagement with handheld devices, and potentially related to this, tasks that demand considerable visual engagement. Some of the risk may be mitigated by existing legislation (e.g. on handheld devices) and the current ALKS specification requiring a 'driver availability recognition system' that should ensure the driver retains a minimum level of situational awareness and is ready to take back control. Nevertheless, at present there is a reliance on manufacturers and software developers to determine what drivers can and cannot do using in-vehicle controls and how the driver availability recognition system will be implemented. The use of ALKS at higher speeds and as an Advanced Driver Assistance system is also considered, although significant risks with both scenarios are raised and further research would be needed to establish what would be safe in these contexts.

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ISSN 2514-9652

ISBN 978-1-913246-91-4

PPR979