A new Approach for Training Needs Analysis: A case study using an Automated Vehicle

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Abstract

Considerable resources are invested each year into training to ensure trainees have the required competencies to safely and effectively perform their tasks/jobs. As such, it is important to develop effective training programmes which target those required competencies. One method that can be used at the start of the training lifecycle to establish the tasks and competencies that are required for a task/job and is considered an important activity to perform when developing a training programme is a Training Needs Analysis (TNA). This article presents a new TNA approach and uses an Automated Vehicle (AV) case study to demonstrate this new approach for a specific AV scenario within the current UK road system. A Hierarchical Task Analysis (HTA) was performed in order to identify the overall goal and tasks that drivers need to perform to operate the AV system safely on the road. This HTA identified 7 main tasks which were decomposed into 26 sub-tasks and 2428 operations. Then, six AV driver training themes from the literature were combined with the Knowledge, Skills and Attitudes (KSA) taxonomy to identify the KSAs that drivers need to perform the tasks, sub-tasks and operations that were identified in the HTA (training needs). This resulted in the identification of over 100 different training needs. This new approach helped to identify more tasks, operations and training needs than previous TNAs which applied the KSA taxonomy alone. As such, a more comprehensive TNA for drivers of the AV system was produced. This can be more easily translated into the development and evaluation of future training programmes for drivers of AV systems.

*Keywords***:** Automated Vehicles, Training Needs Analysis, Driver Training, Hierarchical Task Analysis

*Abbreviations*: AVs: Automated Vehicles, DDTs: Dynamic Driving Tasks, HTA: Hierarchical Task Analysis, KSA: Knowledge, Skills and Attitudes, TNA Training Needs Analysis

1. **Introduction**

Industry and academia invest considerable resources each year into training to ensure trainees have the competencies that are required to safely and effectively perform their tasks/jobs. For example, according to a recent government report, in 2019 in the UK, employers invested around £42 billion into training, which is the equivalent of £2,540 per trainee (Winterbotham, et al., 2020). Therefore, it is important to develop effective training programmes which teach trainees the competencies that are required for the task/job. The ADDIE model proposes that there are five stages involved in the training lifecycle: Analysis, Design, Develop, Implementation and Evaluation (Branson, et al., 1975). One activity that can be performed during the Analysis stage to help establish the tasks and competencies that are required for a task/job and should be targeted in future training programmes is a Training Needs Analysis (TNA) (Moore & Dutton, 1978; Salas & Cannon-Bowers, 2001).

1.1 Training Needs Analysis

A TNA is performed at the start of the training lifecycle (Perfect, et al., 2017). It is a systematic process which analyses the training requirements for a particular task, explores training solutions to meet these requirements and identifies the most appropriate solution for the problem (Huddlestone & Pike, 2016). TNAs are considered useful because they can identify the performance deficiencies that need to be improved and also whether training is the most appropriate solution to improve the deficiencies that were identified (e.g. increasing knowledge and skills) (Barbazette, 2006). Without a TNA, one may develop a training programme which does not improve the deficiencies identified, therefore wasting valuable time and resources (Barbazette, 2006).

1.2 Methods for Training Needs Analysis

A TNA involves five main steps. These are explained below.

1.2.1 Step 1: Identification of Goals and Objectives

The analyst identifies the purpose of the training; the overarching goals and objectives that need to be achieved (Martin, 2017; Nazir, et al., 2019).

1.2.2 Step 2: Identification of Tasks

The analyst identifies the tasks that need to be performed in order to meet these goals and objectives (Bremner, 1994; Perfect, et al., 2017; Zhang, et al., 2018). To perform these first two steps, a Task Analysis can be conducted (Moore & Dutton, 1978; Barbazette, 2006; Martin, 2017; Regan, et al., 2020). Hierarchical Task Analysis (HTA) is one such approach that has been used to perform the first two steps of a TNA (Bremner, 1994; Shepherd, 1985; Stanton, et al., 2009; Walker, et al., 2018, see section 2.2 for an explanation of a HTA).

1.2.3 Step 3: Identification of Desirable Competencies

The analyst identifies the competencies that trainees need to perform the task(s) in question (MacLean & Cahillane, 2015; Perfect, et al., 2017; Martin, 2017; Zhang, et al., 2018). Numerous taxonomies can be used to do this. One such taxonomy is the Knowledge, Skills and Attitudes (KSA) taxonomy (Moore & Dutton, 1978; Ison, et al., 2013; Salas, et al., 2015; Huddlestone & Pike, 2016; Martin, 2016, 2017; Khan & Masrek, 2017). Knowledge refers to the factual, theoretical and conceptual information that trainees need to know/understand in order to perform the task (e.g. procedures, best practice) (Brannick, et al., 2012). There are two types of knowledge: declarative knowledge which is the factual information that a person knows (e.g. facts, meanings, concepts, rules or task information) and procedural knowledge which is the use of declarative knowledge and the knowledge for performing skills/actions (Kraiger, et al., 1993; Blanchard & Thacker, 2010; Baartman & de Bruijn, 2011; MacLean & Cahillane, 2015). Skills is the application of knowledge to manipulate or construct something. It includes motor skills (e.g. hand skills), cognitive skills (e.g. detecting hazards) and meta-cognitive skills (e.g. situation awareness) (Blanchard & Thacker, 2010; Baartman & de Bruijn, 2011; MacLean & Cahillane, 2015; Regan, et al., 2020). Attitudes are a relatively enduring set of beliefs, feelings and intentions towards an entity (e.g. the training process or subject matter) (Eagly & Chaiken, 1993; Blanchard & Thacker, 2010; Regan, et al., 2020).

1.2.4 Step 4: Identification of Current Competencies

The analyst identifies the competencies that trainees currently have for the task in question (Martin, 2017; Zhang, et al., 2018; Nazir, et al., 2019).

1.2.5 Step 5: Identification of Training Needs

The analyst compares the desired competencies (step 3) with the trainees’ current competencies (step 4) to identify the training needs (the gap between the desirable and current competencies) (Zhang, et al., 2018; Nazir, et al., 2019; Regan, et al., 2020). These five steps complete the TNA. In summary, the analyst conducts a tasks analysis (e.g. HTA) to establish the goals and tasks that need to be performed and then uses a competency taxonomy (e.g. KSA) to identify the competencies that are required to perform those goals and tasks (training needs). As such, a TNA has two outputs (a list of the goals, tasks and sub-tasks that need to be performed and a list of training needs) and four inputs to achieve the outputs (task analysis, competency taxonomy and the identification of the desirable and current competencies).

1.3 Case Study: Automated Vehicles

There has been a rapid rise in the development of Automated Vehicle (AV) systems, with Levels 1 and 2 systems already on the road (e.g. Tesla’s autopilot suite (National Transportation Safety Board, 2020b), BMW’s collision and pedestrian warning system with brake activation (BMW, 2017)) and Levels 3 and 4 systems currently in development. The Society of Automotive Engineers (SAE, 2018) defines six levels of driving automation, ranging from Level 0 (No Automation) where the driver performs all dynamic driving tasks (DDTs) to Level 5 (Full Automation) where the automation can perform all DDTs in all road and environmental conditions. In Level 1 automation (Driver Assistance), the driver must perform all DDTs and monitor the road environment, however the automation can provide support for steering or braking and acceleration. In Level 2 automation (Partial Automation), the automation has the capability to control the steering, braking and acceleration of the vehicle, however the driver must monitor the vehicle and the environment and take over control of the vehicle when asked (e.g. system failures, limitations). In Level 3 automation (Conditional Automation), the automation controls all DDTs and monitors the road environment. The driver can engage in secondary tasks (e.g. reading) however they must take over control of the vehicle when asked. In Level 4 automation (High Automation), the automation can perform all DDTs and monitor the road environment. However, the driver is no longer required to take over control of the vehicle. When the limitations are reached and/or system failures occur, the vehicle can transition to a minimal risk condition (e.g. turn on hazard lights and move into the hard shoulder).

In recent years, attention has been directed to driver training for AV systems. For example, Regan, et al. (2020) used stakeholder consultations and the KSA taxonomy to conduct a TNA for drivers of Levels 0-3 automation. They found that drivers of Levels 0-3 automation need knowledge of the safety benefits when using the automation, knowledge of the environmental conditions which are unsuitable for the automation, skills in recognising these environmental conditions, skills in operating the automation and a willingness to use the automation. Similarly, some AV driver training programmes have been developed and evaluated in research studies. In a recent literature review, Merriman, et al. (2021a) identified 26 AV driver training studies. In the majority of the training programmes that were reviewed, drivers underwent a combination of written and practical training to learn about the automation, its capabilities and limitations and how and when to activate and deactivate the automation and perform takeover requests (e.g. Hergeth, et al., 2017; Payre, et al., 2017; Krampell, et al., 2020; Sportillo, et al., 2018a, 2018b; Boelhouwer, et al., 2020). However, this training research has focussed only on Levels 0-3 AV systems. Some vehicle manufacturers are planning to introduce Level 4 AV systems on the vehicle market by the mid-2020s (e.g. Ford Motor Company, 2016; Volvo Cars, 2017; Daimler, n.d.; Honda, 2017), therefore there is a timely need by manufacturers to conduct a TNA and develop training programmes which teach drivers the tasks and competencies that are required to operate AV systems which possess some Level 4 capabilities safely on the road. As such, this article conducts a TNA for an AV system which possesses some Level 4 capabilities.

1.3.1 New Training Needs Analysis Approach

To conduct the TNA, the following approach will be taken. A HTA will be conducted to establish the overall goal (step 1) and tasks (step 2) that drivers need to perform to operate the AV system safely on the road. An HTA was chosen because a HTA systematically decomposes a task into a hierarchy of goals, tasks, sub-tasks and operations (Shepherd, 1985), which are the first two steps of a TNA (see section 1.2 above). Then a competency taxonomy will be applied to establish the competencies that drivers need to perform those goals and tasks (training needs). The KSA taxonomy seems the most appropriate taxonomy to use in this TNA because this taxonomy has already been used to conduct a TNA for drivers of Levels 0-3 automation (Regan, et al., 2020, see above). Additionally, this taxonomy is highly cited and used in the driver training literature. For example, the Royal Society for the Prevention of Accidents (2018) suggests that a good driver training programme not only targets drivers’ skills but also their attitudes, knowledge and understanding of how they can manage driving risks. However, there are limitations with this taxonomy. This taxonomy only includes three competencies (KSA) and as it is unknown what competencies drivers will need to operate an AV system which possesses some Level 4 capabilities safely on the road, this taxonomy may be too generic and broad and may miss some important competencies that drivers need to operate this type of AV system safely on the road. In a recent literature review, Merriman, et al. (2021a) identified nine key themes in driver training for AV systems. These themes were workload, speed of processing, mental models, trust in automation, attention and memory, situation awareness, procedural skills, hazard and risk perception and attitudes and personality (see Table 1). However, when looking at the TNA that was conducted by Regan, et al. (2020), no training needs related to the themes of attention, workload, hazard and risk perception or memory were identified. Therefore, the KSA taxonomy may miss some important competencies that drivers need to operate AV systems safely on the road. As Merriman, et al (2021a)’s themes have been validated by five AV collisions (Merriman, et al., 2021b) and identifies the themes (competencies) that drivers of AVs will need, this article will combine the KSA taxonomy with six of these themes, in order to create a new and more comprehensive AV driver taxonomy and approach for conducting a TNA for drivers of AV systems.

The themes speed of processing, trust in automation and personality will not be included in this AV driver taxonomy for the following reasons. Firstly, personality traits are enduring and stable (Laible, et al., 2020). Although they can be modified by major life events and persistent interventions, their stability makes them hard to change (Bleidorn, et al., 2019). In the 94 papers that were reviewed, Merriman, et al. (2021a) only found two papers which suggested that drivers’ personality (locus of control) could be improved through training (Huang & Ford, 2012; Stanton, et al, 2007a), therefore personality was not included in this taxonomy. Secondly, drivers’ speed of processing (reaction time) and trust in automation are an outcome of mental model, hazard and risk perception and procedural skills training (Merriman, et al., 2021a). Driver training research has found that if drivers underwent training which taught them about the capabilities and limitations of the automation and how to perform takeover requests, this calibrated their trust in the automation and improved their reaction time to takeover requests (e.g. Payre, et al., 2017; Ebnali, et al., 2019a, 2019b; Sportillo, et al., 2019). Therefore, as TNAs identify what competencies need to be trained, rather than how the success of the training can be measured, trust in automation and speed of processing were not included in this taxonomy as themes in their own right. However, if a training element linked to trust in automation or speed of processing (e.g. the training element could increase drivers’ trust in automation), this was noted in the TNA. By combining the two taxonomies together (KSAs and AV driver training themes), it is hoped that a more granular approach will be taken, more detailed training needs will be identified and a more comprehensive TNA for drivers of the AV system will be conducted. Table 1 displays the relationship between the KSA taxonomy and the themes from Merriman, et al. (2021a).

Table 1- The relationship between the KSA Taxonomy and the themes from Merriman, et al. (2021a).

|  |  |  |
| --- | --- | --- |
| KSA Element | Themes from Merriman, et al. (2021a) | |
| Theme | Definition |
| Knowledge | Mental Models | A person’s knowledge and understanding of the physical world, the behaviour of a system or the automation (Stanton & Young, 2005; Saffarian, et al., 2012). |
| Skills | Procedural Skills | The skills that drivers need to control and handle their vehicle on the road (e.g. braking, accelerating, steering: Ebnali, et al., 2019a). |
| Workload | The interaction between the task demands (resources demanded by a task/situation) and an individual’s resources (resources that an individual has to cope with the task demands) (Gopher & Donchin, 1986; Wilson & Sharples, 2015). |
| Attention and Memory | Attention is “*the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought*” (James, 1980, p.403). Memory is “*the ability to remember information, experiences, and people*” (Cambridge Dictionary, 2020). These are cognitive skills (Regan, et al., 2020). |
| Hazard and Risk Perception | The situation awareness of hazardous situations in the road environment (Isler, et al., 2009). This is a cognitive skill (Regan, et al., 2020). |
| Situation Awareness | *“The perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future*” (Endsley, 1995, p.36). This is a meta-cognitive skill (Regan, et al., 2020). |
| Attitudes | Attitudes | A relatively enduring set of beliefs, feelings and intentions towards an entity (e.g. the training process or subject matter) (Eagly & Chaiken, 1993; Blanchard & Thacker, 2010; Regan, et al., 2020). |

1.4 Aim, Objectives and Structure of Article

The aim of this article was to demonstrate this new TNA approach using an AV system which possesses some Level 4 capabilities as a case study, within the current UK road system and laws. This article first describes the inputs to the TNA (section 2). Section 3 will then describe the results (outputs) of the TNA.

1. **Methods: Inputs to the Training Needs Analysis**

This section describes the inputs to the TNA. Section 2.1 describes the AV driving scenario that is used to perform the TNA. In section 2.2, a HTA is conducted in order to identify the overall goal and tasks that drivers need to perform to operate this AV system safely on the road (steps 1 and 2). In section 2.3, drivers’ desirable driving competencies (step 3) and current driving competencies are identified and compared (step 4) and in section 2.4 the AV driver taxonomy described in section 1.3.1 is used to identify the training needs (step 5). This process is summarised in Figure 1.

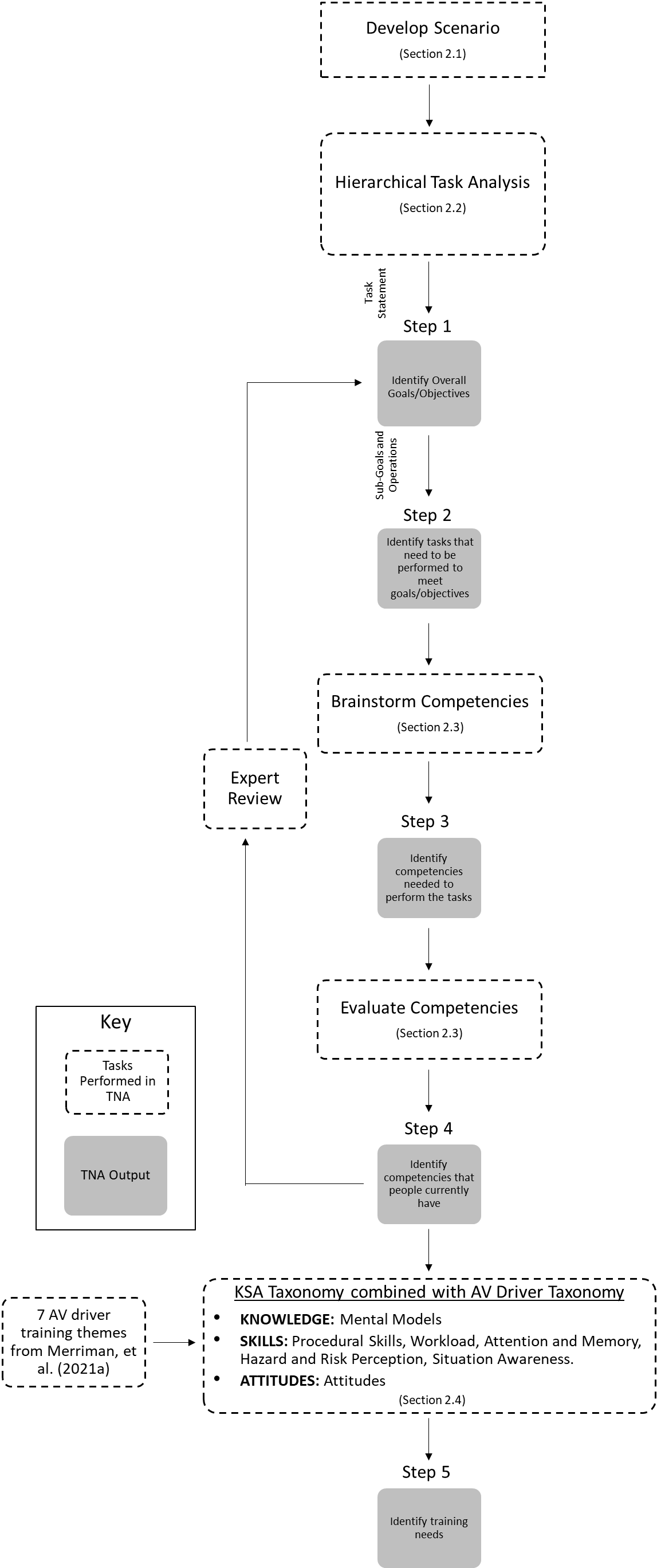


Figure -The process used to perform the TNA. The tasks that were performed are outlined in the dashed boxes and the outputs that were generated from the tasks are outlined in the grey boxes.

* 1. Development of the Automated Vehicle Driving Scenario and Storyboard

As vehicles with Level 4 capabilities are still being developed, it is unclear what capabilities and limitations these vehicles will have and how they will be operated. As such, a scenario and storyboard were created to define the AV system that was being used to perform the TNA, define its capabilities and limitations based on current literature (see below) and to identify the alerts that may occur and the high-level tasks that drivers need to perform to operate this system on the road. These high-level tasks were subsequently decomposed in the HTA (section 2.2).

Multiple sources were used to develop the scenario and storyboard. These included the SAE (2018)’s report on the definitions and taxonomy of driving automation, the research literature on driver training and interface design for AVs (e.g. Gold, et al., 2013; Lorenz, et al., 2014; Kerschbaum, et al., 2015; Payre, et al., 2016) and advertisements, videos and information from vehicle manufacturers about the development of their AV systems (e.g. Audi, 2017a, 2017b; Jaguar Land Rover, 2017; Hyundai, 2018; BMW, 2019; Skoda, 2018; Goodwin, 2019; Shirouzu & Tajitsu, 2019; Toyota, 2019a).

2.1.1 Automated Vehicle Driving Scenario

The AV driving scenario that was used to perform the TNA is described below:

*An AV system which is designed to perform all DDTs in highly reliable road conditions and can reach minimal risk conditions (i.e. has some Level 4 capabilities according to SAE, 2018). In moderately reliable road conditions, the AV system is not designed to perform as well.* *The AV system has enhanced Level 2 capabilities, so some monitoring of the automation and the road environment will be required. In highly unreliable road conditions, the AV system is not designed to perform any of the DDTs.*

This scenario was chosen because this approach is being taken by some vehicle manufacturers. For example, Audi (2017b) planned to develop an AV system which has Level 4 capabilities on highways. When the vehicle leaves the highway, the Level 4 system becomes unavailable. However, the vehicle will continue to support the driver using Levels 1 and 2 AV systems.

2.1.1.1 Dynamic Driving Tasks

* Lateral vehicle motion control (steering)
* Longitudinal vehicle motion control (acceleration, deceleration, maintaining appropriate separation distances)
* Monitors the driving environment, the vehicle and the driving automation system performance
* Response preparation, event response execution and manoeuvre planning
* Enhances visibility through lighting, signalling and gesturing.

2.1.1.2 Operational Design Domain (ODD)

The automation is highly reliable in the following road conditions:

* Speed- Between 50 mph and 70 mph
* Road Type- Motorways
* Weather- Dry, cloudy and dull weather conditions
* Roadway Conditions- Good/clear lane markings and a dry road surface
* Road Geometry- Mainly straight roads (no sharp or multiple bends)

The automation is highly unreliable when any of the following road conditions apply:

* Speed- Below 50 mph or above 70 mph
* Road Type- City streets, construction zones
* Weather- Heavy rain, snow, fog or bright light (from oncoming headlights or direct sunlight)
* Roadway Conditions- Potholes, roadway obstacles, icy or slippery road surfaces or absent, faded or ambiguous lane markings
* Road Geometry- Sharp or multiple bends

The automation is moderately reliable when any of the following road conditions apply:

* Weather- Light rain or moderately bright sunshine
* Road Type- Dual-Carriageways (see section 2.1.1.6)

2.1.1.3 Activation Characteristics

The automation cannot be activated in the “highly unreliable” road conditions (second category). If any of these road conditions apply, the driver must manually control the vehicle on the road. However, Levels 1 and 2 AV systems are present to support the driver with their manual driving (e.g. lane keeping systems, traffic aware cruise control, auto-steer).

The automation can be activated in the “highly reliable” (first category) and “moderately reliable” road conditions (third category). If the automation is highly reliable, the driver does not need to supervise the vehicle, the driving task or be receptive to a takeover request, as the automation has Level 4 capabilities, therefore they can engage in non-driving related secondary tasks. However, in the “moderately reliable” road conditions, the automation will not be able to cope as well. The automation has enhanced Level 2 capabilities, so the driver must watch over the automation and the road environment when the automation is activated (see section 2.1.1.6).

2.1.1.4 Takeover Characteristics

Manual takeovers can occur in two situations:

1. The driver requests manual control over the vehicle (Human-Directed Control Transfer).
2. The automation requests that the driver takes over control of the vehicle (Vehicle-Directed Control Transfer).

The former situation occurs when either the driver anticipates that the vehicle is approaching the end of its ODD, or when the driver wants to manually control the vehicle on the road. The latter situation occurs when the automation anticipates that the vehicle is approaching the end of its ODD (i.e. at least one of the unreliable road conditions apply).

The automation issues an optional and timely request to the driver to intervene (30 seconds). This is in comparison to a Level 3 system where the takeover request is compulsory. Thirty seconds was chosen because a review of the literature showed that takeover lead times range from 0 to 30 seconds and takeover reaction times range from 1.14 to 15 seconds (Eriksson & Stanton, 2017b).

If the driver acknowledges the request, they will manually control the vehicle on the road. However, if the driver does not respond to the takeover request, the vehicle will automatically transition to a minimal risk condition (e.g. enter the hard shoulder, safe stop). This is in comparison to a Level 3 system where the driver must acknowledge the takeover request and take over control of the vehicle (i.e. the vehicle does not reach a minimal risk condition).

2.1.1.5 Minimal Risk Conditions

The road environment is dynamic and is constantly changing, so the reliability of the automation may suddenly change from highly reliable to highly unreliable. For example, the vehicle could be driving on a motorway which has clear line markings and then suddenly the line markings disappear. In these situations and in emergencies, performance-relevant system failures and imminent collisions, the lead time and/or driver reaction time may have to be quicker than 30 seconds. Although the SAE (2018) guidance states that AV systems with Level 4 capabilities will automatically transition to a minimal risk condition when system failures occur, the guidance is unclear about what will happen in emergency situations (situations which require a takeover of less than 30 seconds). However, as recent Level 2 AV collisions demonstrate that drivers are unable to safely take over control of the vehicle in one or two seconds (Merriman, et al., 2021b), the assumption is that in emergency situations the vehicle will automatically transition to a minimal risk condition. This is in comparison to Level 3 systems where the driver must take over control of the vehicle in these situations (i.e. the vehicle does not reach a minimal risk condition).

2.1.1.6 Assumptions Made

Vehicle manufacturers and owner’s manuals clearly state what drivers should do when the automation is highly reliable and highly unreliable (e.g. National Transportation Safety Board, 2020b; Tesla, 2019). Drivers should activate the automation when the automation is highly reliable (e.g. in dry, cloudy and dull weather), and they should not activate the automation when the automation is highly unreliable (e.g. in heavy rain, bright light). However, it is unclear what drivers should do in the fringe/boundary conditions in between the highly reliable and highly unreliable road conditions (e.g. in light rain or sunshine).

Similarly, most vehicle manufacturers are developing AV systems which possess Level 4 capabilities for freeways and highways (i.e. dual-carriageways and motorways: Honda, 2017; Goodwin, 2019; Shirouzu & Tajitsu, 2019). However, it is unclear how the automation will react and how well the automation will deal with pedestrians, cyclists and horse riders. Although Honda (2017), Hyundai (2018) and Toyota (2019b) claim that their AV systems will be able to detect and deal with pedestrians, only one video (Hyundai, 2018) has demonstrated this functionality in practice. As these road users are prohibited from using a motorway (Driving Standards Agency, 2015) but can still legally use dual-carriageways (IAM RoadSmart, 2016), and it will be difficult for the vehicle and the driver to anticipate the presence of these road users, this scenario assumed that the dual-carriageway setting is a moderately reliable road condition. However, as with light rain and sunshine, owner’s manuals do not state what drivers should do in these moderately reliable road conditions. As such, assumptions had to be made. Due to the safety critical nature of driving, a safety-first approach was taken. As the automation is only moderately reliable (not high or low) in these road conditions, this scenario assumed that the automation can be activated, however it will not be able to cope as well. The automation will revert to an enhanced Level 2 AV system, so the driver will need to watch over the automation and the road environment at all times, in case the automation does not respond appropriately (National Transportation Safety Board, 2020b).

2.1.2 Storyboard

The scenario described in section 2.1.1 was used to develop a storyboard for the automation (see Figure 2 for an excerpt, full storyboard included in Appendix B). To create this storyboard, the storyboard from Stanton, et al. (2021) was adapted to fit with the AV system described above and the academic and non-academic literature about AVs (e.g. how they operate, the alerts, activation and deactivation controls) and interface design in AVs (e.g. Lorenz, et al., 2014; Louw, et al., 2015; Hawkins, 2017). For example, Volvo Cars (2015) states that the AV system uses the driver’s journey from the navigation system to determine when the automation can be activated. Therefore, this step was added to the first stage of the storyboard. Similarly, there is a consensus in the academic and non-academic literature that auditory (tones, verbal message) and visual messages will occur on the human-machine interface when the automation changes state (e.g. available, activation, takeover request, deactivation, manual control) (e.g. Schömig, et al., 2015; Volvo Cars, 2015; Zeeb, et al., 2015; Payre, et al., 2016, 2017; Eriksson & Stanton, 2017a, 2017b; Ebnali, et al., 2019a; Sportillo, et al., 2018b, 2019; Stanton, et al., 2021). Therefore, auditory and visual alerts were added to these automation state changes. All modifications are described in the storyboard captions.

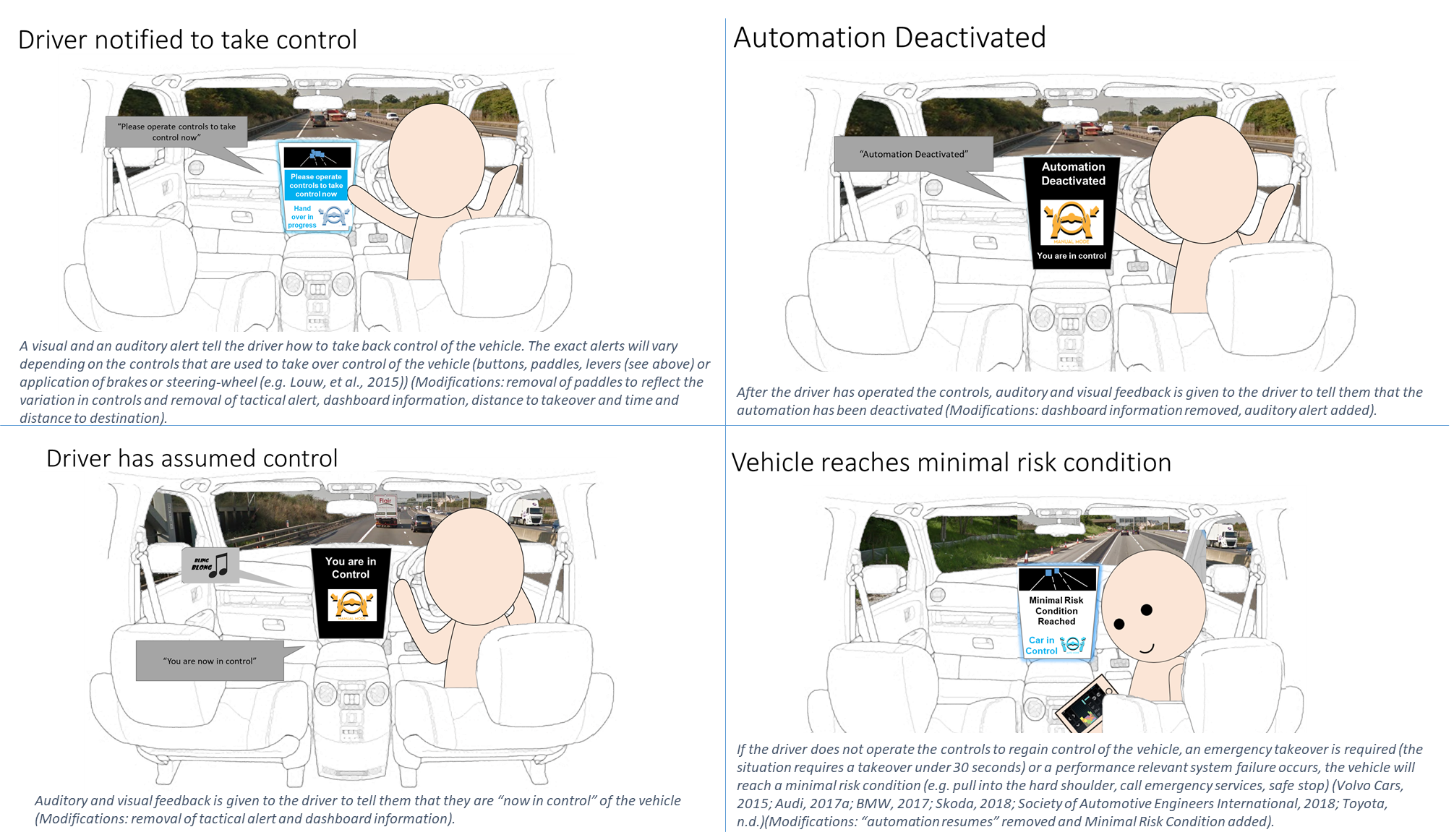


Figure - An excerpt of the storyboard for the AV system that was used to perform the TNA (Images adapted from Stanton, et al., 2021).

2.2 Steps 1 and 2: Identification of Goals, Objectives and Tasks

After the scenario and storyboard were developed, a HTA was conducted in order to identify the overall goal (step 1 in Figure 1) and tasks (step 2 in Figure 1) that drivers need to perform to operate the AV system (defined in section 2.1) safely on the road. A HTA decomposes a task into its “teachable” parts in order to determine the best way to perform the task (Barbazette, 2006). A HTA decomposes a task into a hierarchy of operations and sub-operations, each defined in terms of a goal, and these operations are linked together by plans (Shepherd, 1985; Stanton, 2006; Salmon, et al., 2019). To perform the HTA, guidance from Salmon, et al. (2019), Stanton (2006) and the Chartered Institute of Ergonomics and Human Factors Task Analysis Masterclass was followed (CIEHF, 2021).

Multiple sources were used to conduct this HTA. These included a HTA for manual driving (Walker, et al., 2018), a HTA for Levels 2 and 3 automation (Cruise, 2018), the SAE (2018)’s report on the definitions and taxonomy of driving automation, the research literature on driver training and interface design for AVs (e.g. see section 2.1), information from vehicle manufacturers about the development of their AVs (e.g. see section 2.1), IAM RoadSmart’s Advanced Driver Course Associate Logbook (IAM RoadSmart, 2016) and Observer’s Handbook (IAM RoadSmart, n.d.), the Driver and Vehicle Standards Agency (DVSA)’s syllabus for learning how to drive a manual car (DVSA, 2014a) and the Goals for Driver Education matrix (Hatakka, et al., 2002).

Firstly the overall goal (step 1 in Figure 1) was identified as “*driving an AV, with an automated driving system for dual-carriageways and motorways, on British public roads in compliance with the Highway Code*”. This goal was then decomposed into a series of sub-goals which need to be undertaken in order to achieve the overall goal, to form a hierarchy. Seven sub-goals were identified (step 2 in Figure 1):

1. Pre-Drive Tasks,
2. Manual Driving (when outside the ODD for the automation),
3. Activate the Automation (when in conditions which satisfy the ODD for the automation),
4. Human-Directed Control Transfer,
5. Vehicle-Directed Control Transfer,
6. Emergency Control Transfer and
7. Post-Drive Tasks.

Then each sub-goal was decomposed into the operations that are required to achieve the sub-goal, using the storyboard (Figure 2), the HTAs for manual (Walker, et al., 2018) and Levels 2 and 3 AVs (Cruise, 2018), the research literature on AVs (e.g. Forster, et al., 2019; Kyriakidis, et al., 2015; Pudāne, et al., 2019; Stanton, et al., 2021) and the training materials and syllabus for manual vehicles (e.g. IAM RoadSmart, 2016, n.d.; DVSA, 2014a; see above). For example to perform a Vehicle-Directed Control Transfer, drivers must recognise the alerts that the automation is no longer available, decide whether to take over control of the vehicle, prepare for the transfer of control and manually control the vehicle on the road. These operations were then decomposed further. This process continued until a sufficient level of detail had been established and the purpose of the analysis had been achieved (Stanton, 2006). The procedural guidance from Salmon, et al. (2019) and Stanton (2006) recommends analysts to define their own boundary of analysis (stopping criteria) and to decompose the operations to this boundary. Therefore, this guidance was followed when determining the stopping criteria for this HTA. In this HTA, the decomposition stopped at the control operation/action state level (e.g. operate control to activate the automation, listen to visual alert or move vision to the roadway) as opposed to defining the physical movements to perform those actions (e.g. lift up head and open eyes, move hand to activation control). Finally, following the recommended HTA procedure, the overall goal, sub-goals and operations were given numbers to show the relationships between them and plans were drawn up to determine the sequence and conditions when each sub-goal and operation was triggered.

An excerpt of the HTA is displayed on the left-hand side of Table 3 (white cells). The full HTA with plans is attached as a supplementary file (see Appendix A). In both materials, black text indicates the sections of text that were taken from Cruise (2018), blue text indicates the sections of text that were taken from Walker, et al. (2018) and red text indicates the sections of text that were added to the HTA using the other information sources listed above.

* 1. Steps 3 and 4: Identification of Desirable and Current Driving Competencies

The next steps in the TNA are to identify the competencies that drivers need to perform the tasks that were identified in the HTA (step 3 in Figure 1) and to identify drivers’ current driving competencies (step 4 in Figure 1). These steps are described below.

When determining drivers’ desirable and current driving competencies, it is important to identify the target population. As many different user groups may be exposed to the AV system (defined in section 2.1), the target population for this TNA is broad. The target groups include learner drivers, full licence holders and advanced drivers. These groups each have different driving competencies, therefore different training needs will be required for each group (see Table 2).

Table - The competencies that different drivers will require when operating the AV system on the road.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Driver Group | Definition | Important Characteristics | Current Driving Competencies | New Competencies Required |
| Learner Drivers | Drivers who are 17 years of age or older and are currently learning how to drive. | In the United Kingdom, drivers can learn how to drive from 17 years of age. | Some manual driving competencies. | Some manual driving competencies and all automated driving competencies. |
| Full Licence Holders | Drivers who have passed the standard theoretical and practical driving tests. | Once drivers have become a full licence holder, no formal reassessment is required. | Standard manual driving competencies. | Automated driving competencies. |
| Advanced Drivers | Drivers who have passed the standard theoretical and practical driving tests and have undergone further advanced training. | This includes emergency service drivers and members of the general public who have undergone an advanced driver course. | Standard and advanced manual driving competencies. | Automated driving competencies. |

2.3.1 Manual Vehicle Driving Competencies

In the United Kingdom, all drivers must pass two tests before they can become a full licence holder and can drive unaccompanied on the road (GOV.UK, 2017). The DVSA have released some formal guidelines about the skills and knowledge that drivers will need in order to pass these tests and drive safely on the road (DVSA, 2014a; see Appendix C for a list of these competencies).

In theory, full licence holders will have all the competencies that are required to manually drive a vehicle on the road, so they will not need to undergo any manual vehicle driver training when learning how to drive the AV system. However, once drivers have become a full licence holder, no reassessment is required. This is problematic because The Highway Code, vehicles, technology, rules, regulations and driving tests change over time (DVSA, 2014b). For example, the hazard perception test was first introduced in 2002, so drivers who took their driving test before 2002 would not have taken this test (DVSA, 2014b). Similarly, the driving theory test was first introduced in 1996, so drivers who took their driving test before 1996 did not have to take a theory test (DVSA, 2019). Therefore, even though full licence holders have passed the tests required to manually drive a vehicle on the road, refresher manual vehicle driver training may be beneficial to ensure all drivers are aware of the latest information in The Highway Code, current vehicular technologies, current road laws, rules and regulations and to sharpen their skills on the road (e.g. road positioning, hazard anticipation, gap assessment).

Learner drivers will have some or all of these manual vehicle driving competencies but at varying levels of proficiency, therefore they will need to undergo manual vehicle driver training when learning how to drive the AV system. In contrast, advanced drivers will have learnt additional more advanced driving skills, which go beyond the basic car control skills that drivers learn when learning to drive. These include learning about how to apply the IPSGA system of vehicle control, acceleration sense, limit point analysis, observation links and spoken thoughts (IAM RoadSmart, 2016). Therefore, advanced drivers will not have to undergo any manual vehicle driver training when learning how to drive the AV system. However, as The Highway Code, vehicles, technology, road laws, rules and regulations change over time, refresher manual vehicle driver training may be beneficial to ensure these drivers have up-to-date knowledge about these changing elements.

2.3.2 Automated Vehicle Driving Competencies

Unless drivers have undergone a driver training study for AV systems (e.g. see Merriman, et al., 2021a), no driver has undergone formal training for operating AV systems on the road, therefore their AV driving competencies will be limited. Drivers who have Level 1 and/or 2 AV systems inside their current vehicles may be familiar with the operation of these systems (capabilities, limitations, functionality and use) through experience and/or from reading the owner’s manual for their vehicle. However, their level of competence, knowledge and skills in safely operating these systems on the road is unknown (e.g. drivers may not have read the owner’s manual and/or they may not use these systems: Casner & Hutchins, 2019; Forster, et al., 2019). In contrast, if drivers do not have these systems inside their current vehicles, they will not be familiar with these systems nor have the competencies required to operate these vehicles safely on the road. Additionally, as the capabilities of the automation and the roles between the driver and the automation vary for each level of automation (see section 1.3), even if drivers have some competencies for Levels 1 and/or 2 automation, they will still need to learn additional competencies for this AV system (defined in section 2.1) which also has some Level 4 capabilities. For example in purely Level 2 AV systems, drivers are still required to monitor the automation and the road environment when the automation is in operation. However, in the AV system defined in section 2.1, this is only required when the automation is moderately reliable (see section 2.1.1), so drivers need to be aware of these differing tasks. Similarly, the takeover procedure will vary. In Level 2 AV systems, as drivers are still required to monitor the road environment, they will not need to build an awareness of the road environment before taking over control of the vehicle. However, in the AV system defined in section 2.1, drivers will need to learn about how they can build an awareness of the road environment after looking away from the road for an extended period of time. Therefore all target groups will need to undergo formal training to learn the competencies and tasks that are required to operate the AV system safely and appropriately on the road.

* 1. Step 5: Identification of Training Needs

The last step in the TNA is to identify the training needs (step 5 in Figure 1). To achieve this, the desirable driving competencies (step 3) and drivers’ current driving competencies (step 4) are compared. All drivers’ current AV driving competencies are limited (see section 2.3.2), therefore all drivers will need to learn all the competencies that are required to operate the AV system (defined in section 2.1) safely on the road. To determine what those specific competencies (training needs) were, the new AV driver taxonomy which combined the KSA taxonomy with six themes from Merriman, et al. (2021a) (see section 1.3.1) was used. For each task identified in the HTA, this new taxonomy was used to identify the workload, attention and memory, mental models, situation awareness, hazard and risk perception, attitudes and procedural skills competencies that drivers will need to perform the task.

Once the training needs were identified, this TNA was given to three driver training subject matter experts at IAM RoadSmart for review and suggested modifications were made. Table 3 displays an excerpt of the TNA. The HTA is displayed on the left-hand side of the table (white cells) and the competencies that are required to perform each task (training needs) are displayed on the right-hand side of the table (grey cells). The complete TNA is attached as a supplementary file (see Appendix A).

Table - An excerpt of the TNA for the AV system described in section 2.1.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  | AV Driver Taxonomy | | | | | | |
|  |  |  |  |  |  |  |  |  | Workload | Attention and Memory | Mental Models | Situation Awareness | Hazard and Risk Perception | Attitudes | Procedural Skills |
|  | 5 Vehicle-Directed Control Transfer | | | | | | | |  |  |  |  |  |  |  |
|  |  | 5.1 Recognise alerts that the automation is no longer available | | | | | | | Manage task demands to recognise alerts- Teach drivers to regularly break secondary task performance to check interface. | Direct attention to alerts and help memorise the alerts that can occur and what they mean. | Ensure appropriate mental model for the alerts (know what the alert is referring to and what that means in terms of driving behaviour) and when ODD limits are being reached (i.e. when they need to deactivate the automation). | Ensure awareness of alerts and that system is reaching its ODD limits. | Identify hazards and risks associated with the ODD limits (e.g. speed- speed is falling below 50 mph, weather- bright light or rain disrupt sensors, roadway conditions- no/faded lane markings, road geometry- tight bends). | Not wanting to use automation when ODD limits are reached. See the alert as helpful, useful, guidance and something which supports them and their safety rather than a nuisance, interruption, irritation or annoyance. This is impacted by trust- If drivers trust the automation, they are more likely to have positive attitudes towards the automation and its alerts. | Move away from secondary task and get into a driving position. Ensure appropriate scanning patterns- scan correct areas of the human-machine interface to obtain information. |

1. **Results: Outputs of the Training Needs Analysis**

3.1 Tasks, Sub-Tasks and Operations

The HTA identified seven main tasks that drivers need to perform to operate the AV system (defined in section 2.1) safely on the road. These were Pre-Drive Tasks, Manual Driving, Activate the Automation, Human-Directed Control Transfers, Vehicle-Directed Control Transfers, Emergency Control Transfers and Post-Drive Tasks. These seven tasks were decomposed into sub-tasks (see Table 4):

Table - The sub-tasks for the seven main tasks in the HTA for the AV system defined in section 2.1.

|  |  |
| --- | --- |
| Main Task | Sub-Tasks |
| 1. Pre-Drive Tasks | * 1. Exterior vehicle pre-drive checks   2. Enter vehicle   3. Internal vehicle pre-drive checks   4. Put on seatbelt   5. Conduct a static brake test   6. Enter destination into navigation system   7. Conduct a moving brake test |
| 1. Manual Driving | * 1. Drive the vehicle manually   2. Use the Level 1 and 2 automation systems that are present in the vehicle |
| 1. Activate the Automation | * 1. Recognise the "automation is available" alerts   2. Decide whether to activate the automation   3. Position vehicle ready to activate the automation   4. Determine whether it is safe and appropriate to activate the automation   5. Initiate automation system |
| 1. Human-Directed Control Transfer | * 1. Understand the need to manually control the vehicle on the road   2. Prepare for the transfer of control   3. Manually control the vehicle on the road |
| 1. Vehicle-Directed Control Transfer | * 1. Recognise alerts that the automation is no longer available   2. Decide whether to take over control of the vehicle   3. Prepare for the transfer of control   4. Manually control the vehicle on the road |
| 1. Emergency Control Transfer | * 1. Recognise alerts that an emergency control transfer is required   2. Let the vehicle reach a minimal risk condition |
| 1. Post-Drive Tasks | * 1. Park vehicle   2. Make vehicle safe   3. Leave vehicle |

These sub-tasks were decomposed into operations (see Table 5). Table 8 in Appendix D displays the operations for the main task Activate the Automation. The operations for the other main tasks can be found in the supplementary full TNA (see Appendix A).

Table - The number of sub-tasks and operations for the seven main tasks in the HTA .

|  |  |  |
| --- | --- | --- |
| Main Task | Number of Sub-Tasks | Number of Operations |
| Pre-Drive Tasks | 7 | 75 |
| Manual Driving | 2 | 1487 |
| Activate the Automation | 5 | 201 |
| Human-Directed Control Transfer | 3 | 305 |
| Vehicle-Directed Control Transfer | 4 | 313 |
| Emergency Control Transfer | 2 | 10 |
| Post-Drive Tasks | 3 | 37 |

This HTA demonstrates the complexity with operating the AV system (defined in section 2.1) safely on the road. The seven main tasks may seem relatively simple to perform on the surface, however drivers must perform numerous operations to perform each one safely on the road, therefore they are more complex than they initially appear.

* 1. Training Needs

The TNA identified over 100 distinct training needs. Some training needs were only mentioned once or twice. The training needs that were mentioned most frequently in the TNA (at least 10 times) are described below (Table 6).

Table - The most frequently mentioned training needs in the TNA for the AV system defined in section 2.1.

|  |  |
| --- | --- |
| AV Driver Taxonomy | Training Need(s) |
|  | Drivers need to: |
| Workload | * Know when it is and is not safe to engage in secondary tasks. * Manage their task demands to recognise system warnings and automation alerts- Drivers should regularly break their secondary task performance to check the central interface. |
| Attention and Memory | * Direct their attention to the alerts on the central interface. * Direct their attention to the road environment (e.g. road signs, road surface). |
| Mental Models | * Have an appropriate mental model for the level(s) of automation in the vehicle. * Have appropriate mental models for the capabilities, limitations, ODD (road conditions where it is and is not safe and appropriate to operate the automation) and reliability of the automation.\* * Have an appropriate mental model for how and when to activate and deactivate the automation.\* * Have an appropriate mental model for the automation alerts. Drivers need to know what the alerts are referring to and what that means in terms of their behaviour. For example, the “automation is available” alert means that the automation is available and so the automation can be activated.\* * Have an appropriate mental model for the road type and road environment (e.g. motorways have blue-backed road signs and cyclists and pedestrians are prohibited). |
| Situation Awareness | * Have an awareness that the automation is reaching its ODD limits (e.g. speed, road type, weather).\* * Have an awareness of the benefits of using the automation.\* * Have an awareness and understanding of the automation alerts that can occur.\* * Have an awareness of the tasks that they need to perform once the automation has been activated (e.g. secondary tasks, monitoring). * Have an awareness of the road environment (e.g. environmental hazards, other road users) and the vehicle (e.g. lane position, dashboard warnings). |
| Hazard and Risk Perception | * Identify hazards in the road environment and those associated with the ODD limits (e.g. heavy rain, no lane markings). * Know about the hazards and risks (consequences) if critical tasks are not performed\* (e.g. pre-drive tasks, determining the reliability of the automation) or inappropriate behaviours are performed (e.g. activating the automation inappropriately, not stopping secondary task). |
| Attitudes | * Have safe driving attitudes towards themselves and other road users. * Have confidence in their manual driving skills. * Have positive attitudes towards driving (e.g. enjoy driving, not nervous or stressed when driving). * Have a willingness to use the automation when it is safe and appropriate to do so and not over-rely on the automation (i.e. not wanting to use it) when it is unsafe to do so.\* * Have confidence and acceptance in the automation. * Understand that all vehicle alerts are helpful, useful, provide guidance and something which supports them and their safety rather than a nuisance, interruption, irritation or annoyance. |
| Procedural Skills | * Use appropriate scanning patterns to read the automation alerts. * Use appropriate scanning patterns to determine the reliability of the automation and to decide whether it is safe and appropriate to operate the automation. * Use appropriate scanning patterns to build and maintain an awareness of the road environment (e.g. raise, extend and widen vision across the roadway. Look as far down the road as possible before bringing vision back towards the vehicle). * Have the procedural skills to activate and deactivate the automation and take over control of the vehicle in a safe manner.\* * Have the procedural skills to perform the tasks that are not automated by the automation (e.g. steering, monitoring for Levels 1 and 2 automation systems).\* * Have the procedural skills for manually controlling the vehicle on the road (e.g. brake, accelerate, steering). |

\* The training needs that were similar to those identified in Regan, et al. (2020).

1. **Discussion**

TNAs can be performed at the start of the training lifecycle to establish the tasks and competencies that are required for a task or job. However, current TNA approaches are limited in the number of tasks and competencies that are identified. This article describes the development of a novel TNA approach (outlined in Figure 1) and uses an AV case study to demonstrate this approach for an AV system which possesses some Level 4 capabilities within the current UK road system. A HTA was performed in order to identify the overall goal (step 1 in Figure 1) and tasks (step 2 in Figure 1) that drivers need to perform to operate the AV system safely on the road. Then the desirable driving competencies (step 3 in Figure 1) and drivers’ current driving competencies (step 4 in Figure 1) were identified and compared. This comparison revealed that drivers’ current AV driving competencies are limited, therefore all drivers will need to learn all the competencies that are required to operate the AV system safely on the road. Finally the new AV driver taxonomy, which combined the KSA taxonomy with six AV driver training themes from Merriman, et al. (2021a), was used to identify the training needs (step 5 in Figure 1).

Whilst some tasks and training needs were similar to those identified in Regan, et al. (2020)’s TNA for Levels 0-3 automation (see starred (\*) training needs in section 3.2), this TNA for an AV system which possesses some Level 4 capabilities advanced the work by Regan, et al. (2020) in the following ways. Firstly, this TNA used an HTA to identify the overall goal and tasks (steps 1 and 2 in Figure 1) that drivers need to perform to operate the AV system safely on the road. In comparison, Regan, et al. (2020) used stakeholder consultations. The stakeholder consultations resulted in the identification of five high-level tasks. These were operate, respond, deactivate, monitor and take full control. This TNA went further; by using a range of sources including IAM RoadSmart’s Advanced Driver Course Associate Logbook (IAM RoadSmart, 2016), AV collision reports (e.g. National Transportation Safety Board, 2020a), the research literature on the challenges with AVs (e.g. Stanton & Young, 2000; Merat & Jamson, 2009; Bashiri & Mann, 2014; Endsley, 2019) and information from vehicle manufacturers about the development of their AVs (e.g. Audi, 2017b; Jaguar Land Rover, 2017), the HTA decomposed these high-level tasks into the sub-tasks and operations that drivers need to perform in order to achieve these high-level tasks. As such, the HTA provided a more in-depth analysis of the tasks and operations that drivers need to perform to operate the AV system safely on the road.

For example, to activate the automation (task step 3), this HTA showed that drivers need to recognise that the automation is available (task step 3.1), decide whether to activate the automation (task step 3.2), position the vehicle appropriately (task step 3.3), determine whether it is safe and appropriate to activate the automation (task step 3.4) and initiate the automation (task step 3.5, see Table 4). These sub-tasks were then decomposed into 201 operations (see Table 8). Similarly, the research literature suggests that AVs can reduce drivers’ situation awareness of the road environment and the driving task (Stanton & Young, 2000, 2005; Stanton, et al., 2007b; Merat & Jamson, 2009; Bashiri & Mann, 2014; de Winter, et al., 2014; Endsley, 2019), therefore in order for drivers to take over control of the vehicle in a safe manner (task step 4), they need to have a good situation awareness of the road environment (task step 4.2.6). By using IAM RoadSmart’s Advanced Driver Course Associate Logbook (IAM RoadSmart, 2016) and the driving syllabus for manual vehicles (DVSA, 2014a), this task step was decomposed into the operations that drivers need to perform in order to develop a good situation awareness of the road environment. For example, drivers need an awareness of the environment (task step 4.2.6.1), other traffic (task step 4.2.6.2), vulnerable road users (task step 4.2.6.3), the vehicle (task step 4.2.6.4) and the journey (task step 4.2.6.5). As the identification of tasks is more detailed and comprehensive (the HTA lists the exact tasks that need to be performed e.g. the task steps required to activate the automation or gain a good situation awareness of the road environment), this TNA can more easily be translated into future training programmes. For example, trainers can use this TNA as a syllabus to teach drivers how to perform these tasks, so that they operate the automation safely and appropriately on the road. Therefore, this TNA demonstrates that a HTA is a useful method to identify the tasks and operations that drivers need to perform to operate an AV system safely on the road (i.e. perform step 2 in Figure 1).

Secondly, this TNA combined two taxonomies to identify the training needs (perform step 5 in Figure 1). This resulted in an AV driver taxonomy which consisted of six competencies: workload, attention and memory, situation awareness, hazard and risk perception, procedural skills, attitudes and mental models. In contrast, Regan, et al. (2020) only used three competencies (KSA) to identify the training needs. The application of the six competencies allowed a more comprehensive TNA to be conducted, as more detailed training needs were identified. For example, when the automation reaches its limits (task step 5.1), an alarm will sound. Drivers need to perceive (task step 5.1.1) and understand (task step 5.1.2) this alert to act upon it appropriately. This TNA suggests that in order for drivers to perceive the alert, they need to take regular breaks from their secondary task performance to check the central-interface (workload), they need to look at the right locations on the interface to see the alert (attention), they need an awareness of the hazards that are associated with the ODD limits (hazard perception), they need an appropriate mental model for when the automation is reaching its limits (so that they know why the alert is sounding) and they need a good memory and mental model for the alerts (so that they know what the alert is referring to and what that means in terms of their behaviour). In Regan, et al. (2020), as less competencies were used to identify the training needs, these training needs were not identified. Similarly, this TNA suggests that in order for drivers to develop a situation awareness of the road environment, their attention needs to be directed to the road environment and other vehicles and appropriate scanning patterns need to be trained. For example, drivers should raise, extend and widen their vision across the roadway before bringing their vision back towards the vehicle. These competencies were not applied in Regan, et al. (2020), so these skills were not identified.

Therefore this analysis suggests that the KSA taxonomy alone is not detailed enough when trying to identify the training needs of drivers. This taxonomy misses some important competencies that drivers need to operate AV systems safely on the road (e.g. attention, memory, workload, hazard and risk perception, see above). Therefore, if this taxonomy was/is used to develop training programmes for drivers of AV systems, drivers may not learn/acquire all the competencies (e.g. attention skills) required to operate these vehicles safely on the road. However, the AV driver taxonomy that was used in this TNA is a more comprehensive taxonomy. The application of the six competencies provided a more detailed analysis of the Skills (procedural skills, workload, attention and memory, hazard and risk perception and situation awareness), Knowledge (mental models) and Attitudes (training needs) that drivers need to operate an AV system (defined in section 2.1) safely on the road. As such, this TNA can more easily be translated into future training programmes, as trainers can use this TNA to ensure that these competencies are trained. For example, to ensure drivers develop a situation awareness of the road environment, training programmes should direct drivers’ attention to the road environment and drivers should be taught to extend and widen their vision across the roadway (e.g. by making drivers name hazards/objects in the distance). By using this new TNA approach to establish the task and competencies that are required to operate AV systems safely on the road and using the results to design and develop training programmes to teach those required tasks and competencies, trainers can be more confident that these new training programmes cover the competencies that are required to operate these AV systems safely and appropriately on the road.

This TNA can also be used to evaluate past research on driver training for AV systems, to help understand how AV driver training can be improved in the future. For example, this TNA suggests that drivers need to have appropriate mental models for the capabilities, limitations, ODD and reliability of the automation. In the majority of the training studies that were reviewed by Merriman, et al. (2021a), drivers learnt about the capabilities and limitations of the automation and the road conditions where the automation can and cannot be used (e.g. Boelhouwer, et al., 2020; Ebnali, et al., 2019a; Korber, et al., 2018; Krampell, et al., 2020; Payre, et al., 2016, 2017; Sportillo, et al., 2018a, 2018b, 2019). Therefore this training need was satisfied in these past training studies. Similarly, this TNA suggests that drivers need to have an appropriate mental model and have the procedural skills to activate and deactivate the automation and take over control of the vehicle in a safe manner. In most of the training studies, drivers learnt how to activate and deactivate the automation and perform takeovers (e.g. Ebnali, et al., 2019a; Hergeth, et al., 2017; Krampell, et al., 2020; Payre, et al., 2016, 2017; Sportillo, et al., 2018a, 2018b, 2019), thereby satisfying these training needs. However, this TNA also suggests that drivers need to have an appropriate mental model for the automation alerts, have an awareness of the alerts that can occur and direct their attention to these alerts. Evidence for the attainment of these training needs was only found in four studies (e.g. in relation to icons, state changes, alarms or warnings: Manser, et al., 2019; Mueller, et al., 2020; Sportillo, et al., 2018a, 2019), suggesting that greater attention needs to be directed to these training needs in future AV driver training programmes. Finally, this TNA has highlighted the need for drivers to possess multiple competencies required for manual driving. In Table 6, nine of the most frequently mentioned training needs could be considered a manual driving competency (e.g. have an appropriate mental model for the road type and road environment, identify hazards in the road environment, have safe driving attitudes towards themselves and other road users, have the procedural skills for manual driving). However, these training needs were not considered (refreshed or trained) in these past training studies (Merriman, et al., 2021a). As drivers of Levels 1-4 AV systems will still need to manually control their vehicle on the road (e.g. after takeovers, when outside the ODD for the automation), these training needs must be addressed in future AV driver training programmes.

The approach that was taken in this article is not without limitations. Firstly AV systems which possess some Level 4 capabilities are still being developed, so assumptions had to be made when completing all parts of this TNA (scenario, storyboard, HTA and training needs). To help make these assumptions, a broad range of sources were used. These included the SAE (2018)’s report on the definitions and taxonomy of driving automation, the research literature on driver training, interface design and the driver challenges with AV systems (e.g. Lorenz, et al., 2014; Kerschbaum, et al., 2015; Payre, et al., 2016), videos from AV on-road experiments (e.g. Stanton, et al., 2021), information from vehicle manufacturers about the development of their AV systems (e.g. Audi, 2017b; Jaguar Land Rover, 2017; Toyota, 2019a, n.d.), HTAs for manual (Walker, et al., 2018) and Levels 2 and 3 AV systems (Cruise, 2018), IAM RoadSmart’s Advanced Driver Course Associate Logbook (IAM RoadSmart, 2016) and Observer’s Handbook (IAM RoadSmart, n.d.) and the DVSA’s syllabus for learning how to drive a manual car (DVSA, 2014a). Although research on Level 4 AV systems is being conducted on the road and in driving simulators (e.g. Khastgir, et al., 2018; Hirsch, et al., 2020), it is unclear what capabilities and limitations these systems will have, what road conditions they can safely operate in or how drivers will interact with them until they come to market and drivers interact with them outside the research domain (in a natural setting). As such, the scenario, storyboard, HTA and training needs may have to be modified in the future when more information is known. Additionally, this TNA will need to be validated by observing drivers interacting with the AV system that was used as the case study.

AV systems will be used by different types of drivers and in different countries, therefore future work needs to take these differences into account. This TNA was performed on the current road system, road environment, laws and policies in the UK. However, this context will change within the UK over time and also differs between countries (e.g. left- and right-hand traffic, turning right on a red light). This context will influence drivers’ driving competencies and driving experiences, therefore the TNA will need to be modified for different countries and when the current UK road system, policies and laws change. Similarly, this TNA identified three distinct driver groups (Table 2). However within these groups, there are different demographic sub-groups (e.g. young drivers, elderly drivers). These sub-groups have different driving competencies, therefore they may have different training needs and require their own TNA. As such future work should consider the needs of these unique sub-groups.

Finally, this article used one AV system to demonstrate the new TNA approach (HTA and AV driver taxonomy). The scenario comprised a high-speed motorway and dual-carriageway AV system (SAE, 2018), which was capable of performing some Level 4 functions in highly reliable road conditions and enhanced Level 2 functions in moderately reliable road conditions (see section 2.1). This case study showed that this new TNA approach is a useful approach to establish the tasks and competencies that are required for a task/activity, in this case to operate an AV system safely on the road. This approach and some of the content that was generated is generalisable to other AV systems, domains, tasks and automated systems involving human operators. Some of the tasks and competencies (content) that were identified for this AV system will also be required for other AV systems. For example, it is expected that all AV systems will have vehicular alerts, therefore although the exact type of the alert may vary, drivers will still need to perceive (task step 3.1.1) and understand (task step 3.1.2) the “automation is available” alerts so that they can activate the automation (see Table 8). Similarly, if drivers want to (Level 4 AV systems) or have to (Levels 2 and 3 AV systems) take over control of an AV system, they will still need to build a situation awareness of the road environment (task step 5.3.7) before taking over control of the vehicle (task step 5.4). Some modifications will need to be made for the specific AV system that is being analysed (e.g. type of alerts, removal of the minimal risk condition for purely Levels 2 and 3 AV systems), however some of the tasks and competencies can be applied to other AV systems and the new TNA approach itself (HTA and AV driver taxonomy) can be used to conduct TNAs for these other AV systems. Research on the competencies required for the safe operation of AV systems is limited and as there is a need to understand the training needs for drivers of AV systems (Kyriakidis, et al., 2019), this article takes us a step closer to this need by providing a new and comprehensive TNA approach from which to build upon and apply to different AV systems.

Similarly, this new TNA approach can be generalised to other domains and automated systems involving human operators. For example, many of the challenges that drivers face with AVs (e.g. manual driving skill degradation, over-reliance, inappropriate mental models for the capabilities and limitations of the automation: Saffarian, et al., 2012) have also been seen in other transport domains including maritime (e.g. Pazouki, et al., 2018) and aviation (e.g. Stanton & Marsden, 1996; Casner & Hutchins, 2019) when automation was introduced into the cockpit. Therefore, this new TNA approach and some of the tasks and competencies (content) that were identified in this TNA could be applied to these other domains to establish the tasks and competencies (training needs) that are required to safely operate the autopilot systems. For example in the aviation domain, pilots did not understand how the automation worked and lacked knowledge on the capabilities and limitations of the automation (Casner & Hutchins, 2019), therefore they will need to have an appropriate mental model for the capabilities and limitations of the automation (see Table 6). Similarly HTAs have been conducted across multiple domains and industries including drug administration (e.g. Lane, et al., 2006), process control tasks (e.g. Piso, 1981), warfare training (e.g. Annett, et al., 2000), supermarket checkout (Shepherd, 2001), aircraft landing (Marshall, et al., 2003) and rail crossings (Salmon, et al., 2019). All these tasks involve at least one human operator and are a context where human operator training may be required. As such, the AV driver taxonomy from this new TNA approach could be applied to these HTAs to identify the workload, attention and memory, mental models, situation awareness, hazard and risk perception, attitudes and procedural skills competencies (training needs) that these operators will need to safely perform their tasks. Therefore, although this new TNA approach (HTA and AV driver taxonomy) was demonstrated using a specific AV case study, the approach can be generalised to other AV systems and domains. The content will need to be modified for the exact system/domain that is being analysed, however it is a solid approach from which to build on and conduct a TNA.

1. **Conclusion**

This article describes the development of a new TNA approach and uses an AV case study to demonstrate the approach for an AV system within the current UK road system. This approach went further than previous TNAs for drivers of AV systems by conducting a HTA to identify the overall goal and tasks that drivers need to perform to operate an AV system safely on the road and by combining six AV driver training themes with the KSA taxonomy to identify the training needs. This TNA identified 7 main tasks, 26 sub-tasks, 2428 operations and over 100 distinct training needs. This new approach helped to identify more tasks, operations and training needs than previous literature where other methods (e.g. stakeholder consultations, KSA taxonomy) were used. As such, a more comprehensive TNA was conducted. This TNA approach can more easily be translated into future training programmes. For example, trainers can use this TNA to create a syllabus, checklist and training content to ensure all the required tasks and competencies are taught. Similarly, vehicle manufacturers can use this TNA to create a requirement specification for future AV systems (e.g. content and timing of vehicle alerts). Future work will use this TNA to design, develop, implement and evaluate a training programme for drivers of the AV system.

1. **Acknowledgments**

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1. **Funding**

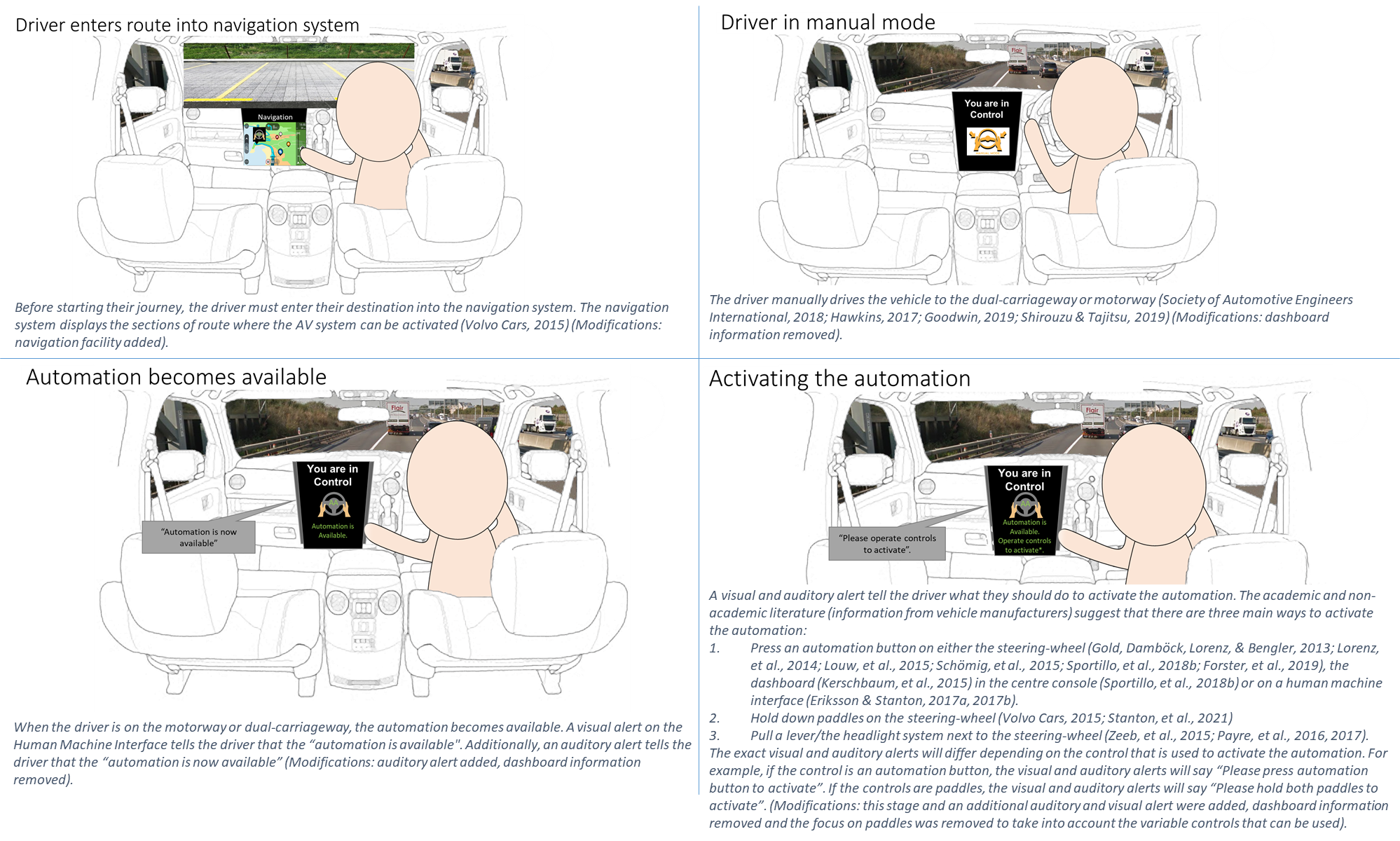
This research was funded by [IAM RoadSmart](https://www.iamroadsmart.com/) and the Engineering and Physical Sciences Research Council. These funders had no involvement in the study design, in the collection, analysis, and interpretation of the data, in the writing of the report, and in the decision to submit this paper for publication.

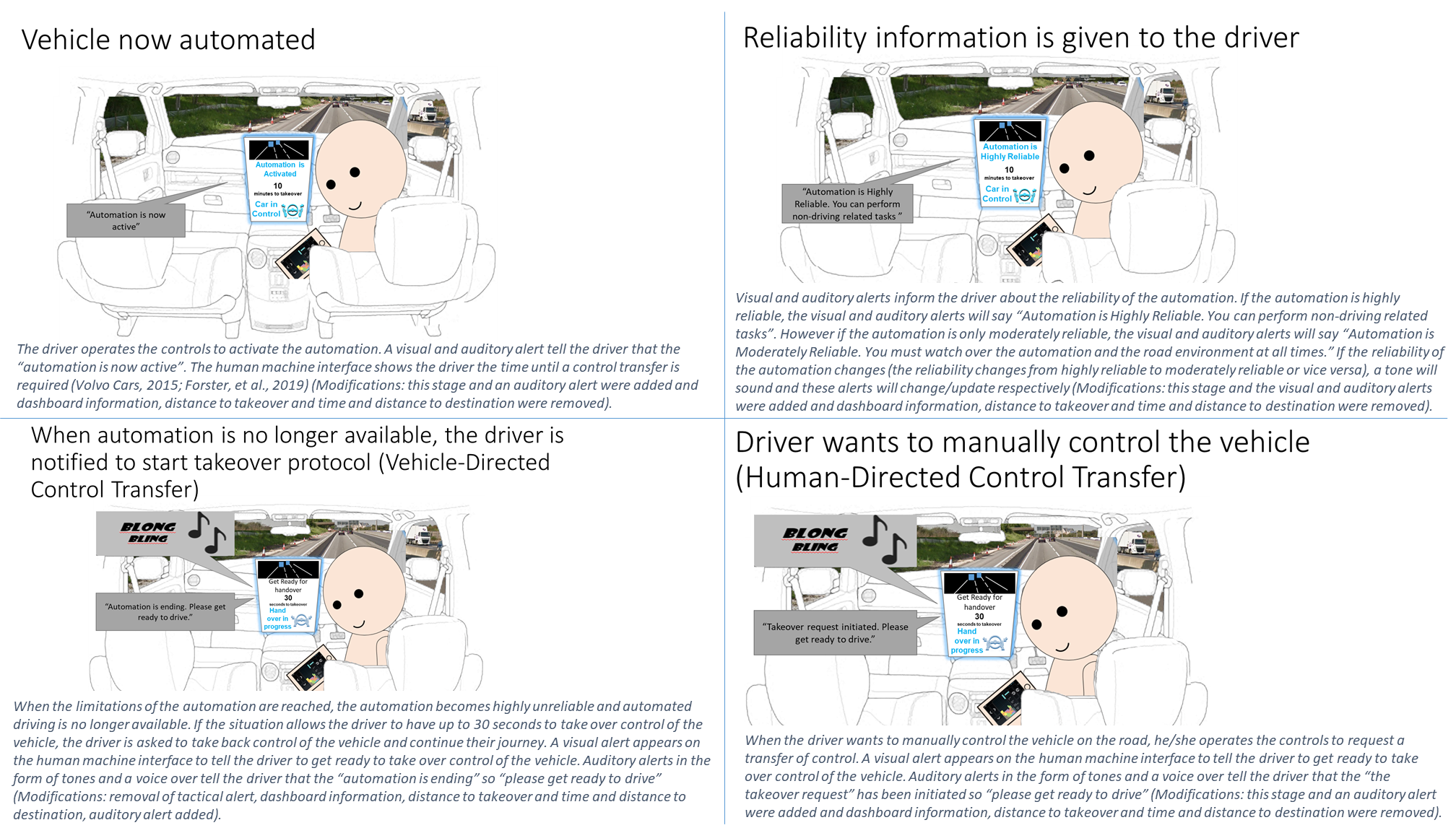
1. **Appendices**
   1. Appendix A

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.apergo.2023.104014>.

* 1. Appendix B

*The Full Storyboard for the Automated Vehicle System that was used to perform the TNA.*





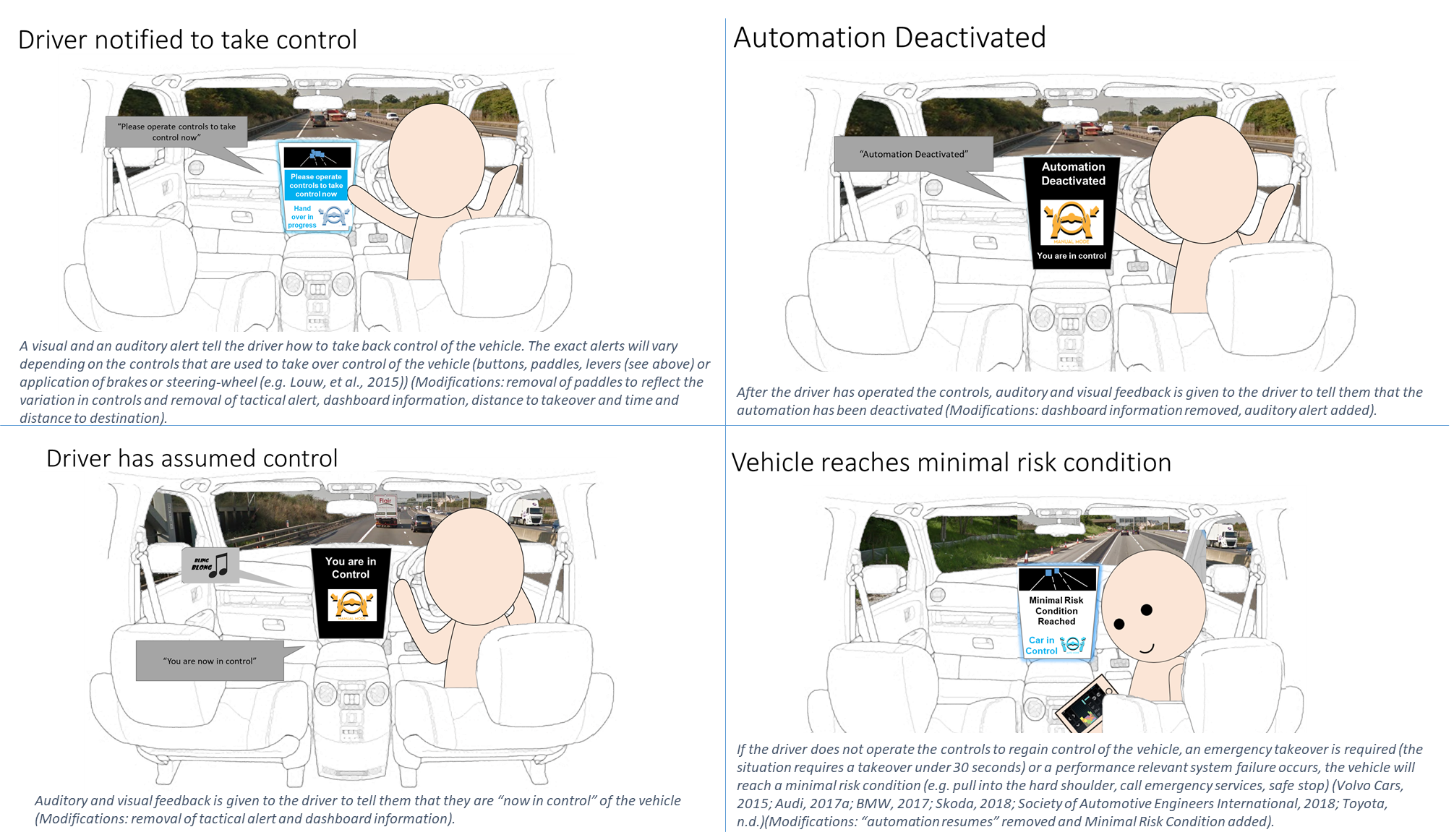


Figure - The complete storyboard for the AV system defined in section 2.1 (Images adapted from Stanton, et al., 2021).

* 1. Appendix C

Table - The Manual Vehicle Driver Competencies

|  |  |  |  |
| --- | --- | --- | --- |
| Competency | What is included | When Tested | References |
| Highway Code | Rules about:   * Pedestrians * Powered Wheelchairs and mobility scooters * Animals * Cyclists * Motorcyclists * General rules/techniques (Signals, stopping procedures, lighting, control of the vehicle, speed limits, stopping distances, lines and lane markings and multi-lane carriageways, smoking, mobile phones and sat nav) * Using the road (overtaking, road junctions, roundabouts, pedestrian crossings, reversing) * Vulnerable Road Users (pedestrians, motorcyclists, cyclists) * Driving in adverse weather conditions (wet, ice, snow, fog, hot weather) * Parking * Motorways (signals, joining and leaving, lane discipline, overtaking, stopping) * Breakdowns and incidents * Rules for roadworks, level crossings, tramways * Lights to control traffic (Traffic lights, motorway signals, lane control signals * Signals for other road users (indicators, brake lights, reverse lights, arm signals) * Signals by authorized people (police, people controlling traffic, traffic officers, school crossing patrols) * Traffic signs (signs giving orders, warning signs, direction signs, information signs, road work signs) * Road markings (across the carriageway, along the carriageway, on edge of carriageway, on curb) * Vehicle markings (on large vehicles. Hazard warning plates) * Road laws and penalties * Vehicle maintenance, security and safety | Multiple Choice Questions in Theory Test | (GOV.UK, n.d.a)  (Driving Standards Agency, 2015) |
| Traffic signs | Knowledge of:   * The signalling system * Regulatory sings * Speed limit signs * Level crossing signs and signals * Tram, buss, cycle signs and road markings * Pedestrian zone signs * Road markings * Traffic calming signs * Direction signs * Motorway signs and road markings * Information signs * Traffic signals * Pedestrian, cycle and equestrian crossings * Road work signs and temporary situations | Multiple Choice Questions in Theory Test | (GOV.UK, n.d.a)  (Department for Transport, 2013) |
| Essential Driving Skills | * Alertness * Attitudes * Vehicle safety * Safety margins * Hazard Awareness * Vulnerable Road Users * Types of vehicles * Road conditions and vehicle handling * Motorway driving * Road rules * Traffic signs * Incidents, accidents and emergencies, * Vehicle loading | Multiple Choice Questions in Theory Test | (GOV.UK, n.d.a)  (Driving Standards Agency, 2012) |
| Hazard Perception | * Scan Roadway * Spot developing hazards in 14 video clips | Hazard Perception Part of Theory Test | (GOV.UK, n.d.b) |
| Perform Manoeuvres | * Controlled Stop * Reverse/Forward Park * Reverse Left/Right * Turn in Road | On-Road Driving Test | (Driver and Vehicle Standards Agency, 2017) |
| Perform Vehicle Checks | * Check brakes before moving * Check tyre pressure, tread depth and general condition of tyres * Check head restraint * Check headlights and tail lights are working * Check for problems with anti-lock braking system * Check indicators are working * Check brake lights are working * Check the power-assisted steering is working * How switch on fog lights, dipped headlights, main beam, how you know these are on and when you use them * Check engine has sufficient oil and engine coolant * Check safe level of hydraulic brake fluid * How clean rear and front windscreens * How demist rear and front windscreens * How operate horn * How operate windows | On-Road Driving Test | (Driver and Vehicle Standards Agency, 2017) |
| Precautions | Adjust seat to reach controls | On-Road Driving Test | (Driver and Vehicle Standards Agency, 2017) |
| Vehicle Control | Smooth use of:   * Accelerator * Clutch * Gears * Footbrake and Parking Brake * Steering | On-Road Driving Test | (Driver and Vehicle Standards Agency, 2017) |
| Moving Off | Needs to be done smoothly, safely and under control with appropriate observations (mirror checks) | On-Road Driving Test | (Driver and Vehicle Standards Agency, 2017) |
| Mirror Use | * Check mirrors before signalling, changing direction or changing speed * Rear Observations * Check blind spots * Act appropriately on information * Mirror, Signal, Manoeuvre routine | On-Road Driving Test | (Driver and Vehicle Standards Agency, 2017) |
| Signal | * Signal in compliance with The Highway Code * Show intentions to other road users * Signal in good time and turn off signal when manoeuvre is completed | On-Road Driving Test | (Driver and Vehicle Standards Agency, 2017) |
| Clearance | * Give enough space to parked vehicles and obstructions * Look out for crossing pedestrians, doors opening | On-Road Driving Test | (Driver and Vehicle Standards Agency, 2017) |
| Response to signs and signals | Respond appropriately to:   * Traffic signs * Road markings * Traffic lights * Pedestrian crossings * Signals given by police officers * Signals given by traffic wardens * Signals given by Highways Agency officers * Signals given by school crossing patrols * Signals given by other road users | On-Road Driving Test | (Driver and Vehicle Standards Agency, 2017) |
| Use of Speed | Make safe progress on road, based on:   * The road conditions * Traffic conditions * Weather conditions * Road Signs * Speed Limits | On-Road Driving Test | (Driver and Vehicle Standards Agency, 2017) |
| Following Distance | * Keep safe distance between you and the vehicle in front * Increase following distance in wet/slippery conditions * Leave enough space when in traffic | On-Road Driving Test | (Driver and Vehicle Standards Agency, 2017) |
| Maintain Progress | * Drive at an appropriate speed for road and traffic conditions * Approach hazards at safe, controlled speed without stopping/slowing other road users * Move away from junctions when safe and appropriate | On-Road Driving Test | (Driver and Vehicle Standards Agency, 2017) |
| Junctions and Roundabouts | * Mirror, signal, manoeuvre * Correct positioning and speed on approach * Look out for other road users * In poor light/bad weather look out for vulnerable road users (e.g. cyclists and motorcyclists) | On-Road Driving Test | (Driver and Vehicle Standards Agency, 2017) |
| Judgement | Sound Judgement when:   * Overtaking * Meeting other road users * Crossing path of other road users   These activities should only be performed when it is safe and legal to do so | On-Road Driving Test | (Driver and Vehicle Standards Agency, 2017) |
| Positioning | Have an awareness of road position and position car in a safe position:   * Position vehicle to the left of the road * Correct positioning for direction * Keep clear of parked vehicles | On-Road Driving Test | (Driver and Vehicle Standards Agency, 2017) |
| Pedestrian crossings | * Identify different types of pedestrian crossings * Take correct action at pedestrian crossings * Monitor speed of approach * Show consideration to pedestrians trying to cross (especially unwell or disabled pedestrians) | On-Road Driving Test | (Driver and Vehicle Standards Agency, 2017) |
| Stopping | * Choose a safe, legal and convenient place to stop * Stop close to the edge of the road * Do not block the road or create a hazard * Do not danger or inconvenience other road users | On-Road Driving Test | (Driver and Vehicle Standards Agency, 2017) |
| Awareness/Planning | * Have an awareness of other road users * Plan ahead and anticipate what other road users are going to do * Anticipate road and traffic conditions * Awareness of vulnerable road users (pedestrians, cyclists, motorcyclists and horse riders) * React in good time to changing conditions | On-Road Driving Test | (Driver and Vehicle Standards Agency, 2017) |
| Ancillary controls | * Operate all vehicle controls safely and efficiently * Keep control of the vehicle when operating secondary controls (e.g. demisters, heating controls, indicators and windscreen wipers) | On-Road Driving Test | (Driver and Vehicle Standards Agency, 2017) |
| Eco Safe Driving | * Drive in an ‘eco-friendly manner’, considering impact on the environment. * Plan well ahead and choose appropriate gears * Avoid heavy braking and over revving of the engine, particularly when stopped or moving off. * Stop the engine when stopping for a long period of time | On-Road Driving Test | (Driver and Vehicle Standards Agency, 2017) |

* 1. Appendix D

Table - The sub-tasks and operations for the main task Activate the Automation

|  |  |
| --- | --- |
| Sub-Task | Operations(s) |
| * 1. Recognise the "automation is available" alerts   Plan 3.1 DO 1 THEN 2. IF 2 is positive (comprehensible) DO 3. If 2 is negative (incomprehensible) DO 4. | * + 1. Perceive the audible and visual alerts   Plan 3.1.1 DO 1 AND 2  3.1.1.1 Listen to the audible alert  3.1.1.2 Look at the visual alert on the Human Machine Interface   * + 1. Understand/Comprehend the alerts   Plan 3.1.2 DO 1 AND 2 THEN 3  3.1.2.1 Use stored mental models of what the alerts mean  3.1.2.2 Recall memories of past experiences when operating the automation  3.1.2.3 Combine the mental models with these memories   * + 1. Proceed to 3.2     2. Continue to drive the vehicle manually (In Walker et al (2018) do 2 AND 3 AND 4 AND 5 WHILE 6 THEN 7) |
| * 1. Decide whether to activate the automation   Plan 3.2 DO 1. If 1 is positive DO 2 THEN 3. If 2 is long AND 3 is positive DO 4. If 1 is negative AND/OR 2 is short AND/OR 3 is negative DO 5. | * + 1. Check Human Machine Interface for an indication that the automation can be activated     2. Look at journey time on Human Machine Interface     3. Evaluate driver's intention to use the automation   Plan 3.2.3 DO 1  3.2.3.1 Evaluate driver's goal for the journey (e.g. get to destination quickly, catch up with friends/work, attend meeting, practice manual driving).   * + 1. Proceed to 3.3 |
| * 1. Position vehicle ready to activate the automation   Plan 3.3 IF 1 is positive DO 2 THEN 3. IF 1 is negative DO 1 THEN 2 THEN 3. | * + 1. Position vehicle in nearside (left) lane   Plan 3.3.1 DO 1 THEN 2 THEN 3 THEN 4. IF 3 AND/OR 4 is positive (cars are present) DO 5 THEN 6 THEN 7. IF 3 AND 4 is negative (no cars present) DO 7. IF 7 is positive DO 6. IF 7 is negative DO 8. IF 8 is positive DO 10 THEN 11 THEN 12. IF 8 is negative DO 9 THEN 10 THEN 11 THEN 12.  3.3.1.1 Signal (indicate) left  3.3.1.2 Look in rear view mirror for approaching vehicles  3.3.1.3 Look in left side mirror for vehicles in the left lane  3.3.1.4 Look in left blind spot for approaching vehicles  3.3.1.5 Monitor the speed and position of vehicles in left lane  3.3.1.6 Wait until there is an appropriate gap in the left lane, according to the highway code  3.3.1.7 Recheck all mirrors for environmental changes  3.3.1.8 Check that there are no emergency vehicles approaching  3.3.1.9 Wait until the emergency vehicle has passed  3.3.1.10 Move across to the left lane  3.3.1.11 Cancel indicator  3.3.1.12 Proceed to 3.3.2   * + 1. Position vehicle safely behind the lead vehicle   Plan 3.3.2 DO 1 THEN 2 THEN 3 THEN 4 THEN 5. IF separation distance is 2 seconds DO 8. IF separation distance is not 2 seconds DO 6 THEN 8. IF heavy traffic, following large goods vehicles, coaches over 12 metres (or other vehicles which are limited to 60 mph), vehicles driving erratically AND/OR in poor weather/visibility/at night DO 7 THEN 8.  3.3.2.1 Observe the lead vehicle and the vehicles in front of the lead vehicle  3.3.2.2 Use stored mental models of safe braking distances as provided in the Highway Code  3.3.2.3 Embody thinking and actual braking distance in any estimates  3.3.2.4 Note when the lead car passes a convenient roadside landmark  3.3.2.5 Count two seconds  3.3.2.6 Press the brake to increase separation distance to two seconds  3.3.2.7 Press the brake to increase separation distance to beyond two seconds  3.3.2.8 Proceed to 3.3.3   * + 1. Maintain the chosen following gap   Plan 3.3.3 DO 1 THEN 2 THEN 3 as required  3.3.3.1 Observe the lead vehicle and the vehicles in front of the lead vehicle  3.3.3.2 Anticipate changes in speed for the lead vehicle and the vehicles in front of the lead vehicle  Plan 3.3.3.2 DO 1 AND 2  3.3.3.2.1 Check for indications of reduced speed on the lead vehicle  Plan 3.3.3.2.1 DO 1 AND 2 AND 3 AND 4 AND 5 AND 6 (5 & 6 provide tentative supplementary cues to speed reduction of the lead vehicle)  3.3.3.2.1.1 Gauge closure of headway/relative speeds  3.3.3.2.1.2 Observe lead vehicle's indicators  3.3.3.2.1.3 Observe lead vehicle's brake lights  3.3.3.2.1.4 Observe driver of lead vehicle for hand signals indicating a reduction in speed  3.3.3.2.1.5 Look for the front of the lead vehicle dipping in response to brake application  3.3.3.2.1.6 Look for wisps of blue exhaust smoke as an indication that the lead vehicle's throttle has just been closed abruptly  3.3.3.2.2 Check for indications of reduced speed in the road environment  Plan 3.3.3.2.2 DO 1 THEN 2 AND 3 AND 4 AND 5 AND 6 AND 7 AND 8 AND 9. IF on a dual carriageway DO 1 THEN 2 AND 3 AND 4 AND 5 AND 6 AND 7 AND 8 AND 9 AND 10 AND 11 AND 12.  3.3.3.2.2.1 Extend vision as far as possible down the roadway  3.3.3.2.2.2 Look for increasing traffic levels up ahead  3.3.3.2.2.3 Look for slow moving vehicles up ahead  3.3.3.2.2.4 Look for brake lights on cars in the distance  3.3.3.2.2.5 Look for hills up ahead  3.3.3.2.2.6 Look for bends up ahead  3.3.3.2.2.7 Look for roadworks and obstacles in the roadway  3.3.3.2.2.8 Look at road signs for hazards up ahead (e.g. bends, hills, junctions)  3.3.3.2.2.9 Look up at the overhead gantries for warnings of potential problems up ahead e.g. lane closure, speed reductions  3.3.3.2.2.10 Look for cyclists up ahead  3.3.3.2.2.11 Look for roundabouts and/or junctions up ahead  3.3.3.2.2.12 Look for red traffic lights up ahead  3.3.3.3 <<GO TO Walker et al (2018) subroutine 2.4 ‘decrease speed’ >> |
| * 1. Determine whether it is safe and appropriate to activate the automation   Plan 3.4 DO 1 AND 2 AND 3 | * + 1. Determine whether the speed condition will be met   Plan 3.4.1 DO 1 THEN 2 THEN 3 THEN 4 AND 5 AND 6 AND 7 AND 8. THEN 9 THEN 10. IF 10 is positive DO 27. IF 10 is negative DO 11. IF there is a slow-moving vehicle causing traffic to slow down DO 12 THEN 13 THEN 14 THEN 15 THEN 16 THEN 17 THEN 18 THEN 19 THEN 20 THEN 21 THEN 22 THEN 23 THEN 24 THEN 25 THEN 26 THEN 27.  3.4.1.1 Look at speedometer for current travelling speed  3.4.1.2 Lift up vision to the road ahead  3.4.1.3 Extend vision as far as possible down the roadway  3.4.1.4 Observe the lead vehicles  3.4.1.5 Observe traffic levels  3.4.1.6 Observe level and fluctuations in traffic speeds  3.4.1.7 Look up at the information gantries and at the road signs  3.4.1.8 Read warnings of problems up ahead e.g. lane/road closures or speed restrictions  3.4.1.9 Use observations to anticipate speed of lead vehicles  3.4.1.10 Use stored mental models of the capabilities and limitations of the system to determine whether the automation is functional at the current speed  3.4.1.11 Continue to drive the vehicle manually (In Walker et al (2018) do 2 AND 3 AND 4 AND 5 WHILE 6 THEN 7)  3.4.1.12 Signal (indicate) right  3.4.1.13 Check all mirrors and blind spot for potential hazards  3.4.1.14 Wait until overtaking lane is clear  3.4.1.15 Move to overtaking lane  3.4.1.16 Cancel indicator  3.4.1.17 Press the accelerator to overtake slow moving vehicle  3.4.1.18 Wait until vehicle is sufficiently ahead of the vehicle being overtaken, as provided in the highway code (2 seconds ahead)  3.4.1.19 Signal (indicate) left  3.4.1.20 Check mirrors and blind spot to see if it is safe to move back across into the nearside lane  3.4.1.21 Wait until it is safe to move back across into nearside lane  3.4.1.22 Move back across into nearside lane  3.4.1.23 Cancel indicator  3.4.1.24 Check mirrors and road ahead to see if it is safe to increase speed  3.4.1.25 Wait until it is safe to increase speed  3.4.1.26 Press accelerator to increase speed, up to the target speed of 50-70 mph (i.e. to reach the speed condition for the automation)  3.4.1.27 Proceed to 3.4.2   * + 1. Determine whether the weather condition will be met   Plan 3.4.2 DO 1 THEN 2 THEN 3 THEN 4. IF 4 is positive DO 5. IF 4 is negative DO 6.  3.4.2.1 Observe current weather conditions  3.4.2.2 Extend vision as far as possible down the roadway  3.4.2.3 Anticipate what the future weather will be  3.4.2.4 Use stored mental models of the capabilities and limitations of the system to determine whether the automation is functional in the current and future weather conditions  3.4.2.5 Proceed to 3.4.3  3.4.2.6 Continue to drive the vehicle manually (In Walker et al (2018) do 2 AND 3 AND 4 AND 5 WHILE 6 THEN 7)   * + 1. Determine whether the road conditions are appropriate for the automation   Plan 3.4.3 DO 1 THEN 2 THEN 3 THEN 4 THEN 5 THEN 6. IF 6 is positive DO 7. IF 6 is negative DO 8.  3.4.3.1 Look up at the information gantries and at the road signs  3.4.3.2 Read warnings of any obstacles on the road  3.4.3.3 Move vision to the roadway  3.4.3.4 Observe the condition of the road (e.g. are lane markings present)  3.4.3.5 Look for sharp or multiple bends  3.4.3.6 Use stored mental models of the capabilities and limitations of the system to determine whether the automation is functional in the current road conditions  3.4.3.7 Proceed to 3.5  3.4.3.8 Continue to drive the vehicle manually (In Walker et al (2018) do 2 AND 3 AND 4 AND 5 WHILE 6 THEN 7) |
| * 1. Initiate automation system   Plan 3.5 DO 1 (THEN 2 THEN 3 THEN 4 THEN 5. IF automation is moderately reliable THEN DO 6. IF automation is highly reliable THEN DO 7. IF reliability of the automation changes, THEN DO 8 THEN 9) OR 10. | * + 1. Pre-Initiation system checks   Plan 3.5.1 DO 1 AND 2. IF 1 AND 2 are positive DO 3. IF 1 AND/OR 2 are negative DO 4.  3.5.1.1 Check that there are no visual warnings regarding the status of the vehicle on the Human Machine Interface  3.5.1.2 Check Human Machine Interface for a visual cue that the automation is available  3.5.1.3 Proceed to 3.5.2  3.5.1.4 Continue to drive the vehicle manually (In Walker et al (2018) do 2 AND 3 AND 4 AND 5 WHILE 6 THEN 7)   * + 1. Operate controls to activate the automation     2. Check that the automation has been activated   Plan 3.5.3 DO 1 AND 2 AND 3 AND 4 AND 5 THEN 6. If cues suggest that the automation is operational DO 7. If cues suggest that the automation is not operational DO 8.  3.5.3.1 Check Human Machine Interface for visual cues that the automation has been activated  3.5.3.2 Listen for audio cues that the automation has been activated  3.5.3.3 Check for cue that automation has been activated through feel of steering  3.5.3.4 Check lane position for visual cue that automation has been activated  3.5.3.5 Check consistency of speed for cue that automation has been activated  3.5.3.6 Use stored mental models and memories of past automation experiences to determine whether the automation has been activated  3.5.3.7 Proceed to 3.5.4  3.5.3.8 <<GO TO 3.5.1 "Pre-Initiation system checks">>   * + 1. Determine reliability of automation (moderate or high)   Plan 3.5.4 DO 1 THEN 2 THEN 3 THEN 4 THEN 5  3.5.4.1 Determine the road-type  Plan 3.5.4.1 DO 1 THEN 2 THEN 3 THEN 4 THEN 5 THEN 6 THEN 7  3.5.4.1.1 Look up at the information gantries and at the road signs  3.5.4.1.2 Observe the colour of the road signs (blue or green)  3.5.4.1.3 Move vision to the roadway  3.5.4.1.4 Observe road features (e.g. central reservation or not)  3.5.4.1.5 Observe vulnerable road users  3.5.4.1.6 Move vision to the navigation system  3.5.4.1.7 Observe road type that is displayed  3.5.4.2 Determine the current weather conditions  Plan 3.5.4.2 DO 1 THEN 2  3.5.4.2.1 Look up at the sky  3.5.4.2.2 Observe current weather conditions  3.5.4.3 Perceive the reliability alerts  Plan 3.5.4.3 DO 1 AND 2  3.5.4.3.1 Listen to the audible alert  3.5.4.3.2 Look at the visual alert on the Human Machine Interface  3.5.4.4 Understand/Comprehend the alerts  Plan 3.5.4.4 DO 1 AND 2 THEN 3  3.5.4.4.1 Use stored mental models of what the alerts mean  3.5.4.4.2 Recall memories of past experiences when operating the automation  3.5.4.4.3 Combine the mental models with these memories  3.5.4.5 Use information and stored mental models of the reliability of the automation to determine how reliable the automation is   * + 1. Remove manual controls over the dynamic driving tasks   Plan 3.5.5 DO 1 THEN 2  3.5.5.1 Release foot from accelerator and brake pedals  3.5.5.2 Remove grip from steering-wheel   * + 1. Watch over automation and road environment   Plan 3.5.6 DO 1 AND 2  3.5.6.1 Watch over the automation  Plan 3.5.6.1 DO 1 THEN 2 THEN 3  3.5.6.1.1 Look at the Human Machine Interface  3.5.6.1.2 Read alerts that are displayed  3.5.6.1.3 Understand/Comprehend the alerts  Plan 3.5.6.1.3 DO 1 AND 2 THEN 3  3.5.6.1.3.1 Use stored mental models of what the alerts mean  3.5.6.1.3.2 Recall memories of past experiences when operating the automation  3.5.6.1.3.3 Combine the mental models with these memories  3.5.6.2 Watch over the road environment  Plan 3.5.6.2 DO 1  3.5.6.2.1 <<GO TO subroutine 4.3.2.3 "Monitor the vehicle and the driving environment">>   * + 1. Perform secondary tasks   Plan 3.5.7 DO 1 AND 2 THEN 3.  3.5.7.1 Remove eyes from roadway  3.5.7.2 Remove eyes from vehicle  3.5.7.3 Engage in secondary tasks  Plan 3.5.7.3 DO 1 AND/OR 2 AND/OR 3 AND/OR 4 AND/OR 5 AND/OR 6 AND/OR 7 AND/OR 8 AND/OR 9 AND/OR 10 AND/OR 11 AND/OR 12 AND/OR 13 AND/OR 14 AND/OR 15 AND/OR 16.  3.5.7.3.1 Eat or Drink  3.5.7.3.2 Grooming/personal hygiene behaviours (e.g. makeup, teeth brushing, applying hand cream)  3.5.7.3.3 Day dream  3.5.7.3.4 Relax  3.5.7.3.5 Watch a video, film or television  3.5.7.3.6 Listen to a podcast, audio book, music or radio  3.5.7.3.7 Take pictures  3.5.7.3.8 Play board or video games  3.5.7.3.9 Chair Exercises  3.5.7.3.10 Read a book, article, newspaper or magazine  3.5.7.3.11 Browse the internet or online shopping  3.5.7.3.12 Work/Study  3.5.7.3.13 Interact with/talk to passengers  3.5.7.3.14 Communicate with others (e.g. Phone Calls, Email, Skype, Social Media, Texting)  3.5.7.3.15 Watch the view, scenery, landscape or other people  3.5.7.3.16 Monitor the road and/or the functioning of the automation/vehicle   * + 1. Recognise that the reliability of the automation has changed   Plan 3.5.8 DO 1 THEN 2 THEN 3. IF 3 is positive (correct understanding has been reached), DO 4. IF 3 is negative (correct understanding has not been reached) DO 5.  3.5.8.1 Perceive the new audible and visual alerts  Plan 3.5.8.1 DO 1 AND 2  3.5.8.1.1 Listen to the audible alert  3.5.8.1.2 Look at the visual alert on the Human Machine Interface  3.5.8.2 Understand/Comprehend the alerts  Plan 3.5.8.2 DO 1 AND 2 THEN 3  3.5.8.2.1 Use stored mental models of what the alerts mean  3.5.8.2.2 Recall memories of past experiences when operating the automation  3.5.8.2.3 Combine the mental models with these memories  3.5.8.3 Move vision to the roadway to confirm understanding  Plan 3.5.8.3 DO 1 THEN 2 AND 3  3.5.8.3.1 Look at the road environment  3.5.8.3.2 Determine the road-type  Plan 3.5.8.3.2 DO 1 THEN 2 THEN 3 THEN 4 THEN 5 THEN 6 THEN 7  3.5.8.3.2.1 Look up at the information gantries and at the road signs  3.5.8.3.2.2 Observe the colour of the road signs  3.5.8.3.2.3 Move vision to the roadway  3.5.8.3.2.4 Observe features of the road  3.5.8.3.2.5 Observe vulnerable road users  3.5.8.3.2.6 Move vision to the navigation system  3.5.8.3.2.7 Observe road type that is displayed  3.5.8.3.3 Determine the current weather conditions  Plan 3.5.8.3.3 DO 1 THEN 2  3.5.8.3.3.1 Look up at the sky  3.5.8.3.3.2 Observe current weather conditions  3.5.8.4 Proceed to 3.5.9  3.5.8.5 <<GO TO 3.5.8 "Recognise that the reliability of the automation has changed">>   * + 1. Act accordingly   Plan 3.5.9 IF automation is moderately reliable DO 1 THEN 2. IF automation is highly reliable DO 3.  3.5.9.1 Stop performing secondary task  3.5.9.2 <<GO TO 3.5.6 "Watch over automation and road environment">>  3.5.9.3 <<GO TO 3.5.7 "Perform secondary tasks">>   * + 1. Continue to drive the vehicle manually (In Walker et al (2018) do 2 AND 3 AND 4 AND 5 WHILE 6 THEN 7) |

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