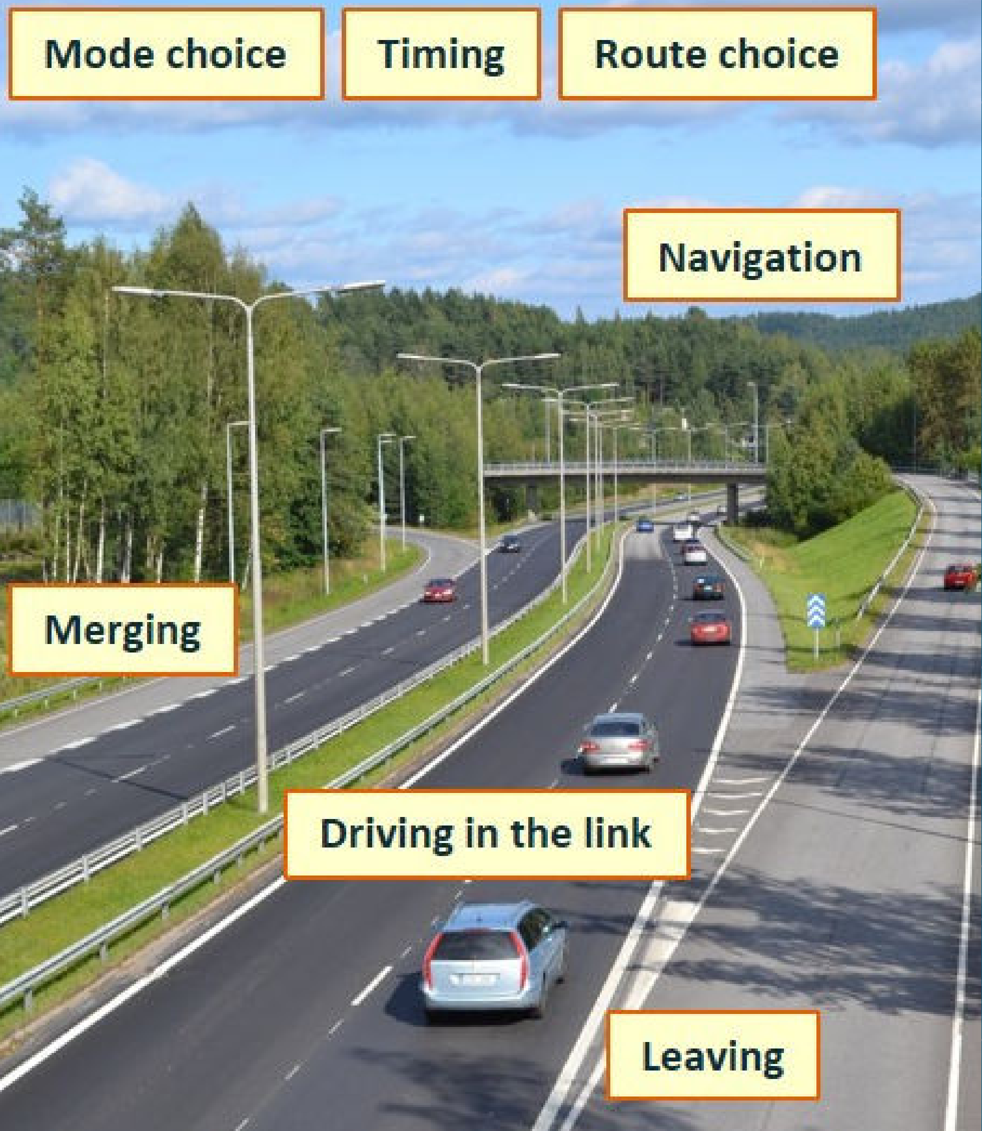

beyond
the obvious

Exploring Driver and Operator Behaviour Models in the Context of Automated Driving

Identification of Issues from a Human Actor Perspective

Pirkko Rämä | Hanna Koskinen

VTT TECHNOLOGY 356

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Preface

The study was carried out as part of VTT's research programme entitled Traffic Safety 2025. The members of Traffic Safety 2025 included Finnish Transport Agency, Finnish Transport Safety Agency, Nokian Tyres plc., VTT. The chairs of the Traffic Safety 2025 program were Dr. Juha Luoma and Dr. Anne Silla.

The board assigned to the study was chaired by Dr. Sami Mynttinen (Trafi), the other members were Dr. Risto Kulmala, MSc. Eetu Pilli-Sihvola, Dr. Mikko Räsänen, MSc. Anna Schirokoff, MSc. Arja Toola and MSc. Hanna Strömmer. The board gave its active and innovative support to the study in form of project meetings and workshops in which the outcomes of analyses were reviewed and elaborated. Several people working for VTT also participated in the workshops and provided their support and knowledge on intelligent transport system to enhance the work.

Espoo, July 2019

Contents

List of symbols

AA	Automation awareness
ACC	Adaptive Cruise Control
AEB	Automatic Emergency Braking
AUTOPILOT	Automated driving progressed by the internet of things (EC project)
CEDR	Association of Road Directors in Europe
C-ITS	Cooperative intelligent transport systems
CTA	Core-task analysis
ESoP	European Statement of Principles
INF	Information processing model
ITS	Intelligent transport systems
L2	Level 2 (partial automation)
L3Pilot	Piloting automated driving on European roads (EC project)
L4	Level 4 (high automation)
LKS	Lane Keeping System
LoA	Level of automation
MOT	Motivational (driver behaviour) theories
ODD	Operational Design Domain
OEM	European Original Equipment Manufacturer
P-assist	Parking assist
POLIS	Cities and regions for transport innovation
SA	Situation awareness
SAE	Society of Automotive Engineers

v2i	vehicle to infrastructure
v2v	vehicle to vehicle

1. Introduction

The study explores partly automated driving task in the light of driver and operator behaviour theories. First is a brief presentation of automation in road transport and examples of human issues from the driver perspective already identified as critical. To learn from other domains with a longer tradition dealing with growing automation, some content is provided regarding automation in industrial work environments. Second, we briefly describe three theoretical approaches to human behaviour which were selected for further elaborating the human issues.

1.1 Increasing automation in road transport

As in many areas of people's daily life and activities, tasks originally assigned to humans in road transport are being replaced by automated functionalities. This implies changes in driver behaviour and in the tasks assigned to the driver, and drivers are having to adapt both as individuals and as part of the traffic flow. Examples of automated systems – the building blocks of automated driving – already on the market are Adaptive Cruise Control (ACC, e.g. https://mycardoeswhat.org/safety-features/adaptive-cruise-control/), Lane Keeping Systems (LKS, e.g. https://mycardoeswhat.org/safety-features/automatic-braking/), Automatic Emergency Braking (AEB), and parking-assist (P-assist). Additionally, several car manufacturers in Europe have published plans to bring fully automated cars to market (see e.g. De Winter, Happee, Martens, & Stanton, 2014). Demo trials are being developed in several European countries (e.g. Drive Me by Volvo Cars 2013; UK GATEway https://gateway-project.org.uk/), and European Original Equipment Manufacturers (OEM) have started piloting automated driving as part of the European Commission's Horizon 2020 programme (e.g. L3pilot, http://www.l3pilot.eu/index.php?id=26). The governments of several countries have indicated plans to enhance automation of road transport (OECD/ITF, 2018); as has the Association of Road Directors in Europe (CEDR, 2016).

Wide use of automation solutions and systems in industrial installations (e.g. nuclear power plants, manufacturing and processing facilities) has been applied for decades. There are many frameworks for describing the *levels of automation* (LoA), but in the context of industrial installations and work activity, the Parasuraman & Sheridan (Parasuraman, Sheridan, & Wickens, 2000) ten-step ladder is often used to distinguish how autonomous[1] a system can be (Table 1 right column). The classification runs from low automation (1) to high (10).

The ten-step framework focuses on the division of decision and operation responsibilities between the human operator and the computer (i.e., automated systems). Levels one and ten represent extremes of manual and fully automatic control. Levels two through five clearly have the human operator as the final decision maker in all operations. From level six upwards, the computer begins taking more responsibility in the operative decision making, and at the highest levels merely informs the human operator about the operation execution, if at all. Thus, within this LoA framework, automated systems may be considered systems that represent level six upwards.

In the context of road transport, the frequently used taxonomy includes levels from zero to five (i.e., from a non-automated to fully automated system) provided by the *Society of Automotive Engineers* (SAE, 2014, 2016). The classification (SAE, 2016) indicates how dynamic driving tasks (i.e., vehicle control, object and event detection and response, dynamic driving fallback) are distributed between the driver and automation. Object and event detection and response are assigned to the automation system from level three upwards. To correspond with the LoA framework introduced by Parasuraman and Sheridan (Parasuraman et al., 2000) in a work context, the SAE classification is presented in reverse order in Table 1, from high to low automation rather than low to high. Coming from a work context, the classification stresses the role of the human operator as decision-maker, whereas the SAE classification designed for road transport focuses on the perception of critical elements and response execution (see the information processing model by Wickens (Wickens, 1992) later in this paper).

[1] In the work context, the word generally used is 'autonomous'. Related to transport, the preferred word is 'automated' and it highlights the possible connectivity of vehicles.

Table 1. Models for LoA: for road transport (SAE, 2016) and the framework used for work environment (Parasuraman et al., 2000).

Automated driving SAE (2016) **Human as an actor, responsibility for detection & vehicle control.** **Automated driving system covers:**		**LoA**	**LoA by Parasuranam & Sheridan (2000)** **Types and levels of interaction:**	
All aspects of dynamic driving; all roadway and environmental conditions = Full automation	**5**	**HIGH**	**10.**	The computer decides everything, acts autonomously, ignoring the human
All aspects of dynamic driving; not in all roadway and environmental conditions (appropriate response by human not expected) = High automation	**4**		**9.**	Informs the human only if it, the computer, decides to
			8.	Informs the human only if asked
Driving mode-specific performance; all aspects of dynamic driving, but on exception the human will respond when requested = Conditional automation	**3**		**7.**	Executes automatically, then necessarily informs the human
			6.	Allows the human a restricted time to veto before automatic execution
Steering and acceleration/deceleration with expectation that the human will perform all remaining dynamic driving tasks = Partial automation	**2**	**LOW**	**5.**	Executes that suggestion if the human approves
			4.	Suggests one alternative
Either steering or acceleration/deceleration with expectation that the human will perform all remaining dynamic driving tasks = Driver Assist	**1**		**3.**	Narrows the selection down to a few
			2.	The computer offers a complete set of decision/action alternatives
Full time performance of human driver = No automation	**0**		**1.**	The computer offers no assistance, the human must take all decisions & actions

A highly automated road transport system assumes that also buses, trams and metros are automated, meaning fundamental changes not only in driver behaviour but in all personal mobility. The present study focused on car driving, and the SAE classification of LoA providing an indication of driver tasks and responsibilities at each level. Furthermore, from the driver's perspective it is significant what parts of a trip and which functions and driving tasks are automated, and for how long – in other words, how deeply and extensively automation is realised during car driving.

In the nuclear power production context, digitalised systems enable more precise monitoring of the plant and the instrumentation, and thus better data for controlling the process (O'Hara & Higgins, 2010). Moreover, automation additions have often been justified, with improvements to the system's overall performance and safety (Endsley, Onal, & Kaber, 1997). However, it has been discussed that implementing automation does not relieve human operators of all tasks, but it shifts them from being responsible for the task of direct control to overall monitoring and supervision of the operation (Lee & Seppelt, 2009; Lin, Yenn, & Yang, 2010; O'Hara, Higgins, Fleger, & V., 2010). Consequently, the way of performing a primary task – such as operating the plant including monitoring, situation assessment, response planning and execution – changes with increasing automation of the process control systems. Therefore, even though progressively applying automation may remove existing human errors, it has been seen to simultaneously introduce new types of errors(Lin et al., 2010). A possible source of such errors in process control is the emergence of new secondary tasks, such as navigating and managing user interfaces (O'Hara, Stubler, & J., 1997).

Acting as a system monitor rather than direct manual controller may, in addition, causes an erosion of skills to perform needed tasks should the automation fail. It also requires the human operator to learn new ways of seeing the process, maintaining vigilance and detecting abnormal situations (O'Hara & Hall, 1992). One of the most critical aspects and concerns of increased LoA is the human operator feeling 'out of the loop' of the process control. Human operators may have difficulty understanding the action of automation and emerging process situation. *Automation awareness* (AA) can be defined as a human operator's concept of the utilised automation and its state in a way that enables him/her to observe, control, and anticipate the events initiated by the automation (Laitio, Savioja, & Lappalainen, 2013). A sufficient level of AA enables the operator to monitor, understand and operate the automated system correctly in the situation at hand.

1.2 Human issues in automated driving

Obviously, human issues are anticipated to be critical also in automated road transport. Specifically, conditional and partial automation (SAE 2016 mainly level three but also level two) has been questioned as problematic for the driver (e.g. Gasser, 2012; Kyriakidis et al., 2017; Logan, Young, Allen, & Horberry, 2017; Merat & Lee, 2012). In all, the driver's role in automated road transport will change fundamentally and needs to be reconsidered.

From the human, or driver's, point of view, several challenges relating to automation have been identified (reviews by Cavoli et al., 2017; Lu et al., 2016; Merat and De Waard, 2014). Among them, concern has been expressed on how to cope with mixed transport of automated and non-automated cars (Michael Sivak & Brandon, 2015) or automated cars and vulnerable road users (VRUs) (e.g., Banks, Stanton, & Harvey, 2014; Hulse, Xie, & Galea, 2018; Parkin, Clark, Clayton, Ricci, & Parkhurst, 2016; Rasouli & Tsotsos, 2018); how to handle the consequences of secondary task engagement with increased automation and, more generally, the transitions between automated and manual driving (Banks & Stanton, 2017; Eriksson & Stanton, 2016; Lorenz, Kerschbaum, & Schumann, 2014; Lu et al., 2016; Merat & Lee, 2012; Varotto, 2018). In 2015, 12 experienced research scientists specialised in human factors and automated vehicles were interviewed regarding the role of human factors in automated driving. The overall conclusion of the study was that this role is not yet clearly established (Kyriakidis et al., 2017). The key issues the specialists raised were (Kyriakidis et al. 2017) as follows: How should the driver be informed about the status of the automated vehicle or traffic situation to keep him/her in the loop? What would the implications be for road safety and capacity? How will automated vehicles be accepted if the monitoring responsibility remains the driver's? User acceptance of automated driving has been the subject of research for some time already, including international comparisons (Kyriakidis, Happee, & De Winter, 2015; Liljamo, Liimatainen, & Pöllänen, 2018; Payre, Cestac, & Delhomme, 2014; Schoettle & Sivak, 2014) and involving other road user groups than drivers (Hulse et al., 2018).

Automation has been reasoned to rule out human error and thereby increase traffic safety dramatically (e.g., Cavoli et al., 2017), although it is well known that automation has not solved all safety problems in the transport modes where it has been widely applied (Kyriakidis et al., 2017; Parasyraman & Riley, 1997)). A disparity has also been identified between researchers' concerns regarding the speed of introducing automated vehicles on public roads before they are proven safe (Kyriakidis et al., 2017).

Intensive empirical research has been done in driving simulators to study human issues focusing on level two and level three automation solutions, and regarding the implications of non-driving-related tasks and traffic situation for transition from automated to manual driving (Banks & Stanton, 2017; Merat & De Waard, 2014; Merat & Lee, 2012; Radlmayr, Gold, Lorenz, Farid, & Bengler, 2014); takeover times from supervisory control to manual control (Kühn, 2016; Merat & De Waard, 2014); driver's SA and workload in highly automated driving (a meta-analysis by De Winter et al., 2014; Merat & Jamson, 2009; Stanton, Dunoyer, & Leatherland, 2011); and how automation affects driving performance (Strand, Nilsson, Karlsson, & Nilsson, 2014).

In spite of recent advances in automatic driving, the interaction between automated vehicles and drivers is still relatively poorly understood, to say nothing of drivers' interactions with VRUs. There are valuable findings, but the question remains whether all most relevant aspects have been covered and addressed, and how well the mechanisms behind the issues are understood. Therefore, one useful starting point for the identification of relevant human issues in road transport could be the current driver behaviour theories. These theories are based on reasoned and thorough analysis of human behaviour in the road transport context, although one may ask whether they are still valid and powerful for revealing the essentials when the degree of automation of road transport increases. Alternatively, approaches can be found in more general theories describing and explaining human information acquisition and processing. In this context, also experience from other modes of transportation, such as aviation, with experience in automation can and has been utilised. In fact, concepts inherited from the information-processing approach, such as SA, have been already quite generally applied when explaining automated driving, especially the transitions between automated and manual driving (De Winter et al., 2014; Lu et al., 2016; Stanton & Young, 2000). Moreover, there is quite a long tradition of automation in industrial installations, also encompassing theories and models developed for analysing operator work activity in process control environments (e.g., Kim J. Vicente, 1999; Norros, 2004; Woods, 1988).

We selected three theoretical approaches that gave us three different frameworks with which to study and discuss human behaviour in automated driving. The first group of theories, from traditional traffic psychology, we called 'motivational theories' (Ranney, 1994). The second model (Wickens & Hollands, 2000) sums up traditions from ergonomics and cognitive psychology and analyses human information processing. The model and its concepts have been applied both in transportation (also in aviation with experience of automation) and in the work environment. The third model, core-task analysis (L. Norros, 2004), has not previously been applied before in the context of road transport. Its origin is in industrial work, but it has been applied in a variety of work contexts such as analysis of first responder activity (L. Norros et al., 2009), operating-theatre work (Wahlström, Seppänen, Norros, & Aaltonen, 2018), farming and food production (Koskinen & Norros, 2018).

The classification of theories is approximate but attempts to catch some of the most relevant features of the models. We acknowledge that the selection may leave out approaches and models which would have been worth discussing. It should be noted, however, that our focus in this study was on human behaviour linked to changes that are occurring throughout the transport system and society as a whole.

1.3 Motivational theories

The first group of theories represent the 'motivational models' of driver behaviour. The approach focuses on how drivers perceive risk of a crash while driving. The origin of the theories is usually road safety, and the intention was to understand human behaviour and define measures to improve safety.

The zero-risk theory (Näätänen & Summala, 1976) stresses the large variety of motives drivers may have. These are categorised as 'principal motives', which are the safety motive and motive associated with reaching the destination, and 'extra motives' referring to several other motives (and emotions) determining driver behaviour, such as hurry, enjoying speed, emotions, aggressiveness etc. The theory suggests that drivers try to keep their perceived risk level at zero, and when the threshold is exceeded some compensatory actions are taken to bring the risk level back to zero. With experience, driving becomes a habitual, largely automatized activity in which risk control is based on maintaining safety margins (Summala, 2007). As a consequence, most of the time is driven without any experience of risk. The "threat avoidance model" by Fuller (1984) posits that driver behaviour is determined by two conflicting motivations, making progress towards the destination and avoiding hazards. Fuller also emphasises the role of learning – with exposure, drivers learn to recognise emerging risks and thereby make anticipatory avoidance responses. In 2005, Fuller (Fuller, 2005) specified that the drivers are attempting to maintain the level of task difficulty, a balance between capability and task demands.

According to Wilde’s Risk Homeostasis Theory (Wilde, 1994), drivers aim to drive at a constant, tolerated level of risk. The theory assumes that perceptual skills define perceived risk, which is compared with the ‘target level of risk’. A risk-adaptation model (Koornstra, 2009) integrates the three motivational theories (zero risk; threat avoidance; risk compensation). The assumptions of motivational theories have been discussed and the value of the theories questioned; for example, (McKenna, 1985) suggested that drivers would rather monitor their own interaction with the road and traffic system than risk; Rothengatter (Rothengatter, 2002) questioned the value of risk theories for traffic safety work in favour of attention theories such as the theory of planned actions (Ajzen & Fishbein, 1980).

Introduction of risk compensation stresses the importance of studying the long-term impacts of any measure and the concept of behavioural adaptation. Kulmala and Rämä (Kulmala & Rämä, 2013) suggested an updated definition for behavioural adaptation: “Any change in driver, traveller and travel behaviours that occurs following user interaction with a change to the road traffic system, in addition to those behaviours specifically and immediately targeted by the initiators of the change.”

1.4 The human as the information processor

The second theoretical approach comes from ergonomics; it is more general and deals with the human being as the information processor. Based on earlier findings and literature, Wickens and Holland (Wickens, 1992; Wickens & Hollands, 2000) summed up and provided a general model of human information processing stages. The model presents four stages – sensory processing, perception, response selection, and response execution – all utilising attention resources. Furthermore, the whole chain is interacting with memory (working memory and long-term memory). Feedback is provided from response execution back to sensory processing. The description of the stages is relevant for all human behaviour. The essential feature in the model is that the attention resources are limited, evident especially in dynamic and complex tasks. In some car-driving situations there may be too many elements in the environment and parallel processing of the information, which increases driver workload above an optimal level.

People seem to form an internal representation, that is, a mental model of the properties of the events when the situation or elements of a situation are repeated. The mental models guide the perception. Especially visual sampling has been studied in the laboratory; when expertise develops, the mental model develops as well and sampling changes accordingly (Wickens & Hollands, 2000).

Endsley (Endsley, 1995) suggested that sufficient SA is important in selecting the most appropriate mental models for a task. SA incorporates a person’s understanding of the situation as a whole and forms a basis for decision-making. Wickens and Holland (Wickens & Hollands, 2000) indicated that SA covers parts of perception and memory processes towards response selection.

The notion of AA has been previously mentioned (though not specifically referred to as ‘automation awareness’) in human behaviour literature (e.g., Whitlow, Domeich, Funk, & Miller, 2002) as well. Furthermore, AA may be regarded as part of the concept of SA (Endsley, 1995). In line with Endsley's definition of SA, the development and maintenance of AA, for example, in complex highly automated work environments is a continuous process that comprises perceiving the current status of the automation system, comprehending this status and its meaning for the system behaviour, and projecting its future status and meaning. Like SA, AA can also be seen as a prerequisite for good quality supervisory control, meaning that in order for the operator to conduct his/her work appropriately, (s)he must have an adequate concept of the automation system's state and of the state of the controlled process. The meaning of design and human behaviour understanding should not be understated: poorly designed automation together with a human operator's more passive monitoring role can take the human out of the loop, and result in degraded awareness of the system and the dynamic features of the environment (i.e., degraded SA).

With experience and consistent practice, the automaticity of human performance in car driving increases. Automaticity is characterised as fast, effortless processing, whereas controlled processing refers to slow serial and effortful processing (see e.g., Ranney, 1994).

1.5 Practice theory and Core-task analysis

The majority of traditional approaches in complex safety-critical work contexts focus on the phenomena of action and interaction and draw attention to the internal structure of human actors (e.g. cognitive and emotional events) in the context of individual and finely specified work tasks. The practice approach, however, focuses on examining how and according to what logic the human actor and the surrounding environment, including organisational structures and tools, get organised "into arrays of action" with regard to the general purposes and goals of the work (Leena Norros, Savioja, & Koskinen, 2015; Schatzki, Knorr-Cetina, & Savigny, 2001; Schatzki, 2005). These arrays of action may express and be explained by their meanings and they reveal the value of the situation and environment for the human actor. Thus, the concept of practice provides a comprehensive way to define work by revisiting the unit of analysis. The concept of practice also provides a basis with which to analyse the core task in complex work (L. Norros, 2004).

Specifically, in core-task analysis, practice is understood as activity as defined in the cultural historical activity theory (Leont'ev, 1978; Vygotsky, 1978) and exploited, for example, in the human computer interaction tradition (Kaptelinin, V., & Nardi, 2012). Activity theory emphasises the contextual understanding of work, and therefore places the general object of activity in a central role. The object of activity is that part of the environment that has become the focus of the human actor's attention and thereby a part of the human-environment system (Engeström, 1987; Järvilehto, 1998). Thus, the object of activity greatly affects how acting is structured. The concept of core task is introduced to strengthen the description of the object of activity and to operationalise it (L. Norros, 2004). The core task provides a functional perspective to work and refers to “the generic developing content of the work and expresses itself as joint functions emerging from the meeting of the human organism’s resources with the possibilities and constraints of the environment for reaching certain global objectives of work activity” (Leena Norros et al., 2015). In analysing the core task, the work activity is generalised beyond individual work tasks to a description of more generic aims and possibilities of certain work. This generalised content of a specific work activity is expressed as the core task. The core task defines how the human actor and the environment can become organised to collaborate in a certain work context. An appropriate and developing work activity and tools cater to the potential inherent in the core task. That is why in the design and development of complex work systems, the core task may provide a reference against which the activity can be viewed and analysed. The actual CTA is accomplished by means of two perspectives on the human-environment system, illustrated by two intersecting triangles in Figure 1. The first triangle models the environmental features of dynamism, complexity and uncertainty becoming reality in a work environment. The second triangle focuses on studying the human actor’s capabilities such as skill, knowledge and collaboration and reflection. Following this, the model highlights points where each of the three environmental features and the human actor’s capabilities come together. Within these points emerge nine core-task functions (see highlighted intersection points in Figure 1). Viewed from the perspective of the human actor’s capabilities, a core task function emerges when, for example, skills enable coping with dynamism and manifest themselves in the form of readiness to act in a specific situation, or skills enabling coping with uncertainty and therefore putting into effect a function of narrowing of options and testing.

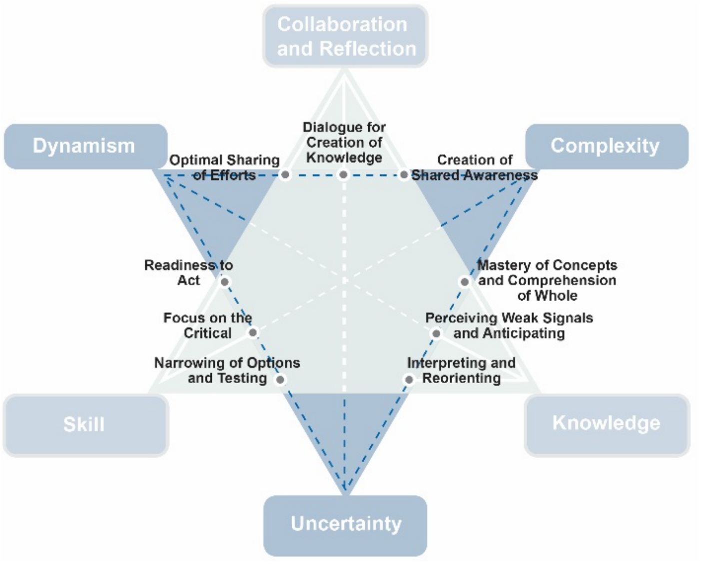

Figure 1. An example of core tasks defined for the work of nuclear power plant control-room operators. The core tasks emerge when human actors apply their resources and capabilities, i.e. skill, knowledge and collaboration to appropriately manage the dynamicity, uncertainty or complexity of the work domain (Leena Norros et al., 2015).

1.6 Aim of the study

The aim of the study was to assess the power of the selected theoretical approaches to human behaviour to reveal human issues in the evolving automated road transport system, and to name and describe car driver issues. Would the theoretical concepts be able to determine new issues, or reason and specify issues already identified in partial and high automation in road transport? In particular, the aim was to define and explain the identified human issues to give specific hints on how to cope with the issues in design or implementation of automation in car driving. Furthermore, the goal was to compare the theories' relevance in automated driving, identify topics not well covered, and suggest preliminary directions on how a theoretical model explaining driver behaviour in the context of automation could be further developed.

The following abbreviations are used from the selected theoretical approaches: MOT for motivational (driver behaviour) theories, INF for Information processing model, and CTA for core-task analysis.

2. Method and materials

A qualitative analysis of two automation scenarios in two driving environments was performed, using the above choice of theoretical approaches to human behaviour. First, we defined two automation scenarios at different LoA: low (level 2) and high (level 4) (following the SAE classification). Second, we broke up the driver tasks in urban and highway environments into subtasks. Third, several contextual circumstances (e.g. traffic and weather conditions) were defined for each subtask and described from the point of view of the three selected theoretical approaches. Finally, we made a content analysis and provided a list of human issues revealed by the analysis. The usefulness of the explored models in the context of automated driving was discussed. The focus was on likely changes that automation would bring with it, compared to a situation without automation support.

2.1 Automation scenarios

The two automation scenarios were selected to represent a future we thought to be realistic and possible for the automotive industry. Generally, in partial automation scenarios (ERTRAC, 2017), the driver is responsible at all times for monitoring and controlling the vehicle. In high automation scenarios ERTRAC 2017(autopilot/Level 4 (L4], ERTRAC, 2015), the vehicle is controlled automatically in the ODD, and in case of interruption of automation in the operational design domain (ODD) the car is stopped – or control-driven to the roadside and stopped – without active participation of the driver. The two scenarios assumed 50% automated vehicle penetration[2]. Connectivity between vehicles (v2v) and to the infrastructure (v2i) was assumed only in the high automation scenarios (urban and highway). It should be noted that connectivity is partial until very high penetration of that feature in automation.

The urban L2 scenario (see Table 2) assumed that the driver would have Automatic Cruise Control (ACC) Stop and Go application, which would be based on following the vehicle ahead. However, even if equipped we estimated roughly that L2 automation support would be available only 25% of the time in urban driving. Conditions in which the automation support would not be available were turning, overtaking, in-lane change, partially when no vehicle ahead, some sudden unexpected situations, foggy, snowy and icy weather conditions, and if the driver was not willing to use automatic support. In addition, the cars would be equipped with an Automatic Emergency Braking system and P-assist. When parking with the L2 P-assist, the driver needs to use the gas pedals and brake, but P-assist takes care of the lateral control. Leaving the parking place is controlled manually by the driver in L2.

[2] The analysis did not make any specific assumption regarding non-equipped vehicles regarding ITS support available. To some degree, however, it was assumed that in the high scenario, practically all vehicles could have some additional ITS or partial automation support.

In the urban L4 scenario, we called the automated driving system 'Urban Autopilot'. We assumed that the Urban Autopilot would be based on 3D maps, high-quality sensors and laser radar. The vehicle would localise itself using not only road markings but would orient also according to other objects on the 3D map such as buildings, posts and trees. However, winter conditions might still be challenging to L4 automation systems; therefore 40% support was assumed in wintertime and 80% in summertime (on average 60%). The nature of non-supported conditions was quite similar to those in the urban L2 scenario. In contrast to L2 P-assist, L4 P-assist was assumed to be fully automatic with no intervention of the driver. In addition, AEB would be available.

In the highway L2 scenario, ACC and Lane Keeping (LK) would be available 60% of the time in winter and 80% (on average 70%) in summer. The conditions in which automation support would not be in use were overtaking and lane changing, heavy rain, fog and snow, sudden unexpected situations, partially on ramps when entering or leaving the highway (merging is not supported), and if the driver was not willing to use automation support. The driver would set the following distance and the speed limit not to be exceeded. In addition, AEB would be available.

In the highway L4 scenario, automated driving support would be most continuous: the Highway Autopilot would handle all dynamic driving tasks (including overtaking) on motorways or motorway-similar roads, 95% of the time, after being taken into use by the driver on the ramp when entering the highway (also in wintertime), until exiting the road section. The driver could still select manual control if unwilling to use the automatic system. In a case of an unexpected (or anticipated) situation calling for action on the part of the human driver, the vehicle would alert the driver, and if the driver did not take over the car it would drive automatically to the side of the road and stop. In order to prepare the driver to take over and leave the highway, a countdown function would start 3 minutes before the exit route led off the highway, based on the destination set by the driver.

Table 2. Automation scenarios (automation available, % of time).

LoA	Urban		Highway	
L2	Automatic Cruise Control (ACC) with Stop and Go app based on following the car ahead. Automatic Emergency Braking (AEB) system, P-assist in which the driver uses the gas and brake pedals and P-assist takes care of the lateral control.	**25%**	ACC, Lane Keeping (LK) AEB	**70%**
L4	Automated driving system 'Urban Autopilot' based on 3D maps, high quality sensors and laser radar Automatic P-assist, which takes the car into and out of the parking space, even if the driver is outside the vehicle, AEB.	**60%**	'Highway Autopilot' taken into use by the driver on the ramp. Countdown based on driver-set destination to prepare for manual control e.g. 3 minutes before exiting AEB	**95%**

2.2 Subtasks, basic case and contextual circumstances in urban and highway driving

The urban driving environment was defined as a suburban area (not downtown) that was clearly a city-type area rather than countryside. Highways were assumed to include 3+3 lanes. Driving tasks in these two environments was further broken up into several subtasks.

The urban driving task included the following six main subtasks: (a) leaving the parking place (or yard)[3;] (b) driving on link sections; (c) driving in intersections; (d) parking; (e) navigation (during the trip); and (f) planning an urban trip. A basic case was analysed first – that is, driving in a car-following situation on a wide road in daylight and in good weather conditions. On top of this description, we analysed how a set of varying contextual circumstances would change the descriptions of behaviour. The original quite comprehensive list of contextual circumstances for urban driving was limited to the following: traffic in front (i.e., free flow or jam); composition of traffic (i.e., pedestrians, cyclists or trams); width of the road (i.e., narrow); traffic lights (i.e., yes); weather (i.e., hazardous); lighting (i.e., nighttime); and incident (i.e., anticipated or sudden).

Structuring the urban driving task as described above, and viewing it from the three selected theoretical points of view, resulted in a matrix involving 216 cells to be filled with descriptive sentences by the authors of this study (i.e., 3 theoretical approaches x 6 subtasks x 12 contextual circumstances of which one is the basic case) (Table 3).

[3] Parking and leaving were originally separate use cases but are combined here.

Table 3. Urban driving task (each cell was filled in with the description (…) from each theoretical approach INF, MOT, CTA.

URBAN	Contextual circumstances											
Subtasks	Basic case	Traffic in front		Composition of traffic			Width of the road	Traf-fic lights	Weat-her	Ligh ting	Incidents	
	Car follow-ing, only cars, wide road, daytime, no incident	Free flow	Jam	Pedestrians	Cyclists	Trams	Narrow	Yes	Hazardous	Nighttime	Anticipated	Sudden
Leaving the parking place	MOTIVATIONAL **(MOT)**	…	…	…	…	…	…	…	..	…	…	…
	INFORMATION PROCESSING **(INF)**	…	…	…	…	…	…	…	..	…	…	…
	CORE TASK **(CTA)**	…	…	…	…	…	…	…	..	…	…	…
Driving on links	MOT	…	…	…	…	…	…	…	..	…	…	…
	INF	…	…	…	…	…	…	…	..	…	…	…
	CTA	…	…	…	…	…	…	…	..	…	…	…
Driving in in-tersections	MOT	…	…	…	…	…	…	…	..	…	…	…
	INF	…	…	…	…	…	…	…	..	…	…	…
	CTA	…	…	…	…	…	…	…	..	…	…	…
Parking	MOT	…	…	…	…	…	…	…	..	…	…	…
	INF	…	…	…	…	…	…	…	..	…	…	…
	CTA	…	…	…	…	…	…	…	..	…	…	…
Navigation (during the trip)	MOT	…	…	…	…	…	…	…	..	…	…	…
	INF	…	…	…	…	…	…	…	..	…	…	…
	CTA	…	…	…	…	…	…	…	..	…	…	…
Planning an urban trip	MOT	…	…	…	…	…	…	…	..	…	…	…
	INF	…	…	…	…	…	…	…	..	…	…	…
	CTA	…	…	…	…	…	…	…	..	…	…	…

Similarly, the driving subtasks in the highway environment were defined as follows: (A) merging; (B) driving on link sections; (C) exiting the highway section; (D) navigation; (E) mode choice; (F) timing; and (G) route choice. Again, in addition to the basic case, a set of specific contextual circumstances were defined also for the highway environment as follows: traffic in front (i.e., free flow or jam/stopping); type of environment (i.e., busy roads); weather (i.e., hazardous visibility fog/rain or hazardous slippery road); lighting (i.e., night-time); and incident (i.e., anticipated or sudden). Consequently, structuring the driving task in the highway environment and viewing it from the three selected theoretical points of view produced a matrix of 169 cells (3 theoretical approaches x 7 subtasks x 9 contextual circumstances of which one is the basic case) (Table 4).

Table 4. Highway driving task (each cell was filled in with the description (…) from each theoretical approach INF, MOT, CTA.

MOTOR WAY	Contextual circumstances									
Subtasks	Basic case	Traffic in front		Type of environment	Weather		Lighting	Incident		
	Car following, quiet roads, good weather, daytime, no incident	Free flow	Jam	Busy roads	Visibility / rain	Slippery / icy	Night-time	Anticipated	Sudden
Merging	MOTIVATIONAL **(MOT)**	…	…	…	…	…	…	…	…
	INFORMATION PROCESSING **(INF)**	…	…	…	…	…	…	…	…
	CORE TASK **(CTA)**	…	…	…	…	…	…	…	…
Driving on link section	MOT	…	…	…	…	…	…	…	…
	INF	…	…	…	…	…	…	…	…
	CTA	…	…	…	…	…	…	…	…
Exit	MOT	…	…	…	…	…	…	…	…
	INF	…	…	…	…	…	…	…	…
	CTA	…	…	…	…	…	…	…	…
Navigation	MOT	…	…	…	…	…	…	…	…
	INF	…	…	…	…	…	…	…	…
	CTA	…	…	…	…	…	…	…	…
Mode choice	MOT	…	…	…	…	…	…	…	…
	INF	…	…	…	…	…	…	…	…
	CTA	…	…	…	…	…	…	…	…
Timing	MOT	…	…	…	…	…	…	…	…
	INF	…	…	…	…	…	…	…	…
	CTA	…	…	…	…	…	…	…	…
Route choice	MOT	…	…	…	…	…	…	…	…
	INF	…	…	…	…	…	…	…	…
	CTA	…	…	…	…	…	…	…	…

2.3 Creation of qualitative data

Each individual combination of driving subtasks by contextual circumstance and driving environment was described using the terms, main concepts, postulates and propositions of the theoretical approaches. Specifically, we focused on the changes that automation would bring with it, and recorded the descriptions in each cell of Tables 3 and 4.

The descriptions were provided by the authors and made up the qualitative data of the study. The outcome was discussed in several expert meetings and in two workshops with 10 experts representing traffic psychology and expertise in automated transport systems. A content analysis of the data and grouping of statements was made to outline the topics and list of human issues.

3. Outcome of the analyses

To avoid too much complexity in reporting, the results of some subtasks were grouped together. The five task groups are presented loosely chronologically from the start to end of the journey: (1) planning of the journey and navigation; (2) leaving the parking space and merging onto the highway; (3) driving on links; (4) driving in intersections; and 5) leaving the highway and parking. For each task, the driver behaviour is analysed and described using the terms of the three theoretical approaches. The relevant approach initiating the argument is indicated in parentheses (MOT/INF/CAT) after each statement.

For each task, the L2 automation scenario is described first, followed by L4 automation descriptions. Automation support relevant to the task is given (*in italics*) before presenting the observations from the three theoretical perspectives regarding driver (or traveller) behaviour; specifically, for the basic case (car-following situation, wide road, no VRUs, no trams, daylight and normal weather). The results from the analyses of the different contextual circumstances are tabulated later in the analysis section (Table 5 to Table 10). Each table adds one contextual circumstance to the basic case (e.g. influence of incidence compared with normal traffic situation).

3.1 Planning of the journey and navigation

Partial automation, L2*: Automation does not directly support planning of the trip. Some indirect effects can, however, be expected*.[4]

Using one's own car (compared with other modes of travel) would make travelling more flexible (assuming reasonable parking facilities) and increase the driver's feeling of freedom, making it more private and fun (MOT). Providing cars with partial automation probably increases driving comfort but does not take away the joy of driving; therefore, the motivational approach suggests that introduction of L2 automated functions would increase the share of trips made by own cars (MOT). The workload would be experienced as lower than in manual driving (INF), and the uncertainty in the driving task less (CTA), due to automation support for manoeuvring of the car; these changes could also result in increased use of own cars. The support in L2 was not expected to have much influence on the timing of the trip. If the driver feels uncomfortable with parking, the availability of L2 P-assist might have some influence on route planning, for example, the driver daring to choose a parking space in a busier environment. This conclusion is motivated by the tendency to avoid high workload situations (INF), complexity and uncertainty (CTA).

High automation, L4*: Automation does not directly support planning of the trip. Some indirect effects on trip decisions can, however, be expected. Before leaving the driver feeds the destination into the system and other criteria for the route. A*

[4] *As a general trend we assumed that navigation systems are quite commonly in use (even if not part of the automation).*

highly automated L4 P-assist is in place. We assume that also automated buses and shuttles are widely applied when L4 is in use, and thus other advanced options are available for transportation. Navigation would be handled as part of the L4 autopilot for the most part.

Advanced automation support is available for most of the travelling time. This changes the nature of the driving activity; the nature of extra motives (e.g., hedonism, time pressure) in car driving changes (MOT). Therefore, it is assumed that car owning and driving would not be as popular as earlier for some drivers, and they might be more willing to look for other travelling options (automated buses and pods, car sharing). Thus, the share of travelling by own car would decrease (MOT). Another option is that new types of motivations, not directly linked to moving from a to b, would appear to reason owning and using a car (MOT). Also, due to increased comfort and a low workload enabling the driver to do parallel secondary tasks during the journey (INF), an own car would be preferred.

In addition, automation might affect the timing of journeys. Drivers could experience the workload as lower (INF) and the complexity and uncertainty less in the driving task (CTA) thanks to automation. Therefore, where drivers earlier tried to avoid busy hours, this might change because of the time spent in the car that may be used for secondary tasks. The change was not assumed to be substantial, because experienced fluency of driving and the traffic flow would still be worse during those hours.

It was assumed that the (urban or highway) Autopilot would ask the destination of the trip and preferred route selection criteria (e.g., shortest, ecological, sceneries) when planning the journey. This could make drivers reconsider their route choices and thereby influence the final choice—the fastest or most fluent route would be favoured according to the motivational theories, but also other motivations might become important, because choosing between the safest and the fastest route would longer be that relevant (MOT). Fluent roads could be favoured, but also main roads due to higher automation support if experienced as increasing driving fluency (MOT). On the other hand, with the changing role of the driver there might be room for other types of reasoning and motives, like sustainable mobility. High automation L4 P-assist could influence route choice in the same way as L2 P-assist, which favours busy environments and hours in cities.

Navigation systems have become somewhat ubiquitous in the car-driving context, and people have learnt to trust them. If the driver is intensively involved in a secondary task (e.g., working or reading news), (s)he may not observe the environment very much (INF). However, when a route is new and unfamiliar, the driver may observe the environment more carefully even with L4 navigation support (CTA).

3.2 Leaving the parking place and merging

***Partial automation, L2**: Leaving the parking place and merging onto the highway are not specifically supported. AEB is supporting emergency braking when needed.*

Leaving a parking space can be a dynamic situation if starting from a busy street or parking spot and merging with the traffic flow. L2 automation does not support estimating the speeds and distances of other cars or the intentions of other drivers, which would reduce the uncertainty related to leaving the parking place (CTA).

The driver may try hastening off the ramp to the highway when L2 automation support is in place, which would benefit the overall driving performance (MOT). From the human information-processing point of view, as there is no automation support available for the merging task, no change is brought about by partial automation (INF). Given the highway-driving task generally, merging and leaving tasks are identified as the most demanding subtasks because of the increased dynamicity, complexity and uncertainty (CTA) involved. If the interaction with L2 automation requires additional attention and provides no clear benefit (e.g., optimal sharing of efforts), the driver might find it easier to handle the whole task manually (at least on short trips). This would lead to the use of L2 automation for only more restricted parts of the driving task and in a more polarised manner (CTA).

Merging in a car-following situation demands social and collaborative behaviour and benefits from a well working cooperation (CTA). With L2 automation support, the driver needs to acknowledge and pay attention to the other road users as before, besides possible interaction with the automation.

High automation, L4*: The Urban Autopilot monitors and controls driving, and supports gap acceptance when merging. In some rare situations manual control is still needed. In the merging subtask, the driver has to steer the car into the merging lane and activate the Highway Autopilot. The driver still bears partial responsibility for defining the gap and merging onto the highway lane. AEB is in use in case of an emergency.*

As soon as the route is selected and set in the L4 automation system and the driver is seated, (s)he can be involved in other activities, causing SA of the car driving task to decline (INF). The driver can take the car out of the parking place while either outside or inside the vehicle using the automation. With time, manual driving skills decline, thus exceptional situations where automation would not work can be experienced as challenging or risky (MOT, INF).

In the first phase, the automation setups (speed and distance in front) are done according to learned safety margins and defined speed limits, and the risk experience is thereby not changed (MOT). Over time, or in specific contextual circumstances, the automation setups may be adjusted, for example, with the following distance reduced or the speed increased. Consequently, some learning process is taking place to adapt to the new settings (MOT). The information processing model emphasises the driver's focus on the primary task, that is, handling the tasks related to entering the highway and maintaining SA. Increased automation may, however, impair SA and change the allocation of attention between the tasks not always appropriately from a safety or fluency perspective (INF).

From the core task point of view, the merging-onto-the-highway task may still be a demanding one in highly automated highway driving until connectivity is very widely applied. This is because interaction with the L4 automation is needed and the driver may also have an active role in defining the gap for merging and deciding the optimal moment for activating the Highway Autopilot (CTA).

3.3 Driving in links

Partial automation, L2*: Speed is controlled automatically as long as the driver does not accelerate or brake. Following distance (FD) to the vehicle in front is controlled automatically (a minimum value is set or selected). In an urban environment the driver is monitoring and controlling the vehicle's position in the lane, as lateral control of the vehicle by automation may not be continuous. Lane keeping is supported on the highway by automation most of the time. The ACC is also functioning at slow speeds and in a stopping flow. Overall, the support is available roughly 25% of the time in urban areas. When driving on a highway the figure is 60%. The AEB may activate in case of emergency.*

The motivational theories assume that drivers favour high speeds. Consequently, they would set the ACC speed somewhat above the speed limit (not too much, due to automatic speed enforcement being fairly widespread). If systematically applied this way by the majority of drivers, this could lead to an increase in the mean speed of the traffic flow due to automation (MOT). At the same time, however, the variance of speed could be decreased with the use of automated speed control. With time, drivers tend to accept shorter following distances than before, as the experience of risk related to short following distances decreases (MOT). For fluency, the driver prefers automation-supported driving on the highway. However, when encountering slower vehicles, the driver would quite frequently take control of the vehicle in order to overtake (MOT).

In the core task approach, the focus is on interaction between the driver and automation support. The driver needs to learn how to optimally use and interact with the automation in order to perform the driving task and achieve the operative goals. Maintaining the focus on the driving task and performing monitoring may be challenged by the fact that the physical activity related to the driving (i.e., steering, accelerating, braking) is handled by the automation and the driver is no longer holistically involved in the task performance (CTA). Moreover, the feeling of control of the vehicle is going to change – the link between actions and vehicle reactions is no longer that obvious. Lack of focus on the driving task may lead to the execution of secondary tasks, especially on highways but also in urban driving, and consequently a decline in SA of the vehicle control (INF). The visual demand, however, remains pretty much the same as in manual driving, and the execution of most secondary tasks may demand the same visual capacity and load the same channel as the driving task (INF).

In terms of the information processing model, partial automation supports response selection and execution (see Figure 1). Consequently, the feedback from execution to sensing and perception is changed as well (INF). The driver needs to create new mental models and give up some automacities gained by earlier manual driving experiences and learn new ones (INF). As a consequence, the workload may increase at least temporarily. After a learning period, the workload is experienced as reduced (INF).

The complexity of the task may be increased with partial automation, as in urban driving the driver may need to shift from supported to non-supported driving quite frequently due to the physical environment (intersections) and dynamic changes in the traffic flow (other road users, speed changes, turning vehicles etc.) (CTA). Driving on a highway link section is not that demanding but is a well-learned activity; with the support of L2 automation the driver can divert more attention to secondary tasks. Forming new mental models is also required for switching between supported and non-supported driving (INF).

High automation, L4*: Speed is controlled automatically, and the system keeps the car in lane. When encountering a slower vehicle, the car changes lanes and overtakes automatically. The driver does not need to monitor the situation or control the car; (s)he can be involved in secondary tasks, look at the landscape, sleep etc. The driver can also take manual control.*

Over time, once automation penetration is high and vehicles are connected, drivers will get used to quite short following distances. Speeding will no longer occur, as the maximum speed is set by the L4 automated system. The experience of risk may decrease (or stay at zero), as crashes will occur far more seldom (MOT).

It is assumed that the driver chooses some other tasks than driving as primary, and monitors traffic as a secondary task. In an exceptional situation, the driver is alerted by the automation system to take control. High automation assumes that the takeover can be managed without time pressure and the workload remains reasonable (INF). However, with time and with only a few manual control experiences, the driving task without automation support becomes more difficult and the workload heavier, as experience with manual driving has become rare (INF). When high automation can be fully used, the driver becomes a passenger; that is, the core task of the driver changes completely (CTA).

3.4 Driving in intersections

Partial automation support, L2*: Speed and following distance are controlled automatically when following another vehicle (max/min values selected). The driver monitors and has lateral control. The driver also takes over longitudinal control when turning. The obligation to give way may interrupt the automation support if someone comes between the lead vehicle and the follower (the ego car). AEB is active in emergency situations. Specific for intersections is more frequent interaction with other road users and a more frequent shift to manual control due to turning, braking or accelerating.*

Subjective risk is close to zero (as in totally manual driving), and the driver delegates the responsibility to the L2 automation system to keep the speed and following distance. The driver prefers to follow the vehicle in front but may need to give way, stop or turn and thus interrupt following and thereby allow interruption of the automated driving. As the driver would prefer to keep automated driving, their behaviour may become somewhat inflexible (MOT). However, if the connection is interrupted, the shift to manual driving occurs without substantial problems. SA is good, as transitions are expected at intersections (INF). It should be noted that most of the time is not supported by automation (25% in urban driving) and therefore mental models of manual driving dominate (INF). In some cases, however, the driver might ignore the intersection due to involvement in a secondary task (INF).

From a driver's point of view, the core task function 'interpreting and reorienting' is emphasised in order to manage potential uncertainty and handle driving in the intersection (CTA). Carrying out these tasks successfully requires forming an appropriate SA and interacting and communicating with the other drivers (and VRUs, see Table 6) in the intersection.

High automation support, L4*: The Urban Autopilot handles both lateral and longitudinal control. The driver may need to monitor the environment, for example, due to VRUs (automation support approximately 60% of the time). The intentions of pedestrians or cyclists are not fully comprehended by automation (e.g. pedestrian about to cross the road) and therefore the driver may need to take control in some cases in order to give way.*

The driver cannot fully count on automation, as support is assumed to be available 60% of the time (80% in summer and 40% in winter) but needs to shift from manual to automated driving and vice versa, and in each case activate the corresponding mental models (INF). Intersections are places where the support is most typically interrupted, which may temporarily increase subjective risk (MOT). As a compensatory action the driver can shift to manual control. The basic case did not assume VRUs in the vicinity of the automated car. However, close to an intersection in an urban area the driver may need to observe the environment more carefully due to potential VRUs (INF, CTA).

If the driver does not experience the automation (high automation system) as effective and the automated driving as fluent, (s)he may take manual control of the car to advance the driving task (change lane or speed up) (MOT, CTA). The core task function 'mastery of concepts and comprehending the whole' is needed to handle the complexity of the environment, namely an intersection. Moreover, this type of knowledge becomes even more relevant when designing the interior and equipment of the car, which changes with increased automation, becoming e.g. more like an office (CTA).

3.5 Leaving a highway section and parking

Partial automation, L2: *In the exit, the driver has limited automation support. AEB may activate in the case of an emergency. L2 P-assist is supporting lateral control of the car when parking.*

According to the motivational theories, drivers would try to optimise the use of automation support in favour of fluency and speed. When driving on a highway section, the driver has become habituated to the high speed and the subjective risk is low or zero (MOT). Controlling the switch to manual driving safely may demand more substantial reduction of the driving speed than the driver subjectively assesses or experiences. Consequently, the effects of "speed blindness" may be emphasised or prove more harmful due to the concurrent changeover (MOT). In addition, as there still is very limited automation support in the exit task, the driver may try to delay switching to manual driving as long as possible (MOT). From the human information-processing point of view, as there is no automation support available for execution of the exit task, there is not much change due to L2 automation compared with non-automated driving.

Automation support may have given room to secondary tasks while driving, and it is critical that the driver refocuses attention back to the primary (i.e., driving) task (INF). Being accustomed to automated driving, the ability to reorient and adapt and shift the focus from a secondary to primary task are highlighted while exiting, all of which is related to transformation from automated driving to manual driving (INF, CTA). When considering highway driving generally, merging and exiting are the most demanding phases. This is because of the increased dynamicity, complexity and uncertainty in the situation and task performance (CTA).

The support of L2 P-assist would ease the motoric performance (i.e., response execution) and thereby reduce the workload related to parking. It is assumed that with time, the driver would compensate this by parking more quickly (MOT). Consequently, the time allocated to visual scanning of the environment would decrease, and the driver could allocate the responsibility to detecting obstacles to the system (INF). In addition, the driver relying on P-assist could back up and park without turning their head. Any failure or defect in the detection system could result in an increased crash risk (MOT, INF).

Moreover, previously learned 'automated patterns of behaviour' (a concept named by Rasmussen (Rasmussen, 1983) and Wickence (Wickens, 1992) uses the word 'automacity') related to turning the steering wheel combined with visual search patterns will decline, and the driver needs to develop new mental models to operate with the L2 P-assist equipped car (INF).

Complexity of the parking task is reduced because part of it – lateral control – is handled automatically (CTA). Moreover, L2 P-assist might support the driver in performing sequential rather than parallel actions: *without* automation support, the driver is simultaneously dealing with visual scanning, motoric performance, communication and interaction with other road users regarding when to enter the parking space, whereas *with* automation support the driver could first focus on scanning the environment and then enter the parking space (CTA). This implies that the driver has passed a learning process successfully.

High automation, L4*: Before exiting the highway (e.g., 3 minutes), the highway autopilot starts countdown to when the driver will exit and take the necessary manual actions. P-assist for parking the car is assumed to be a simple push-a-button type of task. The driver can even park the car while outside the vehicle.*

The exit task requires the driver to interfere with the driving activity. If the automated driving has been fluent, the driver may try to take control by maintaining the same fluent driving style (MOT). Human information processing models highlight the shift from secondary to primary task. The countdown announcement is central in defining how timely and well the driver comprehends the situation and takes control (INF). The Core Task approach emphasises the joint functioning of the human driver and the automated systems in order to achieve the operative goals (i.e., reaching the destination safely). How well the driver knows the functionalities and limits of the automated systems, and how well (s)he has learned to use them in the driving task, is critical especially in situations that demand interaction with an automated system (e.g. exit task). A decision is required from the driver as to when to take control (CTA).

When there is high demand for interaction between the automation and the driver, the driver needs to reorient and shift focus from the secondary to the primary task. Slowing down to an appropriate speed may be challenging after driving at highway speeds for a while (MOT, INF, CTA).

In the few situations demanding manual parking, the situation is experienced as more troublesome than when the driver was wholly without automation.

3.6 Effects of contextual circumstances

The driving situation and, thereby, use and effects of the automated functions may change with the traffic situation, composition of traffic, road width, vicinity of traffic lights, weather and lighting circumstances, and incidents, compared to the basic case. The assumed changes related to these factors are listed in the following tables for partial (L2) and high (L4) automation.

3.6.1 Effect of other traffic

For a free flow condition, the driver can select driving speed without the influence of other vehicles; the potential increase of driving speed due to partial automation may then be emphasised. The demand for automation support depends on the driving situation; it would be highlighted in congested traffic and in jams, but for other reasons also when driving on links with less traffic. Automation would increase comfort and reduce workload caused by car driving; this might be seen in involving secondary tasks already in L2. Regarding jams, communication aspects and entering the traffic flow are highlighted in both automation levels L2 and L4. (Table 5)

Table 5. Effect of traffic in front (abbreviations refer to the theoretical approaches).

Automation scenario	**Effect of traffic in front – free flow and jam**
L2	An increase in mean speed is expected specifically in free flow on links (MOT). Dynamicity would increase along with driving speed (CTA), and motivate using automation support.
	In a jam, there are several parties involved who should be aware of the intentions of others. This sets specific demands on L2 automation system design to support communication specifically (CTA).
	In a jam, the volume of traffic increases the amount of uncertainty, but the dynamicity may be smaller due to lower speeds (CTA). Automation support may result in carrying out secondary tasks in a slow-moving queue (INF).
	In a free-flow situation, leaving or parking would be less work-loaded (INF) – the dynamicity and complexity is clearly reduced when we do not assume other cars in the vicinity (CTA). This may decrease task demand and use of automation support.
L4	A driver trying to enter heavy traffic flow may be uncertain as to when a slot will open up and shift to manual control. (MOT, INF, CTA)
	In a jam, the driver with high automation support may become impatient, look for the possibility to overtake and shift to manual control. (MOT)
	P-assist is assumed to decrease uncertainty in a jam, as the driver can be more confident about his/her parking (CTA).

3.6.2 Effect of traffic composition

When there are VRUs or trams having the right of the way and demanding more space than cars, obviously the level of complexity is increased. In some cases, encountering VRUs makes the driver reallocate his/her mental capacity, and driving becomes an attention-demanding priority task. New ways to alert the driver for specific occurrences need to be considered (Table 6).

Table 6. Effects of heterogeneity of traffic.

Automation scenario	Effect of heterogeneity of traffic – pedestrians, cyclists and trams
L2	The presence of VRUs in the vicinity increases the complexity and uncertainty of driving (CTA). More demand is on the drivers, and possible fast reactions (dynamicity) may be needed on their part. Highlights the role of information and presentation of the user interface. May lead to non-use (CTA).
	When driving on a link, the driver may prefer to keep the connection to the vehicle in front (to keep L2 support). The situation could therefore lead to the driver ignoring pedestrians and cyclists, even trams (MOT, INF).
	Generally (in the city/on busy roads), over time the driver's trust in automation support may increase and the influence of the environment decrease. (INF)
	When parking in the presence of other cars (car-following, busy environments), the limited attention capacity may tend to be allocated to car traffic, and the risk of ignoring VRUs increases, e.g. a cyclist passing the parking car. (INF)
	L2 automation-supported parking might become more fluent and faster. Thus, from a cyclist's point of view, cars may appear more suddenly in front of him/her, causing increased dynamicity and uncertainty (CTA).
L4	Complexity may increase when cyclists are in the vicinity of the automated car, especially passing on the side where the automated car is intending to drive. This sets specific demands for the car to detect the cyclists. New arrangements of the driving space in cities may be needed to reduce crash risk. In addition, it is possible that many VRUs are acting against the rules (CTA).
	New ways to alert the driver, to take control and shift focus on the primary task may be needed for high automation VRU use cases specifically (INF).

3.6.3 Effect of road width

Narrow streets, typically combined with visual obstructions and presence of VRUs, may be technically challenging for automation. Situations are complex and may lead to manual driving (Table 7).

Table 7. Effects of width of the road.

Automation scenario	Effect of road width
L2	In an urban environment, automation should decrease uncertainty caused by narrow streets or lanes and visual obstructions (CTA).
	If VRUs act in an unexpected way, this may lead to higher subjective risk and the driver shifts to manual control on narrow streets specifically (MOT).
L4	On narrow residential streets and roads with piles of snow there may be less space for parking. P-assist can be considered beneficial in this situation (CTA).

3.6.4 Effect of traffic lights

In L2, no specific problems related to traffic lights due to automation were identified (Table 8). When in use, driving in an intersection would be supported by the lights. Queuing vehicles at traffic lights may make it challenging to enter the traffic flow from a parking place in the period before high penetration of connectivity.

Table 8. Effects of traffic lights.

Automation scenario	Effect of traffic lights
L2	Traffic lights may interrupt the connection to the lead vehicle. SA should, however, be quite good, as traffic lights are expected in an urban environment and are clearly visible. Consequently, there should not be any specific problems in switching to manual driving (INF).
L4	In some incidents (e.g. someone walking against a pedestrian red light), sudden hard braking may be necessary and will be done automatically.

3.6.5 Effect of weather and lighting conditions

Adverse weather conditions may be technically challenging for automation, and in those cases automation support may not be available. With time, drivers having automated cars are going to have fewer opportunities to gain manual driving experience. Consequently, this could influence willingness to use one's own car when adverse weather and road conditions are forecasted (Table 9). A feeling of uncertainty related to driving skills and automation support is emphasised in night-time driving and in adverse weather conditions.

Interruptions in automation support highlight the importance of AA – the driver needs to be aware of the status of the automated vehicle. Understanding the limits of automation becomes critical in adverse conditions.

Table 9. Effects of weather and lighting conditions.

Automation scenario	**Effect of weather and lighting conditions – hazardous visibility or slippery, night-time**
L2	If the driver is used to automation and the support is deactivated in bad weather, the uncertainty may be magnified. (CTA)
	In hazardous slippery road conditions the demands on the driver increase, specifically in conditions not easily detectable to the driver (e.g. black ice). L2 automation as such does not support driving in adverse conditions nor provide specific information on weather conditions (MOT, INF, CTA).
	In night conditions, a discrepancy in task allocation between the driver and the automation follows from the human not being the best equipped to monitor the driving and surroundings (CTA).
	In poor visibility and at night, P-assist reduces uncertainty in particular (CTA).
L4	In snow and on icy roads, the driver may need to take control. The situation displays uncertainty and complexity, and it may be extra demanding because the driver may have less driving experience after intensive use of automation (CTA). Over time, limited support could decrease the use of one's own car in adverse weather because uncertainty is increased (CTA).
	The ability of drivers to cope in demanding situations (e.g. hazardous visibility fog/heavy rain) declines due to less hands-on driving experience (INF).
	The perception by the driver of a situation (SA) and the adjustments made by L4 automation may not always correspond to each other, specifically in hazardous visibility fog/rain conditions (e.g. speed too high and FD too short). This highlights the importance of good AA at all times (INF). The driver may feel uncertain about the automation's ability to handle a situation (INF, CTA).
	In hazardous visibility fog/heavy rain, takeover times may be longer than in good conditions, especially if the route or a specific exit is unfamiliar (CTA).
	In hazardous slippery road conditions, the driver may not feel confident taking control or making decisions about the driving due to lack of information and experience. Even if the Autopilot handles the driving, the driver may feel uncertainty/fear in that situation (CTA).

3.6.6 Effect of incidents

In case of an incident, the driver is supported when needed with the emergency braking system in both automation scenarios (Table 10). Anticipation based on being well informed is highlighted. Due to automation, driving skills may deteriorate, which may be critical in case of an incident. Unforeseen interactions may occur in sudden incidents.

Table 10. Effects of incidents.

Automation scenario	**Effect of incidents – anticipated or sudden/unexpected**
L2	In an incident, EBR makes braking more efficient. However, the support may not cover all aspects of the incident and there is a risk to delegating too much responsibility to automation (MOT, INF).
	At any rate, uncertainty and dynamicity increase when encountering an incident (CTA). However, automation support is limited.
	In case of an incident, the role of information is highlighted; it should support the driver to handle the manual control (INF). Information about the incident improves SA and keeps the driver in the loop. The content and level of detail of the warning message is central (INF, CTA).
L4	The role of information is central to alerting the driver before encountering an actual situation, and to increasing SA (INF).
	In an unexpected incident, the automated car may not be able to handle the situation and the human may need to take control. The role of knowledge is emphasised (CTA). Real-time information would support the actions (INF).
	The variance in how prepared to react drivers are may grow, because some of them can be focused on secondary tasks at the expense of a good SA (INF).
	Sudden-onset conditions may be more demanding, because the driver may have less driving experience after regular, intensive use of automation (CTA, INF).
	If a connected and automated car fails to notice or understand a message warning of a hazard, the driver needs to decide upon and take the required actions. This also relates to AA. Whether a warning is delivered and how, and the quality and details of the information may have a role in how and by whom the warning is acted upon (CTA).
	In a sudden situation, the driver most likely will still try to react to the incident, even if (s)he was not the one handling the driving. Unforeseen interactions may occur because simultaneous actions may be taken by the automation and the driver (CTA).

This chapter presented the qualitative 'raw' data of the analysis. On top of this data, a content analysis was made to reveal and list the human issues and assess the main findings. We ended up with a list of 20 human issues, which are presented in the next chapter.

4. Discussion

The study focused on automated driving and three selected human behaviour theories. Our main interest was to find out how these theoretical approaches would contribute to identifying and understanding the human issues of automated driving, and the development objects relating to these. Three theoretical approaches – motivational driver behaviour theories (MOT), the model of the human as an information processor (INF), and core-task analysis (CTA) – were selected to study how the currently ongoing change towards automated driving appears in the light of human behaviour theories: What hypotheses regarding partial and highly automated driving can be deduced from the three theoretical approaches? What are the key human issues, and do the theoretical approaches provide a more detailed understanding of these issues, and insight into how they should be solved/addressed in the design and deployment of automated driving? In addition, the aim was to assess the power of the selected theoretical approaches to describe automated driving.

In the definition of automation scenarios, we utilised the SAE (SAE, 2016) classification. In the analysis, we focused on L2 and L4 automation; L2 was selected as it is already on market and, we assume, will be for a remarkable period of time. We did not address L3; on one hand this 'conditional automation' releases the driver from responsibility by indicating that object and event detection is taken care of by the system, and at the same time L3 indicates the driver responsible as a 'fallback-ready user'. The role given to the driver is ambiguous (as pointed out by e.g., Banks, Eriksson, Donoghue & Stanton, 2018; Gasser, 2012) and inconsistent for a human actor. The most recent update to SAE (SAE, 2018) gives some additional specifications but does not really change this issue related to L3. For us, L3 seems to be feasible only for the technical development and for the intermediate demonstration and piloting phase of automation, whereas L4 (high automation) designed for specified roads, road sections or environments is more realistic to deploy ('full automation' in the first place with limited *Operational Design Domains*, ODD) and, therefore, important to study. It is acknowledged that even in L4, the driver's role such as monitoring the environment does not become totally redundant (Banks & Stanton, 2017; Noy, Shinar, & Horrey, 2018). In addition, it is noted that the SAE type of classification is a normative one indicating what should happen, whereas Lu et al. (Lu et al., 2016) suggested an alternative, more descriptive LoA framework, specifically focusing on driver behaviour in the transitions of automated driving – from automated to manual driving and vice versa. Actually, that descriptive classification can also be seen as complementary, focusing on boundaries of the SAE-type categories. In all, there seems to be space for additional LoA specifications in road transport (OECD/ITF, 2018) Banks & Stanton 2017). For the human driver, from the perspective of the theoretical approaches discussed, the amount of automated driving, or relative share of it, because of behavioural adaptation, is critical.

With the intention of studying the feasibility of current human behaviour theories, we applied a bottom-up procedure to describe driver behaviour initiated by automation – as an alternative to the top-down models combining psychological concepts and constructs (Heikoop, 2018; Stanton & Young, 2000; Varotto, 2018). We followed the journey from planning the trip, leaving from the parking place and merging, driving on links and intersections, to exiting the highway, arriving at the destination and parking the car, and described the behaviour utilising the concepts of the selected three theoretical approaches. Introducing automation seemed to influence and change all of these driving subtasks.

In this chapter, we summarise the results of our analysis as 20 human issues. We remind the reader that in spite of the subjective nature of the work, the issues are above all considerations or statements initiated by the selected theoretical approaches. Furthermore, we acknowledge that we did not cover all possible issues with our data and that the conclusions could somewhat vary by subjective emphasis. However, it is assumed that the above analyses demonstrate how the theoretical approach can be useful in identifying human issues of importance. Based on the content, we created four thematic categories for presenting and discussing the emerged human issues. The categories are (1) strategic decisions, (2) role of information and skills, (3) interaction and communication, and (4) road safety.

4.1 Strategic decisions

The driver was treated in the analysis as a traveller who has not yet decided their mode of travel, specifically use of their own car. When planning the trip, critical strategic decisions (Michon, 1985) regarding the journey are made, influencing the driving task in the coming trip, sustainability (including road safety) and efficiency of the road transport system. In the planning phase, the driver decides the mode of travel and timing of the trip and makes a route plan of how to reach the destination. Use of automation support was also treated as a strategic decision in the study. Especially in an urban environment, we assumed transport services enabling realistic and reasonably well functioning alternatives for using one's own car; the trip could be made by public transportation and the shortest trips by cycling or walking. The analysis revealed the following human issues and hypotheses related to the strategic decisions of the driver:

1. The share of trips made by car is assumed to increase with automation. In L4 automation, some factors reducing this trend were identified (see points 3 and 8 below).
2. P-assist systems may encourage people to plan their trips to include parking in busy city centres.
3. Over time, drivers get used to automation support (in L4), experience it as comfort, and their driving skills deteriorate. Therefore, they may prefer other modes of travel over their own car, especially when the weather forecast indicates adverse conditions which would require manual driving.
4. The motivational approach highlights the importance of fluency in travelling and suggests that the drivers would favour the fastest routes when setting the route in the automation system. The direction of the change in timing of the trip was not clear – one could argue both for and against driving more in peak hours.

Moreover, new types of reasoning and motivations for route choice may become important in future travelling, particularly ecological motives and sustainability.
5. Due to changes in workload while driving, the time allocated for traveling will get new content and can be used for new activities. Some effect was assumed also on timing of the trips.
6. Limited support of partial automation in some environments, specifically on urban roads, may be confusing. Overall, this may influence the feeling of trust and use of automated functions, and thus slow down deployment of automated driving.
7. Trust in automation develops with driving experience. Public reports of even a few serious crashes with automated driving systems could be enough to reduce trust.
8. The role of the car as fulfilling the extra motives may change; driving being fun may become enjoyment of travelling. New ways to travel and spend time while travelling may emerge and thereby influence the use of own cars.

In the L2 automation scenario, it seemed that some effects may be undesired such as potentially more car traffic overall. All three approaches pointed in this direction, which is in line with previous suggestions and findings (review by Milakis et al., 2017). Moreover, traffic would increase in the city centres in particular. This would result in poorer traffic fluency, increased pollution and health problems, and a reduction in physical exercise. The finding calls for active policy measures by public road authorities, as also indicated by POLIS (POLIS European cities and regions networking for innovative transport solutions, 2018) in a recent discussion paper. Availability of parking places, where they are built, placement of buildings and activities, and offering of other transport services than private cars may, with increasing automation, become even more critical than today in preventing trends not favourable to society.

In the L4 automation scenario, the trend to use cars more may be similar, but some factors also point in the other direction. For example, in adverse weather conditions where one could encounter a situation demanding manual driving, the driver could prefer more sustainable (safe) public transport to cars. The supply and quality of the public and shared transport service will be critical in influencing peoples' mode choices and sustainability. However, given the increased comfort and fluency, lower workload and less uncertainty of driving one's own car, we expected the share of trips made by car to increase also in the L4 scenario. Consequently, the demand for automated driving functions will be high for adverse weather conditions associated with road safety problems and reduced subjective safety.

Regarding the routes, the motivational approach suggests that the most fluent routes would be preferred. However, in the L4 scenario, route choice could be integrated more with the planning phase of the trip. This could offer more possibilities for alternative routes and route selection criteria, such as comfort, subjective safety or environmental benefits. Anyway, offering alternative routes could make drivers more conscious about route selection as a strategic decision and help them make well-reasoned decisions. On-board navigation support should consider the driver's knowledge of the route selected, prior driving experiences and route history. In all, the industry may have a remarkable role in influencing route choices. The navigation service of an automated car should favour the most sustainable choices.

In automated driving (from L3 upwards), the driver is allowed to utilise part of the travel time for other activities than monitoring the environment and taking care of dynamic driving tasks. From the driver's perspective, this changes the value of time spent in the vehicle, now that it can be used more freely and efficiently than before. Consequently, the value of time should be reconsidered (e.g., de Almeida Correia & van Arem, 2016; Milakis et al., 2017); there might be reasons to update the values for the cost benefit analyses.

Limited and intermittent automation support in an urban environment may lead to the driver experiencing confusion and frustration. L2 highway assist does not support merging and leaving the highway actively, even if these subtasks were assessed as most demanding in the CTA. This also highlights the demand for flexibility of driver behaviour – the driver needs to adapt his/her to more substantially varying workload conditions than before. The benefits of automation can be perceived as too little compared to the trouble of giving up existing cognitive automacities developed with experience, especially if the frequency of manual driving is high. This would affect the willingness to use automated functions specifically in urban areas. The analysis emphasises new user needs and demands that drivers are subjected to when new technology is developed. The LoA classifications raise the question of who – man or machine – is best at a specific task. An example could be observing in darkness or driving in heavy rain; how the driving task should be optimised and how supporting information should be designed before full automation.

Trust in automation is expected to increase with positive experiences. These can be gained personally but also via media – including news, general information and social media – which are all going to affect the acceptance of automated road transport (Anania et al., 2018; Körber, Baseler, & Bengler, 2018). For the deployment, acceptance of automated driving is needed – limited functionalities can reduce utility and use (CTA); unreliable functions can reduce trust. This may be challenging also for the automated driving pilots, for example in ongoing EU projects (L3pilot, AUTOPILOT etc.), potentially not being able to demonstrate the entire benefits of automation to test users. However, this is even more critical for the full deployment of automation; it is obvious that immature systems cannot be launched on the market.

The nature of car driving is changing. The car is becoming an extension of one's living room or a kind of office with all the equipment needed for comfort in work and business. High automation will fundamentally change personal mobility, expectations for transport services, the role of the car, and the motives related to moving from one place to another (MOT). The role of drivers as consumers will get new content, with a pronounced need for new knowledge. The core task of the driver will change totally. "The fundamental change of transport system" along with increasing automation has been recognised generally (e.g., Carsten and Kulmala, 2015). The motivational approach gives some more insight into 'why' and 'how' when discussing the joy of speed and fun of driving as key motivations in car driving. Furthermore, the theory of reasoned actions (Ajzen & Fishbein, 1980) discussed factors influencing attitudes to better understand and explain emergence of motives. The theory – widely applied in road safety research (Åberg, Larsen, Glad, & Beilinsson, 1997; Forward, 2009; Haglund & Åberg, 2000) – introduced the concept of 'subjective norm' indicating the importance of personally important people on one's choices and intentions. These concepts might be feasible also in studying drivers' intentions to utilise automation, user acceptance and trust.

4.2 Role of information and skills

The analysis emphasised the role of information. On one hand, specific and effective messages are needed to alert the driver to take control of the vehicle when necessary. On the other hand, high automation implies that during automated driving, distraction would no longer be a severe problem, but there would be more room for delivering on-board information. The analysis revealed four types of information needs or options to provide information:

9. Real-time information to support SA; AA, detection of incidents, and anticipation of takeover situations.
10. General guidance to introduce new automation functions; to support use, increase knowledge and awareness of automated driving and vehicles.
11. Education or practice to support the creation of new appropriate mental models for partial or highly automated driving.
12. Training to maintain manual driving skills.

Real-time information becomes critical in driving situations where automation cannot be fully utilized; for example, in case of an incident an effective signal is needed to alert the driver to take over. Another example is adverse conditions associated with discontinuity of automation support. Furthermore, well-designed real-time messages would support SA more generally, including detection of objects in the environment, interpretation of small signs and details, and anticipating exceptional situations.

Situation-related information is seen as beneficial also when the vehicle is driven automated; the driver should be kept in the loop as any operator in an automated work activity (Kaber & Endsley, 1997). The driver should have the locus of control while making the trip, even if direct feedback from one's actions diminishes. One critical element is a good understanding of the capabilities and status of automated control of the car. As stressed by the core task approach, keeping the driver in the loop becomes an own design task, as the driver is no longer holistically involved via his/her own physical activity in controlling the car. In line with this, disengagement from the steering task resulted in less effective obstacle avoidance (a driving simulator study by Navarro, François, & Mars, 2016). AA will be based on a well-organised interaction between the driver and user interface highlighting the importance of the interface design. There are several specific design tasks to be recognised: how to inform the level of automation (L2 or L4); how to support the driver when automation is deactivated; how to offer activation of automation; how to prevent unforeseen interactions like simultaneous actions by the automation and the driver, etc. In addition, AA as a key concept explaining a well-functioning automated human machine system should be identified as one of the key performance indicators when studying automated driving. AA should preferably be studied as a continuous process – it would be valuable to study the level of AA by time, explaining the driver reactions, rather than an overall average. There is an analogy with measuring workload; several type of measures, also continuous, are justified (Solis-Marcos, 2018).

The main source of information in car driving is the visual sense (e.g., Luoma, 1991; M Sivak, 1996). Automation is probably better than a human in response execution, but especially low automation systems may be poorer in perception and interpreting the meaning of all signals perceived. A crucial aspect in car driving is how to perceive the environment and detect the critical elements in it. Demands (focus of attention) for perceptual skill will be quite the same in low automation but probably quite different in high automation compared to manual driving. As a specific use case, when learning a sequential way to act with a low automation P-assist, the less-loaded driver is significantly benefitting from additional information making other parties in blind spots visible. In some situations, such as merging onto the highway, the change in the driving activity is going to be minor due to low automation. However, as the overall situation is changed there might be need for additional information to support the SA.

Well considered general information would serve the introduction of automated cars – the general public should to some degree have knowledge about the automated system and its functionalities (e.g., Anania et al., 2018). Already when introducing intelligent information services, this need has been stressed (e.g., ESoP, 2007). In the context of automated driving, the need is by no means less but rather highlighted even more. General knowledge would help travellers understand big shifts in the transport system and thereby be aware of the current state of vehicles. Moreover, it would serve as a knowledgebase for keeping drivers in the loop. Analysis of the complexity of the task, as part of a CTA, could be valuable in deciding what kind of general guidance is needed when introducing new automated driving systems.

Increased automation highlights the need to renew driver training. In addition, probably some updating of training will be needed to support drivers in creating new mental models for handling automated vehicles, and later to maintain manual driving skills should they be needed in some situations. It is acknowledged that some people are readier and more capable than others to take new technology solutions on board, thus there will be some variation in educational needs. However, the option should be provided due to these major shifts in the transport system, not least from the equity and system points of view. In the very long-term perspective, specific services might be needed to rescue stopped automated vehicles with drivers of limited driving experience.

Overall, full automation is not expected to become a reality for decades. Therefore, driver education in manual driving needs continuous updating to both maintain these skills and meet recent technology demands. The whole learning process of car driving is going to be radically different as the connection between driver manoeuvres and vehicle movements change. In manual driving, part of the driving skill is understanding how the vehicle reacts to the control systems (pedals, steering wheel); in automated driving, less experience is going to be gained about this relationship.

4.3 Interaction and communication

Communication and interaction are a particular ongoing process in road traffic. An example is entering a roundabout, which represents fine adjustment of how to react to the movements of other parties. The following issues were raised with respect to communication:

13. Communication when one wishes to enter the traffic flow was identified as a subtask changing to some degree with increased automation in road traffic.
14. Communication with passing cyclists while parking or leaving a parking space calls for specific attention.
15. Overall, use of automation calls for improved communication between parties. This was identified as a specific design task.

Cooperative Intelligent Transport Systems (C-ITS), electronic connectivity of the vehicles (v2v) and automatic optimisation of vehicle movement when entering the flow could be tools for organising communication needed between vehicles. Especially, in the L2 scenario C-ITS was not assumed to be widely applied. Furthermore, in the L4 scenario communication cannot be built on connectivity between vehicles until the penetration of C-ITS is very high. Therefore, lack of connectivity is going to be topical for a long time (also due to the potential security issues related to connectivity, OECD/ITF 2018) both between cars and between automated cars and VRUs. Specifically, communication between automated vehicles and VRUs has been assumed to be challenging. An example is a cyclist with considerable speed at intersections. New arrangements of city space and roads may be needed to ensure road safety: clearer separation between bicycle (pedestrian) and car traffic in cities to reduce crash risk, a topic for design and further research.

Communication demands were highlighted in dense traffic flow. Connected automation provides one way to enhance communication in the traffic flow (v2v) and thereby improve the efficiency of the system. The same concerns traffic lights. When merging in the vicinity of traffic lights, anticipation of the traffic light phase could be organised with connected automation (v2i, vehicle to infrastructure). Many positive impacts of automated driving presume connectivity. The core task perspective explicitly addresses the social and collaborative aspects of behaviour. Merging onto a highway in a car-following situation was identified as a challenging task setting high quality demands for the user interface.

Communication between parties should be seen as a specific design task. One key element is the user interface – whether it is going to support well-timed communication and seamless interaction between the parties.

4.4 Road safety

High automation tackles the main road safety problem, which is speeding (Elvik, Vadeby, Hels, & van Schagen, 2019; Nilsson, 2004) . Selecting the maximum speed would no longer depend on individuals' decisions but would be done by the road transport system according to commonly agreed rules, technically utilising factory installations. The introductory phase of partial automation is still affected by road safety concerns relating to driving speeds and headways, but, in the light of our analysis, even more to the human as information processor, learned automacities supporting manual driving, and new learning needed. The analysis suggests that there are elements that tend to increase risk in the L2 scenario in the transition phase towards high automation. The following traffic safety issues were identified:

16. Mean speed may increase with low automation. Following distances are assumed to become shorter in high and connected automation assuming high technical performance and also because of driver behaviour adaptation.
17. A lower workload is expected in automated driving, thereby leading to reduction in crash risk. However, execution of secondary tasks with L2-level automation, when the driver has the responsibility to monitor the environment and control the vehicle, may increase risk in exceptional, unexpected situations.
18. Learned automacity skills may no longer be valid, and the driver needs to develop new mental models and automacities. This learning phase may be associated with an increase in crash risk in some situations where the visual demands remain the same but the workload is increased due to the new (learning) situation.
19. With low automation, drivers may not be willing to give way to other participants (VRUs, trams, cars) if this implies giving up the automated driving (in L2 automation assuming car-following).
20. Use of L2 P-assist can lead to more fluent parking and a lower number of damage-only crashes. However, in case of any lack or error in the detection system, combined with delegation of responsibility to the system, an increase could be seen in the risk of severe crashes.

Automation is designed to improve traffic safety as the main goal (e.g., OECD/ITF, 2018), and it is assumed to prevent several types of crashes. In low automation, mean speed could be higher than with manual driving. In addition, our analysis suggested that adaptation to (high) speed could be highlighted in automated driving and be harmful in partial automation. Increased speed reduces the time available for the driver to detect, interpret and respond to situations. However, as long as traffic is mixed, with both automated and non-automated parties sharing the same space, driving speeds are not likely to increase much if at all. In addition, a recent driving simulator study gave some evidence that whether driving manually or automated would not influence the experience of "comfortable" speed and thereby improve safety (Solís-Marcos, Galvao-Carmona, & Kircher, 2017). Also, the AEB mitigates the consequences of a potential crash by reducing speed in an emergency. Shorter headways are not regarded as a safety problem as long as the choice is technically feasible.

The obvious advantage of automated driving is to reduce workload. However, use of driving time to accomplish secondary tasks at lower levels of automation (up to L3, partly L4) has been identified as a potential safety problem (e.g., Merat and De Waard, 2014). Specifically, the interaction with low-level automation support systems loads attentional resources. Not-driving-related tasks are questionable, because the support is limited and does not much ease the processing of visual information. The increase in risk can be significant if at the same time the driving task becomes more complex (for a while) and the driving speed increases. Furthermore, the nature of secondary tasks makes a difference in how easy it will be to alert the driver: e.g. whether a driver involved in a visual task should be alerted by an auditory signal and vice versa. In general, auditory takeover requests seem to be more efficient than visual only (meta-analysis by Zhang, Winter, Varotto, & Happee, 2019), and also selected as the most preferred option for low-urgency scenarios (Bazilinskyy, Petermeijer, Petrovych, Dodou, & Winter, 2018). Furthermore, as the main source of information is visual and visual information is essential to building a good SA, a recommendation in favour of auditive tasks as secondary might be considered. At the same time, it is acknowledged that any secondary task can be problematic due to the more general cognitive load. With partial automation and in an urban environment, the complexity of the driving task may increase if the driver needs to shift frequently between supported and non-supported driving. An increase in complexity may be mostly related to comfort and willingness to use automation, but can also be a traffic safety issue, as pointed out also for example by Banks et al. (Banks et al., 2014).

Positive from a safety perspective is that the highest speeds could already be cut down with low automation, due to a change in the decision process of selecting the driving speed – more as a strategic decision before the trip than momentary decisions during the trip. Factory installations are assumed to be kept by the general public and therefore have a remarkable role in influencing this development. Overall, driving speeds of the traffic flow along with increased automation penetration should be carefully considered and followed up.

With L4 automation no speeding was assumed, and headways would become shorter (mode of headway). Consequently, the efficiency of the traffic flow will increase, and driving become smoother. Regarding changes in mean speed and following distances, there should not be any new or significant safety problems as long as the technologies are reliable and support available. A well-functioning automated road transport system could tolerate higher speeds without safety problems. However, some problems may evolve due to behavioural adaptation; the drivers get used to smaller safety margins and behave accordingly also when driving manually. It is crucial that the user interfaces will effectively support AA and recognition of non-automated phases in driving (also stressed e.g. by Banks et al., 2018). Anyway, automation and especially L4 automation is expected to improve road safety considerably.

The experience of risk is going to change. How it will change is difficult to anticipate and depends on the nature of the drawbacks and crashes with automated vehicles. It may be that disturbances and crashes are experienced more seldom, but the consequences could be very harmful and severe. The nature of incidents will influence the experienced probability of disturbances.

4.5 Role of theories

All the selected theoretical approaches contributed to defining the major human issues. The number of issues identified was somewhat larger for information processing and core task analyses than motivational driver behaviour theories. However, all theories have their own value, and the different models exposed different aspects.

We made a rough quantitative estimate of how much (i.e. how many individual statements) each theoretical approach contributed to the main topics of the issues (Table 10).

Table 11. Comparison of theoretical approaches (number of issues indicated in shades of grey: dark = high number…light = low number).

Approach	**MOT**	**INF**	**CTA**
Strategic decisions			
Role of information and skills			
Communication			
Road safety			

All approaches provided the most insight on the topic of traffic safety. Motivational theories have the advantage that they discuss measures such as speed and driving distances, which are also basic concepts of traffic flow and traffic technology. They clearly indicate that the driver tends to have too high a speed due to the low or minor subjective risk. Moreover, the increase in mean speed is exponentially linked with more fatal and injury accidents (Elvik et al., 2019; Nilsson, 2004). The evidence regarding mean speed and safety is based on the current type of transport system with manual driving, and one could assume that the system will remain quite similar in this respect for decades, even if automated systems are emerging. However, in the future, when automated driving is more ubiquitous and applied extensively, these laws may no longer be valid. Updates and new concepts to describe the quality of the system will be looked for. Motivational theories highlight the importance of behavioural adaptation, according to which behaviour is adapted to the acceptable risk level (Fuller, 2005). The driver of an automated car, however, would no longer have that many possibilities to adapt their behaviour. It is also assumed that the level of tolerated risk will be reduced, but drivers are probably going to recognise new risks related to automation and make avoidance responses to these as well.

The view of the information processing approach presents concepts like capacity, SA and workload as relevant for traffic safety. There are some commonalities with the core task analyses, even if the models also substantially differ from each other. In the literature on automated driving, SA and workload have been directly linked to traffic safety; for example, according to de Winter et al. (De Winter et al., 2014 p.197), there are "two most important Human Factors constructs that are predictive for performance and safety." SA and workload were the key elements also in psychological models proposed for automated driving (Heikoop, 2018; Stanton & Young, 2000; Varotto, 2018). These concepts seem to have relevance for traffic safety also in our analysis. However, the measures themselves (de Winter, Eisma, Cabrall, Hancock, & Stanton, 2018; Wickens, 2008) and the nature of the relationship with safety in road transport are not that clear: What would be the needed level of SA from a traffic safety perspective? How can the use of time in automated cars be optimised? What would be the optimal level of workload (vs. mental underload, Solís-Marcos et al., 2017)? It is noted that many empirical studies in driving simulators focus on the issue of how to maintain SA in automated driving, and what the realistic takeover times are with L2 and L3 automation (e.g., Merat & De Waard, 2014; Zhang et al., 2019).

All the theoretical approaches raised issues related to strategic decisions. Driving as an activity will change radically with high automation, which may bring a fundamental change to what the car represents for a human. Based on motivational theories the change is seen as inevitable; however, how it will be seen in the way cars are used is hard to anticipate. CTA emphasises trust in automation, which is assumed to be one of the key factors affecting acceptance and use of automated driving functionalities, as discussed previously by e.g. Kyriakidis et al. (Kyriakidis et al., 2017). Possibly, increased use of own cars will be a major issue when designing future transport systems. How drivers specify routes may also change and give room for traffic management activities to support alternative, more sustainable choices.

The CTA approach highlights the importance of knowledge and skills. Information is needed to maintain SA and improve AA. Understanding the limits of high automation is critical; a wrong mental model of automation may be confusing and cause incidents. The role of information on many levels was recognised as a specific design task. The approach also encourages revisiting the unit of analysis: studying the whole system where the driver and individual vehicle are part of a complex transport system. The core-task approach discusses functions like "interpreting" and "reorienting" to managed uncertainty or "mastering of concepts and comprehending the whole" when driving in intersections. CTA has been closely linked with the design of work environments – to increase comfort and enhance the prioritisation of tasks.

Communication between parties is emphasised in automated road transport. This element was brought up by the CTA but not much in the other two theoretical approaches. Interaction between parties is typical for road traffic, and it is needed not least from an efficiency and capacity point of view (e.g. Bellet, in Kyriakidis et al., 2017). The traditional driver behaviour theories appear as quite individualistic. Also examples from aviation are in many cases not applicable, as the element of communication is missing. The CTA explicitly discusses collaboration aspects, which can be a topic for further research. Recently, game theory has been studied as a possible approach to studying communication and negotiation in lane changing (Yu, Tseng, & Langari, 2018; Zimmermann et al., 2018). The ongoing tendency to deploy cooperative and connected services in road transport (European Commission, 2016) stresses the importance of communication between the parties. Based on our analysis, automated driving could benefit from C-ITS in many ways: not only to support efficiency of traffic flow by enhancing shortening of headways, but also in building a better SA.

The analyses focused on driver behaviour in the light of driver and operator theories. Changes in driver behaviour due to automation are interesting as such, but more importantly they are linked to changes in road safety, efficiency of traffic flow and sustainability of the transport system. Changes in driver behaviour result in changes throughout the transport system or even more widely in the society. Milakis et al. (Milakis et al., 2017) have suggested a triple model for analysing these mechanisms. We compared our findings with the framework of nine impact mechanisms of intelligent transport systems on road safety (Kulmala, 2010). The approach has recently been applied in automated driving (Innamaa et al., 2018). It seems that our analyses best cover the direct effects on traffic safety and personal mobility, and indirect effects on traffic safety. When it comes to other indirect effects, the analyses covered to some degree impacts on non-users and choices of mode of travel. Less covered areas were effects on exposure and crash consequences. Regarding impact areas, efficiency and environmental effects were not much affected. All these create a need for further analyses.

Automation influences human behaviour as a whole, and not only in the tasks it is designed for and which it eases remarkably. The driver gets used to automation, and challenging non-automated tasks (such as merging onto or leaving a motorway and parking) can be experienced as even more challenging, not to mention the moment of shift from automated to manual driving.

5. Concluding remarks

A list of human issues was discussed, many of which have been raised and deliberated in the literature before. However, theoretical models provide a context for individual topics. They bring relevant and useful insight into the findings and increased in-depth understanding of the issues as part of a more holistic picture. It is seen as highly valuable for decision-making to give interpretation to individual findings. The list of identified human issues also gives insight into research questions which should be addressed in future studies, for example in field tests.

All the approaches were useful in identifying the topics, and together provided quite a versatile picture of human issues. Human behaviour as driver and traveller is in a process of change. Existing theoretical views do not have the power to describe or explain it, especially in relation to high automation. In fact, the aim of automation is to rule out some critical features of human behaviour that were central to driver behaviour theories describing manual driving. Consequently, an appropriate theoretical framework would be needed for the human actor's behaviour in relation to an automated road transport system, which would identify the critical elements and their internal relationships in a structured way.

Examples of individual topics to be covered better are communication between parties in traffic, education, and information delivery to drivers and other participants in road traffic. Several system-level critical aspects of road transport were not well addressed, because the analysis focused on individual travellers and drivers. The perspective of an individual driver seems, however, to be too limited. The CTA, having automation as one of its key elements and not previously applied to road transport, showed to be a promising model and should be further analysed and applied to this context. An advantage of this model seems to be that it discusses human action as part of the system (work environment and its constructs). It would be important to learn all we can from other domains such as work activities and aviation. These lessons learned can best be utilised only if given a multidisciplinary approach with a fundamental understanding and knowledge of the human as driver or traveller and road transport as a dynamic system.

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Title	**Exploring Driver and Operator Behaviour Models in the Context of Automated Driving** Identification of Issues from a Human Actor Perspective
Author(s)	Pirkko Rämä & Hanna Koskinen
Abstract	The study aimed to systematically determine key human issues related to automated driving by utilising selected theoretical approaches applied in road traffic and work environments. The aim was also to compare the descriptive power of theoretical approaches to automated driving. Three approaches were applied to partial and high automation scenarios: (1) motivational theories, (2) model for the human as an information processor, and (3) core-task analysis. A descriptive analysis using the terms of theoretical approaches was conducted for automated driving in the contexts of urban and highway driving. In all, the qualitative data provided encompassed 13 subtasks of a trip made by car (e.g. choosing the route, entering a highway, driving in an urban intersection) in several contextual circumstances (traffic situation, environment, weather etc.). The study resulted in a list of 20 human issues related to automated driving. The issues were categorised in four groups highlighting the common aspects identified. These were: strategic decisions related to personal mobility; road safety; the role of information in automated driving; and communication and interaction in traffic. Each theoretical approach appeared useful in defining the issues, and the views were found to complement each other. Increasing automation in road transport calls for reforming the theoretical background and developing new models. The core-task analysis, not earlier applied in road transport, emerged as a promising model and is suggested to be applied in more detailed analysis of automated driving, specifically regarding information and communication aspects.
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Nimeke	**Kuljettajan ja operaattorin käyttäytymistä kuvaavien mallien soveltaminen automaattiajamiseen** Keskeisten kysymysten tunnistaminen ihmisen toiminnan näkökulmasta
Tekijä(t)	Pirkko Rämä & Hanna Koskinen
Tiivistelmä	Tutkimuksen tavoitteena oli määritellä keskeiset automaattiajamiseen liittyvät inhimillisen toiminnan kysymykset hyödyntäen systemaattisesti kolmea valittua teoreettista mallia tai lähestymistapaa, joita on sovellettu liikenteen ja työtoiminnan tutkimuksessa ja kehittämisessä. Tavoitteena oli myös verrata ja arvioida, miten hyviä nämä teoriat ovat kuvaamaan ja selittämään automaattiajamisen keskeisiä kysymyksiä. Työssä tarkastellut lähestymistavat olivat (1) kuljettajakäyttäytymisen motivaatio teoriat, (2) malli ihmisestä informaation prosessoijana, (3) perustehtäväanalyysi. Tarkastelun kohteena olivat osittaisen automaation ja korkean tason automaattiajamisen skenaariot. Automaattiajamisesta laadittiin kuvaukset kaupunki- ja moottoritieympäristössä käyttäen vuorollaan kunkin lähestymistavan termistöä ja ajattelutapaa. Tätä laadullista analyysia varten automatka jaettiin 13 osatehtävään esimerkiksi reitin valinta, moottoritielle liittyminen, ajaminen kaupunkiristeyksessä), jotka saattoivat toteutua useassa eri olosuhteessa tai tilanteessa (esimerkiksi pieni tai suuri liikennemäärä, hyvä tai huono sää, erikoistilanne/onnettomuus tai normaalitilanne). Tutkimuksen tuloksena listattiin 20 automaattiajamisen inhimillisen toiminnan kysymystä, jotka luokiteltiin neljään luokkaan keskeisen sisältönsä perusteella. Neljä sisältöluokkaa olivat: henkilön liikkumisen strategiset päätökset; liikenteen turvallisuus; informaation merkitys automaattiajamisessa; kommunikointi ja vuorovaikutus liikenteessä. Kaikki teoreettiset lähtökohdat olivat hyödyllisiä inhimillisten kysymysten tunnistamisessa ja osoittautui, että näkökulmat täydentävät toisiaan. Tieliikenteen automaation lisääntyminen näyttää myös luovan tarvetta uudistaa teoriaperustaa ja kehittää uusia malleja. Perustehtäväanalyysia ei oltu aiemmin sovellettu tieliikenteeseen. Perustehtävä malli osoittautui lupaavaksi lähestymistavaksi ja sitä ehdotetaan sovellettavan jatkossa automaattiajamiseen, erityisesti informaation ja kommunikaation yksityiskohtaiseen tarkasteluun.
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Exploring Driver and Operator Behaviour Models in the Context of Automated Driving
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The study aimed to systematically determine key human issues related to automated driving by utilising selected theoretical approaches applied in road traffic and work environments. The aim was also to compare the descriptive power of theoretical approaches to automated driving. Three approaches were applied to partial and high automation scenarios: (1) motivational theories, (2) model for the human as an information processor, and (3) core-task analysis. A descriptive analysis using the terms of theoretical approaches was conducted for automated driving in the contexts of urban and highway driving. In all, the qualitative data provided encompassed 13 subtasks of a trip made by car (e.g. choosing the route, entering a highway, driving in an urban intersection) in several contextual circumstances (traffic situation, environment, weather etc.). The study resulted in a list of 20 human issues related to automated driving. The issues were categorised in four groups highlighting the common aspects identified. These were: strategic decisions related to personal mobility; road safety; the role of information in automated driving; and communication and interaction in traffic. Each theoretical approach appeared useful in defining the issues, and the views were found to complement each other. Increasing automation in road transport calls for reforming the theoretical background and developing new models. The core-task analysis, not earlier applied in road transport, emerged as a promising model and is suggested to be applied in more detailed analysis of automated driving, specifically regarding information and communication aspects.

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