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In the middle of the Loop

Adjusted-ECOM – An in-the-loop measurement model used for highly automated road vehicles

Master of Science Thesis in the Master Degree Program, Industrial Design Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenborg, Sweden 2015

Department of Product- and Production Development
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Abstract

Methods for how to keep the driver in-the-loop in highly automated vehicles is a research area that gets more and more attention while cars, trucks etc. are evolving to more complex vehicles that can operate on a higher level of automation. However a generally accepted and used measuring and validating method to determine whether a driver is in- or out-of-the-loop is not developed yet. The purpose of this thesis was to propose a theoretical model, with the aim to provide a structured way to test and analyse in-the-loop concepts. This model is called Adjusted-ECOM.

The Adjusted-ECOM is built upon the original Extended Control Model and uses the same structure of four concurrent control layers that divides the strategic and dynamic driving tasks. The Adjusted-ECOM is adapted to a Driver-Vehicle System where the tasks of the control layers can be shared between two entities within the system. The model does this by claiming the Driver-Vehicle System functions as a heterogeneous Multi-agent system where two agents, the human and the automation-system collaborate to achieve common goals and individual tasks. The SAE International’s new standard J3016, which is also used in the Adjusted-ECOM, determines which driving-tasks are assigned to the agents in the different levels of automation. The Adjusted-ECOM indicates which inputs and outputs the different driving-tasks have. If an agent cannot provide inputs to the driving-tasks that agent, and consequently the whole Driver-Vehicle System, is out-of-the-loop. The approach to divide the Extended Control Model´s control-layers between levels of automation with help of the theory of Multi-agent system is not unique and it has been tested before. But it has not been adapted to road vehicles neither to their levels of automation. This is what the Adjusted-ECOM tries to achieve.

The benefits of the Adjusted-ECOM have been proven with help of a truck simulator study where the participants were professional truck drivers. The Adjusted-ECOM was able to specify when and why the participants were out-of-the-loop by referring to the specific tasks according to the Adjusted-ECOMs different control layers.

The thesis work also reveals a concept function, called the Armed State which provides a safer and easier way of transition between different levels of automation. It does this by helping the Driver-Vehicle System to stay in-the-loop in the higher control-layers of the Adjusted-ECOM. The concept alters the relation between human and machine by changing the activation point of the automation system. According to a pre-set value the Armed State either can inform the driver about a possible transition or initiate the transition itself, depending on the Armed State function uses the automated or manual switching feature. The effect and usefulness of the concept and its features can be seen in all types of traffic situation but the Armed State is more aiding in dense traffic, for instance driving in queue, than driving on an empty highway. The benefits of the Armed State are more safety oriented and don´t provide a significant improvement in fuel consumption or financial benefits.

Keywords: automated driving, vehicle automation, level of automation, in the loop measurement, multi agent system, driver vehicle system, mode transitions

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NOMENCLATURE

Abbreviations

ACC	Advanced Cruise Control
ASA	Automated System Agent
BHC	British Highway Code
DIL	Driver-in-the-Loop
DOOL	Driver-out-of-the-Loop
DVS	Driver-Vehicle System
HA	Human Agent
HMI	Human Machine Interface
HWT	Headway Time
LKA	Lane Keeping Assist
LoA	Levels of Automation
RQ	Research Question
V2X	Vehicle-to-Vehicle & Vehicle-to-Infrastructure

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1 INTRODUCTION

1.1 Background

The project carried out at the Volvo Technology AB and focuses on the future´s highly automated truck. In order to reduce accidents and provide increased comfort for the drivers vehicle manufacturers offer more and more advanced driver assistance systems. The technology that enables automation for different driving tasks is under development. Currently, adaptive cruise control, lateral steering support, automatic braking, parking assistance etc. are available on the market. Higher degree of automation of the driving tasks can be one solution for reducing accidents as well as for creating more efficient use of lanes, improve fuel efficiency, etc. However, to implement a higher degree of automation in a truck raises many difficulties from a human factors perspective. The driving environment is neither static, predictable nor a priori controllable. The more advanced an automated control system is, the more crucial can be the assistance of the human operator (Bainbridge, 1983).

The thesis work is dedicated to automated road vehicles in a highway traffic environment. Road vehicles can operate on different levels of automation (LoA) and these levels can be distinguished based on the automation´s capability of maintaining driving tasks. The complexity of driving tasks performed by the automated system and the human driver differ between these levels. This project addressed to LoA in road vehicles.

The project focuses on Driver in the Loop (DIL) and how to keep the driver in the loop while controlling a highly automated vehicle. There are many reports and studies about DIL some of them focuses on keeping the driver in the loop e.g. (Chiang , et al., 2010), (Li, et al., 2013) & (Saffarian, et al., 2012). Other ones revolve around how to take the driver back into the loop e.g. (Lorenz, et al., 2014), (Bernd, 2001) & (Gold, et al., 2013). There are also existing guides regarding how to design interfaces to keeping the driver in the loop (IHRA, 2011).

1.2 Research Questions

There are reports that discuss the phenomena “driver-in-the-loop” and there are existing interface concepts claiming that they are good in keeping the driver-in-the-loop. However none of these provide a measurement technique, formula or model that can answer what to measure and how to validate an in-the-loop concept. Without validating a concept it is hard to know if the concept is good or not. This gap in the understanding of DIL leads to the following Research Questions (RQs):

RQ1: *How could DIL be measured in a highly automated road vehicle system?*

RQ2: *How could a new Human-Machine-Interface (HMI) be designed to help the driver stay in-the-loop?*

1.3 Aim

The aim of this thesis work is to create an HMI concept that helps the driver to be more in-the-loop. The concept needs to be able to handle different LoA in a highway traffic situation. To be able to verify and compare the concept the research questions (RQs) needs to be answered.

1.4 Goals

DIL is relevant with regard to traffic safety and driver behaviour. Limitation regarding current and future driver assistance systems could be found with help of a deeper understanding of the DIL phenomenon. This will help the development of new and further development of existing driver assistance systems. The new enhanced system may, in addition to enhanced safety, create financial and environmental benefits for road vehicles.

1.5 Delimitations

The thesis is delimited to Driver-Vehicle Systems (DVSs) that are using different automation modes while driving on highways. The use-case used in the thesis regards a truck that needs to handle highway traffic-jams and switches between automation modes. This will be simulated in a truck simulator provided by Volvo Technology AB, which will be used as the primary validation tool. The most crucial limitation of the simulator is that it only can be used for restricted time for each participant thus it will be hard to compare with real case scenarios where the available time is much longer.

1.6 Report structure

The current thesis report follows a regular academic report structure that contains a Theoretical framework, Methods, Process, Result, Analysis, Discussion, Conclusion, Recommendations and Future work. The thesis work addresses two subjects that both needs separate Result and Analysis sections. The outcomes of the analyses are commented in a shared Discussion section.

2 THEORETICAL FRAMEWORK

The Theoretical framework is a summary of the existing knowledge and previously performed research on the subject. This chapter presents the theoretical reference frame, which is necessary for the future research, model and concept development.

2.1 Automation

Automation in the area of vehicles refers to a way of transport where the operation inputs are not directly controlled by a human driver and the human driver is not expected to constantly monitor the surroundings while the vehicle operates in self-driving mode (NHTSA, 2013). Automated driving vehicles exist for quite some time with the autopilot for the aviation industry as a leading example. But the concept of fully self-driving road vehicles is not a reality in writing moment. The technological developments in the area will make it possible to create a self-driving road vehicle in a foreseeable future (ERTRAC, 2010). There are several reasons for pursuing the goal of a self-driving road vehicle. Increase comfort and safety (Mulder, et al., 2012) are two reasons that are more valuable for the driver while fuel efficiency (Merat & Lee, 2012) is good for delivery companies, and road optimization is beneficial from an infrastructural point of view. The automation of road vehicles could even alter the way of building roads and other infrastructure elements with regard to the flexibility of a self-driven vehicle (van Schijndel-de Nooij, et al., 2010).

2.1.1 Technology

Automated road vehicles are becoming a reality with help of the collaboration between varieties of sensors that operate within the vehicles. These sensors scan the environment and read the status of the vehicle. The vehicle´s computers interpret the input from the sensors and adapt the vehicle´s performance according to them. A human driver communicates and operates the vehicle via the on-board HMI. The flow of information from the environment through the sensors to the human driver is illustrated in figure 1.

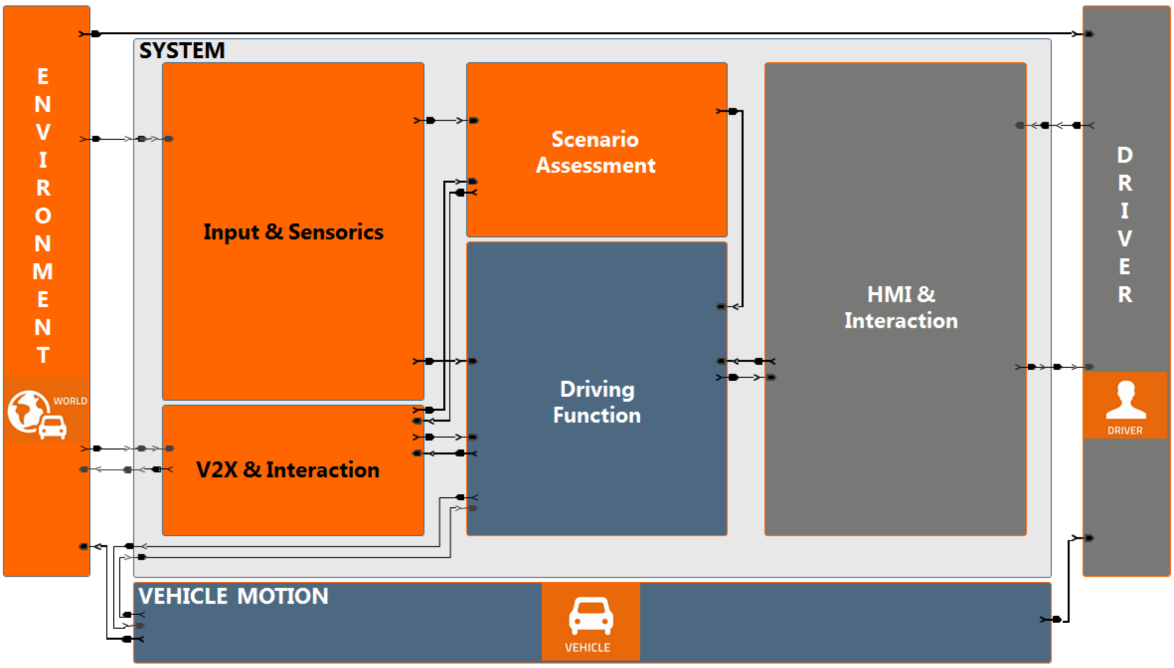


Figure 1: The flow of information in a technologically advanced road vehicle (European Council for Automotive R&D EUCAR, 2014)

The information from the environment is transferred to the driver through a system of connected computers, the motion of the vehicles or by the environment itself. The system uses the HMI to inform the driver about the in- and outputs of the vehicle´s system and its surroundings. The vehicle also interacts with other vehicles and road entities with help of the Vehicle-to-Vehicle and Vehicle-to-Infrastructure connection (V2X). By introducing V2X driving becomes safer and more comfortable for the drivers and at the same time facilitates a better road transport network by reducing conjunction and promoting a more efficient use of infrastructure (Merat & Lee, 2012).

2.1.2 Sensors

Sensors are vastly used in the development of automated road vehicles (Conner, 2011). Several different sensors collaborate to create a perceivable image of the surroundings of the vehicle. The sensors have different reachability and areas of expertise and can be divided into four different kinds, Ultrasonic, Camera, Radar and LiDAR (Armstrong, 2014), see figure 2.

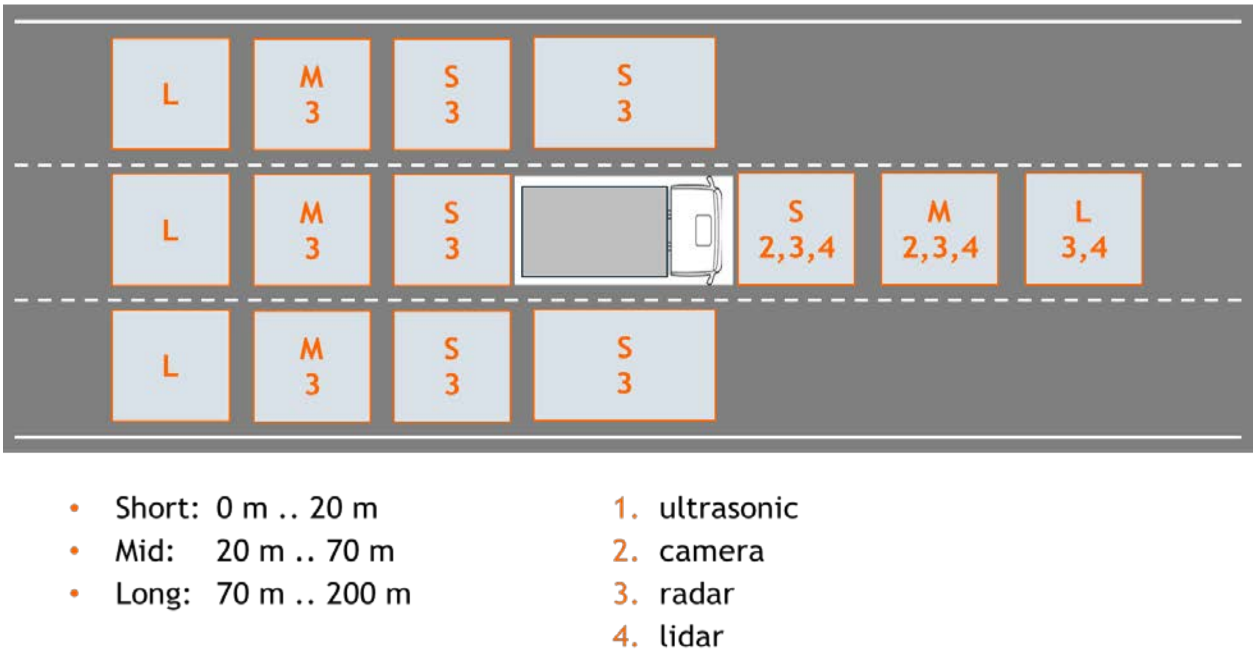


Figure 2: Types of sensors and their reachability in an automated road vehicle (European Council for Automotive R&D EUCAR, 2014)

The sensors are mostly focusing on oncoming obstacles ahead where the danger usually approaches the fastest. All the sensors are therefore scanning the area in front of the vehicle and only one is used to scan towards the back and the sides. The most used sensor is the radar which is used all-around the vehicle. The radar sensor uses pulses of radio waves and measures how the waves are reflected from objects back to the sensor (Oxford University, 2010). This technique makes it possible to measure the direction, distance and speed of objects. The second most used sensor the LiDAR (Light Detection and Ranging) uses the same technique as radar but instead of radio waves it uses laser light pulses. These types of sensors are more appreciated in the engineering communities because they permit the development of precise, realistic, three-dimensional representations. It can do so by producing high measure point density with extremely high accuracies (Carter, et al., 2012). The cameras used in an automated road vehicle are aiming to position the vehicle with respect to the lanes the vehicle is currently driving in. The computers analyse the images taken by the cameras and with help of special design algorithms define the correct path for the vehicle (Bellino, et al., 2005). The last input device is the Ultrasonic sensor, which transmits sound waves and calculates the distance of objects by measuring the time difference between the transmutation and the echo of the transmutation (Sinha, et al., 2013). The ultrasonic sensors are used in a close proximity of the vehicle and measure distance to objects less than 10 meters around the vehicle. The short distance depends on the attenuation of ultrasound in air which is significantly affected by conditions of the atmosphere, in particular turbulences caused by wind and vehicle movement (Alonso, et al., 2011). Theses drawbacks cause the ultrasonic sensors to be reduced to close quarter slow speed usage, like parking aid systems. But the ultrasonic sensors are simpler and much cheaper than the other systems which make them beneficial.

2.2 Driver-in-the-loop

What is a “loop” and what is the person’s role in-the-loop is a question that is indistinct and the answer depends on the area that is investigated. The concept of “Human-in-the-loop” is often used in the area of simulations. A Real-Time Human-in-the-Loop simulation is used to get valuable insight into the impact of new automation and controller tools (Sollenberger, et al., 2005). This approach has been used in development processes in many kinds of industries, in an air traffic control room (Sollenberger & Hale, 2011), power plant (Roth, et al., 2010), marine infra-structure (Bronaugh, 2011), construction vehicle (Kleer, et al., 2014), space missions (Smets, et al., 2010) and by the military (Crone, et al., 2007) to mention some. The Human-in-the-loop simulations are used because they crate the opportunity to explore realistic human system behavior thus makes it possible to identify problems and new requirements much more rapidly. Human-in-the-loop simulation is a well-known term used in many industries, but it´s not used when discussions revolve around if the human is in- or out-of-the-loop. During a Human-in-the-loop simulation measures are taken regarding the human workload or situation awareness and not if the human is in- or out-of-the-loop (Williams, et al., 2014). Even if the Human-in-the-loop simulation and the reports written regarding the subject don´t generate a deeper understanding of what it means to be in- or out-of-the-loop it’s important to mention them in this context. Most of the literature regarding in-the-loop revolves around Human-in-the-loop simulations making the vast majority of the findings almost useless.

The European project Automated Driving Applications and Technologies for Intelligent Vehicles (AdaptIVe) uses a definition to describe being in- or out-of-the loop with respect to road vehicles and automation, which has been put forward by the International Harmonized Research Activities (IHRA). The AdaptIVe project asks questions like: *How long does it take for drivers to get out-of-the-loop?; What are the safe mechanisms for keeping drivers-in-the-loop?; How can we simulate the feeling of being 'totally out-of-the-loop*?' etc (European Council for Automotive R&D EUCAR, 2014). The IHRA explains how the human (driver) can be in-the-loop by referring to the humans’ awareness and involvement in the DVS. Another approach is provided by former US Air Force Colonel John Boyd who developed a model for decision-making in air combat that aims to give the pilots a competitive advantage against their enemies (Boyd, 1976). The model does this by making it possible for the pilots to assess the situation better and faster than the opponent by supporting quick, effective and proactive decision-making (Mind Tools, u.d.). The model is called Observe, Orient, Decide, Act (OODA) Loop. The outline of the OODA-Loop is a four-point decision loop where the four stages are:

1. Observe - collect current information using as many sources as practically possible.
2. Orient - analyze the information, and use it to update the current reality.
3. Decide - determine a course of action.
4. Act - follow through on the decision.

The OODA-Loop is continuous and from observation of the actions it is possible to realize if the intended result is achieved see figure 3. If the result is compatible with the initial goals it is possible to move on to the next action. The OODA-Loop creates the possibility to maintain awareness, and proactivity in a rapidly changing world (Mind Tools, u.d.).

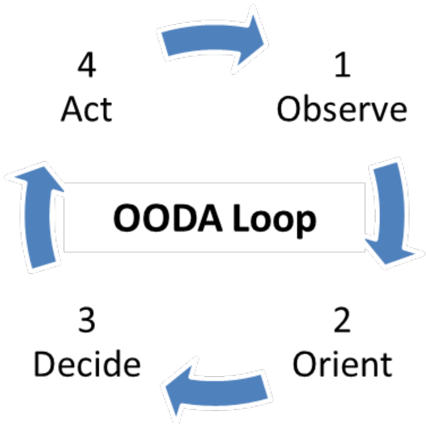


Figure 3: The operation of the OODA-Loop

The methodology behind the OODA-Loop is related to how to operate a vehicle and how the driver of the vehicle supposed to handle the change of the surrounding environment with relations to the driver´s overall goals. The general idea about a continuous loop, which is divided into different sections, seems related to the notion of being in-the-loop according to IHRA, where in the loop is a continuous cycle made up by many different aspects.

In this project the definition of driver in- and out-of-the-loop presented by IHRA is used. The reasoning behind this is that the IHRA definition is internationally used in big research projects related to road vehicles and automation.

2.2.1 Driver-in-the-loop

The description of DIL according to the IHRA is:

> *"The notion driver-in-the-loop means that a driver is involved in the driving task and is aware of the vehicle status and road traffic situation. Being in-the-loop means that the driver plays an active role in the driver-vehicle system".* (IHRA, 2011)

Within the current project the DIL is interpreted as a state when the driver is involved in the driving task and plays an active role in the DVS.

The investigation regarding if a driver is in-the-loop in this project revolves around what the driving tasks are and what role the driver has in the DVS. The driving tasks are described by the required inputs to the DVS that need to be completed. The role of the driver is explained by defining which inputs the driver is supposed to manage.

2.2.2 Driver-out-of-the-loop

The IHRA also describes the DOOL as:

> *"Out-of-loop performance means that the driver is not immediately aware of the vehicle and the road traffic situation because they are not actively monitoring, making decisions or providing input to the driving task."* (IHRA, 2011)

In this project the description of DOOL is interpreted as a state when the driver is not actively providing input to the driving task. By doing so the driving tasks are not completed as they should.

2.3 Multi-agent system

Applying the theory of Multi-agent system to the current project is plausible since it provides a general understanding regarding the collaboration between different entities within a system. The aspect of the Multi-agent system leads to deeper investigation of the driving tasks and divides them up between the human and the automation system.

According to Barber & McKay (1998) a Multi-agent system can be seen as a group of entities collaborating to achieve either individual or common goals. Schreckenghost et al. 2002 describes the Multi-agent systems as a cooperative system with human and software agents where the software agent controls the system and performs other complex tasks mostly autonomously. Multi-agent systems require adaptability to perform in complex and dynamic environments (Barber, et al., 2000), like driving a road vehicle on a highway. To adjust the theory of the Multi-agent system to the current case when a road vehicle operates in higher LoA the DVS needs to be defined.

2.4 Extended Control Model

The Extended Control Model (ECOM) provides a framework for analysing the vehicle-driver interaction in relation to goals on multiple control-layers. ECOM has been successfully used for building up a logical model of human intentions that maps the perceptions and possible future actions (Windridge, et al., 2013). With other words the ECOM can predict the drivers' actions by modelling the drivers' intentions. The ECOM has been used for modelling car drivers during many road vehicle driver investigations (Windridge, et al., 2013b; Renner & Johansson, 2006; Shaukat, et al., u.d.; Windridge, et al., 2013a). Relied on this it is assumed that the ECOM model is validated and can be the basis of this project work as well.

The ECOM is a hierarchical perception-action model that describes a joint cognitive system. The joint cognitive system involves four different but concurrent control-layers that are connected to each other (Tracking, Regulating, Monitoring and Targeting) (Hollnagel, 2015). As with the OODA-Loop the system in the ECOM can be characterised by its ability of maintaining control under varying conditions. The ECOM describes the performance of the joint system by the four control-layers. In terms of the model, the four control-layers ensure that key performance parameters are kept within desired ranges, and that the progress of the location of the vehicle relative to the overall goal is tracked, see figure 4, (Windridge, et al., 2013b)

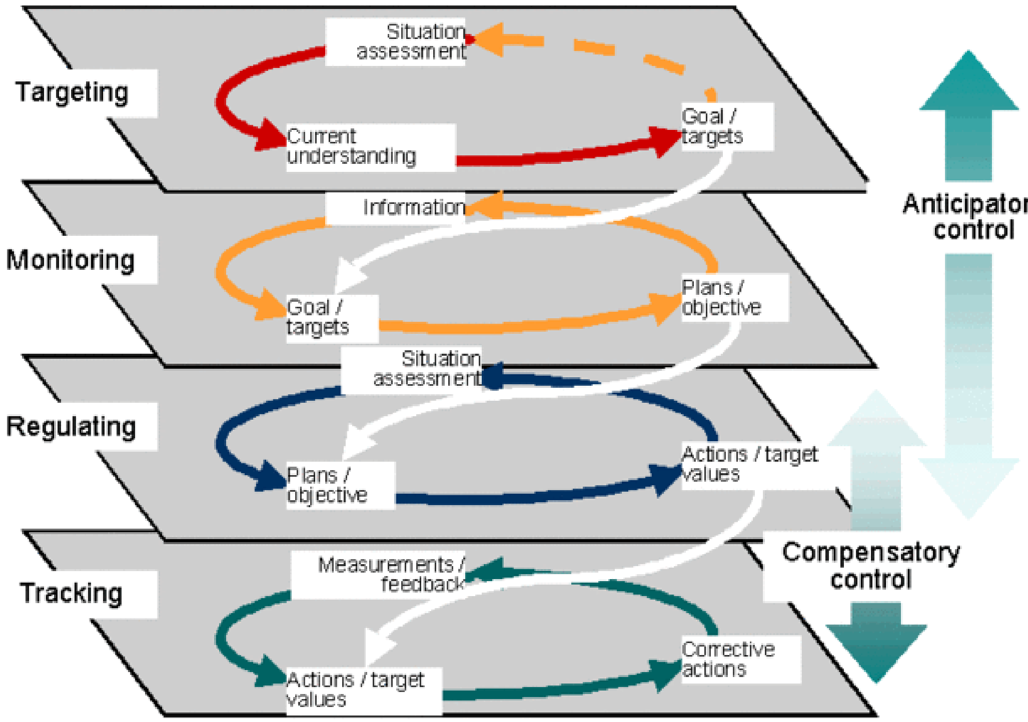


Figure 4: The Extended Control Model *(Hollnagel, 2015)*

TRACKING CONTROL-LAYER

Tracking can be defined as *"the response of an operator or control system intended to nullify the effects of some external disturbance"* (Hollnagel, 2015). In the driving situation, the tracking control refers to the momentary, automated corrections to disturbances, e.g. wind gusts (Cacciabue, 2007). Maintaining the intended speed, the lateral position on the road, etc. belongs to the Tracking control-layer (Hollnagel, 2015). These activities require criteria and/or target values that are derived from the Regulating control-layer.

REGULATING CONTROL-LAYER

The Regulating control directs tracking control by providing input to it (actions and target values). In driving, regulating activities are concerned with keeping desired safety margins to other traffic elements, avoiding obstacles and changing position relative to other cars (e.g., overtaking), etc (Hollnagel, 2015).

MONITORING CONTROL-LAYER

Activities at the layer of Monitoring are mainly concerned with setting objectives and activating plans for actions. This can involve monitoring the condition of the vehicle and the location of the vehicle. Whereas position refers to the vehicles relative position to other traffic elements, location refers to the vehicle position to the features of the environment, specifically the intended destination (Hollnagel, 2015).

TARGETING CONTROL-LAYER

The last control type is at the layer of Targeting where goals and targets are set. An obvious kind of target-setting is with regard to destination. Goal related settings have to do with driving performance criteria. For instance, if a user apprehends that s/he will arrive late to the destination, it may lead to a revision of the criteria for the other layers, notably Regulating and Tracking. If time is short, the style of driving may be changed by increasing the speed, reducing the following distance and in general take greater risks (Hollnagel, 2015).

2.4.1 In- and outputs

The different control layers have different in- and outputs to consider according to what kind of system the ECOM is operating in. Figure 4 shows what kind of in-and outputs the different layers have according to a road vehicle system.

2.5 Level of automation

LoA is used to determine the way of collaboration between the different entities of the DVS and what roles they have within the system. The SAE International’s new standard J3016 (SAE, 2014) is adapted for road vehicles and has been used in previous international research projects. The standard should be able to determine this because it’s developed for *“clarifying for each level what role (if any) drivers have in performing the dynamic driving task while a driving automation system is engaged*” (SAE, 2014). Using LoA to divide up the control layers of the ECOM has been done by vehicle researchers before (Taylor, 2003). It´s therefore assumed that it should be possible to use LoA to divide up the ECOM control-layers for road vehicles as well.

LoA is a term that is commonly used in the field of automation and automated vehicles. LoA defines in which degree the human and the computer is involved in the control of a complex system (Kaber & Endsley, 1999). The LoA refers to the tasks and the interaction between the tasks that the human and computer are doing to maintain a good performance (Kaber & Endsley, 2004). Different researchers and industries use different LoA models whereas these models can vary between three to ten levels. In the field of automated road vehicles there are two different LoA standards under discussion. The J3016 standard uses a model with six levels and the American National Highway Traffic Safety Administration standard (NHTSA, 2013) which uses five levels. The difference between these two standards is that the J3016 standard separates high automation level from full automation while the NHTSA combines them into one. The focus during this project is the J3016 standards illustrated in figure 5.

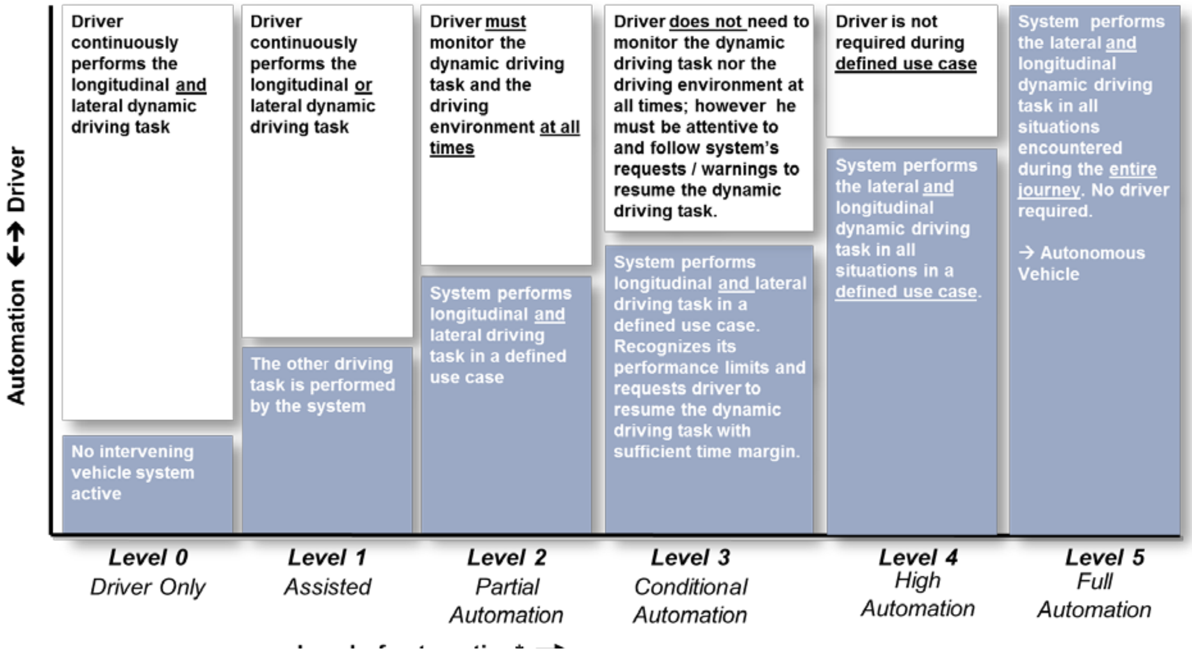


Figure 5: The six levels of automation of the SAE International's new standard J3016

The J3016 standards six levels of automation are: Driver Only (0), Assisted (1), Partial Automation (2), Conditional Automation (3), High Automation (4), Full Automation (5). It is important to mention that the J3016 standard doesn't include warning and momentary intervention systems, like collision warning and minimum risk manoeuvre. It´s because of these kinds of systems do not change the humans' role regarding the dynamic driving tasks. The dynamic driving-tasks are the tasks associated with regular vehicle handle which includes the operational (steering, braking, accelerating, monitoring the vehicle and roadway) and tactical (responding to events, determining when to change lanes, turn, use signals, etc.) aspects of driving (SAE, 2014). The dynamic driving tasks don´t include the strategic aspects (determine destinations and waypoints) of the driving.

2.5.1 Modes

A device, such as a machine or a system, can behave in various ways and each behaviour pattern is defined by the device´s inputs, outputs and stat as a function of time (Degani & Kirlik, 1995). All complex systems that can perform a variety of functions have modes, the more function the more modes (Norman, 1983). These modes will define the state of the system and determine the inputs and outputs. In this project the modes are referred to different LoA the DVS is operating on. The LoA define the inputs and outputs for the DVS and it describe the state by deciding in which degree the human and the computer is involved in the DVS. When switches between the LoA occur the involvement of the human and the computer in the DVS will change. This means that the responsibility towards the inputs and outputs will change between the human and the computer.

The following section gives an insight into the used methods that have been used throughout the thesis work. It is to demonstrate how methods informed the research and the design approach.

3.1 Information gathering

At the beginning of the thesis project a Pre-study section summarized the formerly performed research on the subject. Impersonal research (literature study) was performed. The theoretical reference frame was presented in the Pre-study that played an important role in providing a better understanding of the aim and purpose and the core of the problem area. The Pre-study meant a basis for the subsequently performed research, the so called “Theoretical Framework”. During the information gathering the existing knowledge was completed with additional data and subjective information. Subjective information was gathered from personal research by conducting interviews and surveys. In this phase of the project the scope of the design space has been widened.

3.1.1 Interview

As personal research methods interviews and surveys have been conducted. With these methods the aim was to find out what other people think of a specific concept, service and technical area and how humans can cooperate with automated systems. The target group of the interviews was airplane pilots and instructors, because the aviation industry works with automated systems for a long time and therefore has large data and knowledge about it. Although a huge amount of information has been found in articles, books and on the Internet, the opinion of people who worked with such automated systems was to some extent different from these findings. During the interviews the complexity, ergonomic structure and way of use of the current automated system has been discussed with pilots and instructors. Previous findings have been completed with this additional information. New directions for development have been pointed out and the Ideation and Concept generation phases have been affected by the collected data.

After the analysis of the gathered data only the desirable information remained (narrowing down the scope). The research questions had been answered, which helped to point out directions for ideation and further development therefore defined the scope of the final result.

3.2 Ideation

During the Ideation phase large quantities of ideas were produced based on the results of the information gathering. Several sessions have been conducted with different ideation/design tools. The aim of using several ideation tools was to meet different approaches to the same problem area thus get inspiration from different directions. Each tool has been developed to create conceptual solution for the different stages of the ideation. The tools that have been used within the current thesis project have been divided up into two subparts ”*Use-cases*” and ”*Ideas*” that were handled simultaneously. The Use-cases subpart referred to the scenarios that provided a placement for the Ideas, while the Ideas subpart referred to the conceptual solutions themselves.

3.2.1 Use-cases

STATUSCOPE
The Statuscope has been used to get a better understanding of the content and the context of the problem and enhance the design of the solution's form. The Statuscope has been a recently developed design tool for defining design space focusing on automated vehicles (Szymaszek, 2014). The Statuscope presented a clear and well-structured approach to find and distinguishing the different use-cases. The tool has been developed during a previous master thesis at Chalmers and is not yet validated.

NINE WINDOWS
Nine windows has been described as a technique that helps to examine the innovation opportunity across the dimensions of time (past, present, future) and scale (supersystem, system, subsystem) (Silverstein, et al., 2009). The core of Nine windows is a simple grid consisting of nine fields. Identifying the problem in the centre field and filling in the remaining eight fields provides eight additional perspectives (Silverstein, et al., 2009). Using this method in the early stage of the project provided a better scope of the innovation opportunity.

3.2.2 Ideas

STATUSCOPE AND NINE WINDOWS
The use-cases have been developed simultaneously with the ideas mostly while using the same ideation method. The Statuscope and the Nine windows were useful to point out directions for development and enhance the design of an idea, function wise and shape wise. These two methods have been used to determine features and functions.

BRAINSTORMING
Brainstorming has been chosen as one of the idea generating methods because it provides a free and loose atmosphere for thinking. The ideas and the sketches created in the Brainstorming sessions have been discussed continuously thus it triggered further more ideas. Criticism was not allowed during the brainstorming sessions with regard to the limitless ideating. The quantity of ideas was more crucial than the quality.

TRIZ 40
Design principles that are based on known solutions have been provided by the Theory of Inventive Problem Solving (TRIZ) tool. TRIZ has been used to solve contradiction in technical features and improvement in one feature can result in deterioration in another feature at the same time (Silverstein, et al., 2009). This tool was selected for ideation because it provided a framework for innovative thinking and problem solving.

3.3 Evaluation I

The purpose of the evaluation was to narrow down the amount of ideas thus narrowing the scope of the project. The evaluation started with the analysis and sorting of the use-cases and the ideas to get a clear overview what has been created so far. The selection of use-cases and ideas has been carried out by group discussions and with the help of the KJ method.

3.3.1 Group discussion

Group discussion was a more open way of comparing ideas but did not provide a well-structured table form of ranking and selection. The discussions sessions have been conducted with co-workers from Volvo Trucks who had more knowledge about possible solutions and technologies for automated vehicles that already existed or were under development. Simultaneously with the group discussions the KJ method has been used to enhance the sorting and grouping of the use-cases and ideas.

3.3.2 KJ method

The KJ method has been known as an idea sorting tool that provides a way to organize and prioritize the creative ideas and achieve consensus about which ideas are worth further developing (Silverstein, et al., 2009). The KJ method is well suited with certain ideation methods like brainstorming where the quantity of the ideas was more important than the quality. The method has been designed for sorting out large amount of ideas and groups them together.

3.3.3 Iteration

Backtracking to the original aim of the project helped to keep the project in the right track. It also helped the selection of the previously organized and prioritized ideas and use-cases by determine which relate to DIL and to the original goal of the project. The remaining ideas were prepared for further development and concept generating.

3.4 Concept generation

In this part the previously selected use-cases have been combined with the ideas and the theory. The reason behind this was to create a final concept that is able to demonstrate the theory and the functions of the concept feature (ideas) in realistic use-cases. The created groups have then been further developed and have become pre-concepts.

3.4.1 Use-cases and LoA

The pre-concepts have been matched with the appropriate LoA during the concept generation phase. The inputs and outputs, that were necessary for the DVS to work properly, have been determined with the help of the newly developed model. These inputs and outputs were the basis for defining the targets of measurements in the simulation study.

The use-cases required the DVS to use a higher LoA as much as possible while driving on a highway so the entities of the DVS were able to share driving tasks with each other. But at the same time the human had to be able to respond appropriately to system requests and intervene if the system fails. This description fitted to the Level 3 of automation and because of this Level 3 was the highest LoA the DVS could operate on. The use-cases stated that the DVS couldn’t use a higher LoA when not driving on highways, approaching a queue or driving by a construction site. This meant that the DVS needed to operate on a low LoA while traveling in those conditions. To make the use-cases simpler for testing only Level 0 of automation has been used while entering and leaving the highway, approaching a queue and driving by a construction site. This implied that the human has full responsibility over all inputs at these periods. The DVS was able to operate on either Level 0 or on Level 3 of automation.

3.5 Evaluation II

During the second evaluation process a selection of the pre-concepts has been made to get a satisfying final concept suitable setting direction and core values. The selection has been carried out by group discussions with co-workers from Volvo Trucks. Group discussion is a more open way of ranking and selecting ideas, based on the original aim. The new theoretical approach has been described and discussed with the supervisors of the thesis project. The selected final concept has been further developed and detailed in the Final Concept chapter.

3.6 Final Concept

In this chapter the outcome of the second evaluation has been further developed and a final concept has been formed. The final concept was described in details, with regard to the use-cases and the functionality of the concept feature, which supposed to answer all the questions that arise during the project. The use-cases with corresponding driving tasks were matched with the used LoA. With this the driving tasks of the human and the system, creating the necessary inputs to the DVS, have been determined. The support function of the concept feature was also shown.

3.7 Simulator study

3.7.1 Preparation

Before the start of the simulator study preparations were required. What and how to measure had to be answered and defined clearly. To determine the targets of measurement the British Highway Code (BHC) has been used. This is new, frequently updated source of laws and regulations regarding driving including driving on motorways (UK Government, 2015). The British laws differ from the Swedish laws in many points, but they also contain requirements that are more general and built on general knowledge. These general requirements have been chosen for the study. Further reason why the BHC was chosen was that no other general driving regulation has been found which would have been adaptable for all the countries. Finding the right target of the measurements from the BHC and the right technique to measure it was crucial for providing the accurate data for later investigation, analysis and validation. The use-cases have been translated into a computer simulation. The recent study was combined with another study currently running at Volvo Trucks. Because of the recent study's flexibility it was manageable to combine the different use-cases and concept features into one simulation. The computer simulations have been programmed by a co-worker at Volvo ATR. Previously simulated test routes and cluster design elements has been reused as well and adjusted to current test. The cluster design/interface design was not part of the project but reusing one earlier type resulted in a more authentic and realistic simulation.

After setting the target of measurements, choosing measurement techniques and applying the program to the simulator pilot-tests were conducted. The purpose of the pilot-tests was to find out problems in the simulation that remained hidden until then. Small adjustments helped to correct all the found problems.

During the simulation study the participants were told to deal with a planned secondary task that functioned as a distraction. The distraction was supposed to simulate a general behaviour of drivers, who decrease attention on the road and traffic situations and focus on tasks that are not related to driving. The secondary task consisted of reading out loud a numerical sequin that has been displayed on the top right corner of the simulator screen. The sequence is a replication of the secondary task developed at Ford's VIRtual Test Track EXperiment (VIRTTEX) (Ljung, et al., 2007).

To avoid predictability variables have been built into the simulation. These variables provided randomization of the test runs in an effort to minimize the possibility for the participants to prepare for upcoming events/tasks.

When the simulation was prepared a number of questioners were created. The questioners were built upon old AdaptIVe questioners created by Volvo Trucks and they focused on the background information about the participants and the instrument cluster, see Appendix B. A Van Der Laan questioner was also used to determine the participants' perceived satisfaction and usefulness of driving in level 3 of automation (Van Der Laan, et al., 1997). The Van Der Laan questioner was also used to assess the concept and compeer it to the other functions.

When the simulator and the questioners were considered to be ready for the tests, appointments were booked with participants. All the participants were professional truck drivers, with valid driving license, to get a detailed feedback and comparison with today's technology.

3.7.2 Test setup

Objective measurements were provided by the simulations while subjective measurements were provided by the questionnaires. These two types of information together resulted in a detailed description of the overall feeling of the simulation study. Participants were driving four runs in the simulator, two-two runs with different status of the concept. The order of the runs was generated individually for each participant using a randomizing tool in Microsoft Excel. This was done so none of the runs got a benefit from always being the last one. This means that the participants needed to do three runs in the simulator to be sure that they have used all the aspects of the Final concept at least once. The participants were answering the questioners in between the runs and the order of the questioners differed with relation to the randomization of the test runs. From the concept and models point of view the orders of the test runs was irrelevant and by randomize the test runs the result of the simulation study could be more balanced.

As stated before the simulation test was the primary validating tool of the Final concept and the model. For the validation hypotheses had to be created and confirmed or declined. During the tests three hypotheses have been created for the concept, two about objective and one about subjective matter. The model is a purely objective hence it only have hypothesis about objective matters.

4 THE PROCESS

The Process section follows the same structure as the Methods part and describes how the different methods have been used and how they directed the design process.

4.1 Information gathering

During the thesis a literature study was conducted to get an understanding of the terminology that was used in the field of automated vehicles. The literature study included research regarding the terminology used throughout the field and the terminology used by the client. The field of automated vehicles was so new that a common language has not been established yet and because of that the used terminology differed between researchers. The literature study included an overview of different systems that tries to keep the DIL within the area of automated vehicles. The overview included different types of highly automated vehicle systems, such as cars, trucks, planes and industrial machines. This gave an insight into works that focus on how to keep the operators in-the-loop. The thesis included interviews with people who work in fields that use highly automated systems. This generated an insight into how people perceive these kinds of systems.

The information gathering and the interviews are completing the pre-study with subjective information and the personal opinion of airplane pilot and the instructors about autopilot in airplanes and automated systems in general. During the interviews the participants showed the different functions and problems in a real 737 Boeing simulator which is a fully functioning copy of the real aircraft. Overall the participants find the autopilot system assisting and effective but at the same time the autopilot is neither easy to use nor reliable. That connects to the safety feeling of the system that the pilots and instructors find quite unsafe.

4.2 Development

4.2.1 Ideation

In this thesis conventional ideation tools, used within the field of Industrial Design Engineering, are going to be combined with tools developed for creating Human Machine Interactions, enhancing the awareness towards the system and preventing out-of-the-loop behaviour. Combining different methods will aid the creation of concepts that are using both in and out of the box thinking. For the evaluations of the ideas a combination of Industrial Design Engineering evaluation tools and discussions with experienced people in the field of automated vehicles will be applied.

USE-CASES

During the ideation process several use-cases are created for different highway situations attempting to cover most of the possibilities to be able to see which time span is the most problematic and which direction is the most promising for innovative ideas. Possible highway situations are for instance entering the highway, driving on the highway without problem, planned change in the route, or system malfunction. The system malfunction could result in either a certain reaction from the HA or a safety emergency brake from the ASA. The use-cases differ from each other in the type of transition (expected or unexpected switch between LoA), direction of transition (switch to Level 3 from Level 0), speed of transitions (slow or immediate switch), ASA and HMI functionality (normal or failure) and the state of the HA (engaged by secondary task/unresponsive/distracted).

IDEAS

The ideas are developed simultaneously with the use-cases, sometimes while using the same ideation method. A workshop is conducted with co-workers at Volvo Trucks, see figure 6, where the ideation methods Statuscope and Nine windows are introduced and used. Ideas are created in the areas of interface elements, types of stimulus and positioning of interface elements to enhance the systems effectiveness in getting and keeping the DVS in-the-loop, see figure 7. The idea generation follows a structure way, which makes it is easier to investigate and further process the outcome later on.

Figure 6: Workshop with Volvo co-workers

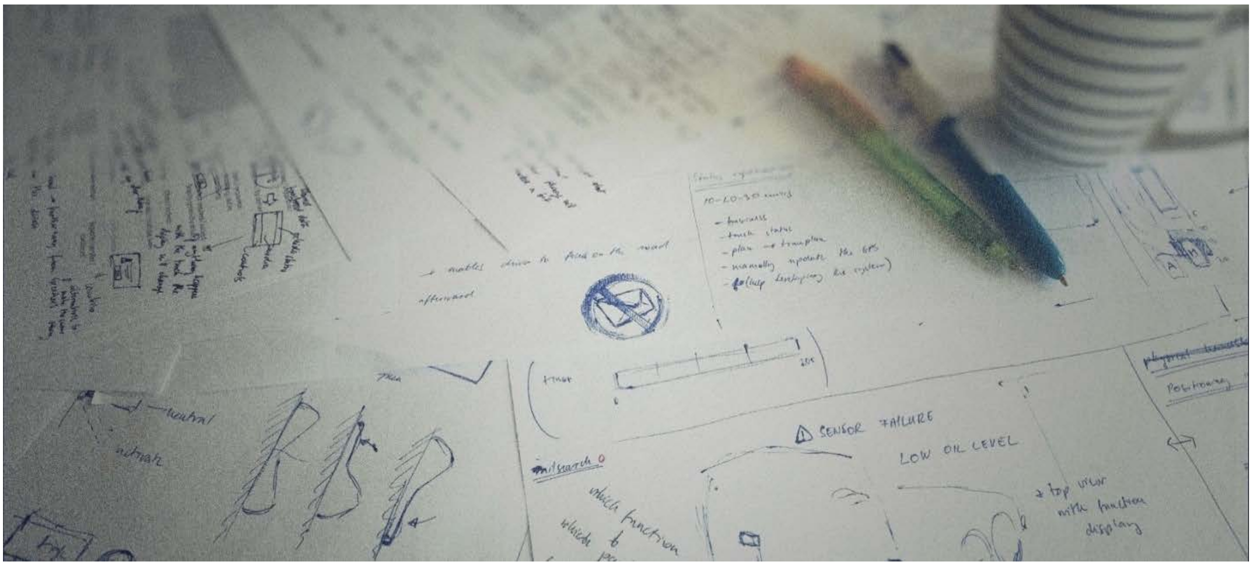


Figure 7: Ideating session

4.2.2 Evaluation I

To organize the outcome of the Ideation sessions the KJ method is used during the first evaluation circle, see figure 8. Four use-cases are selected out of all the created ones for further development. The concept features are evaluated as well and arranged into the four use-cases according to their functionality. The concept features are divided like this to create the optimal solution to the individual use-cases. The use-cases are closely related to each other so the concept features could easily be transferred between the use-cases and still be considered as useful features. The first two use-cases are focusing on keeping the DVS in-the-loop and the last two use-cases are aiming for getting the DVS into the loop.

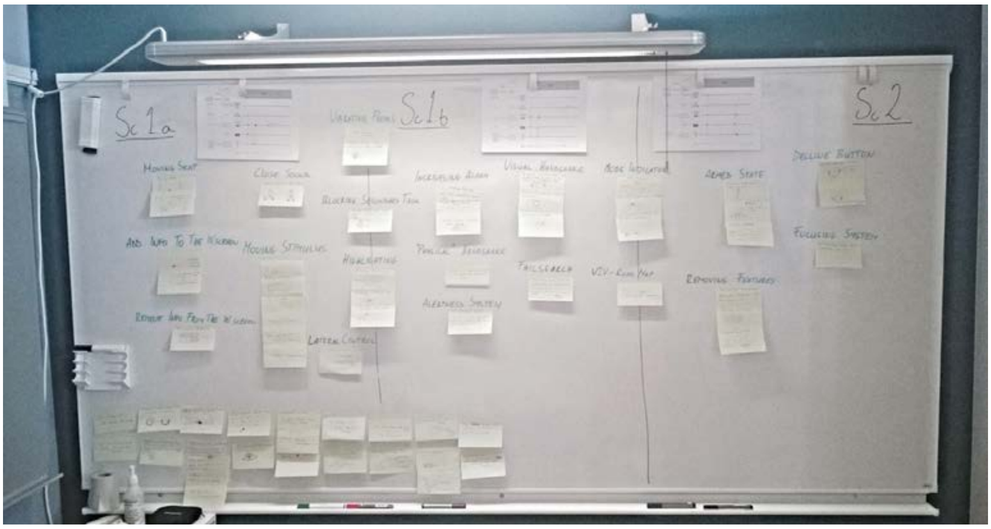


Figure 8: Arranged ideas with the KJ method

The created arrangements are further developed in the Concept Generation phase when coherent pre-concepts are generated out of four use-cases.

4.2.3 Concept generation

The groups that are formed out of use-cases and ideas in the first Evaluation phase are developed further in the Concept generation phase and become coherent pre-concepts. The four pre-concepts provide solutions for different highway situations and a chronological order can be seen between them. They follow each other covering main checkpoints of driving on a highway: entering the highway, driving on the highway, slow unexpected switch to a lower LoA, and an immediate unexpected switch to a lower LoA before an emergency manoeuvre.

4.2.4 Final Concept

The Final concept operates with two use-cases while the other two was discarded. The Final concept only contains one concept feature that was found during the Concept generation phase. This concept feature is enhanced with secondary functions to enhance its usability.

4.2.5 Measuring and testing

An objective study is performed within the truck simulator at ATR, Volvo Trucks. The simulation study uses a scenario where a truck encounters highway traffic-jams and expected switches between LoA. Combined with the simulation study a subjective study is conducted, which intends to answer the questions regarding the drivers' acceptance and trust towards the system. The subjective study is conducted with help of situation specific questionnaires. The following five hypotheses supposed to be either confirmed or declined after the tests:

The Final concept

Hypothesis 1 (objective): The Final concept can make a significant difference in reaction time when the participant is distracted.

Hypothesis 2 (objective): The Final concept is meaningful from a safety and fuel efficiency point of view.

Hypothesis 3 (subjective): The participants will see the benefits of the Final concept.

The model

Hypothesis 4 (objective): The model will help to determine when the participant is out-of-the-loop in the different simulations.

Hypothesis 5 (objective): The model will help to determine on which control layer the participant fails to perform the necessary driving tasks.

4.3 Simulator study

The simulator study is designed with the Final concept and both use-cases in mind. This means that the study includes parts where the vehicle is driving according to the two selected use-case. The simulation is built up so expected switches between LoA are happening in different parts of the simulation. The simulator study has a lot of queue related driving and the reason for this is that the simulation study will be part of the AdaptiVe research. The AdaptiVe research will investigate the participants' acceptance towards queue assistance system that uses the third LoA while the truck is driving in a queue (between 0-30 km/h). The AdaptiVe research functions with the investigation of the Final concept since the investigation requires lots of expected switches between the two LoA. Queues on the motorway produces the opportunity for theses switches to logically occur within the simulation.

4.3.1 Preparation

The simulated environment is a section of the E6 between Gothenburg and Mölndal. The road has a number of files in both directions and there is varying density of surrounding traffic. The participants encounter construction sites, queues and variations of vehicles in the surrounding flow of traffic. The participants are instructed to drive the simulated truck as safe as they should have done if it was a real truck and that the top speed of the vehicle is 80 km/h. The participants have a 5-10 minute long practise run in the simulator before the test begins. The participants are practising and getting a feeling about how the simulator is behaving with regard to acceleration, breaking power etc. The participants are told that they can use Highway Assist (HWA) when they are driving on a motorway between 50-80 km/h and Queue Assist (QA) when travelling between 0-30 km/h. These two functions operate in level 3 of automation and they are both referred to as Autopilots. The participants are told that the speed gap between the two autopilots needs to be handled in the lower LoA which means that they need to drive manually (Level 0) between the activation of the two autopilots. The participants are also introduced to the two different routes of the simulations which they will drive twice, one time while using the Final concept with secondary function and one time without the secondary function. Lastly the participants are introduces to the VIRTTEX secondary tasks.

INSTRUMENT CLUSTER

The instrument cluster uses a total amount of eight different visual cues that informs the participants about the conditions of the road and the vehicle as seen on figure 9.

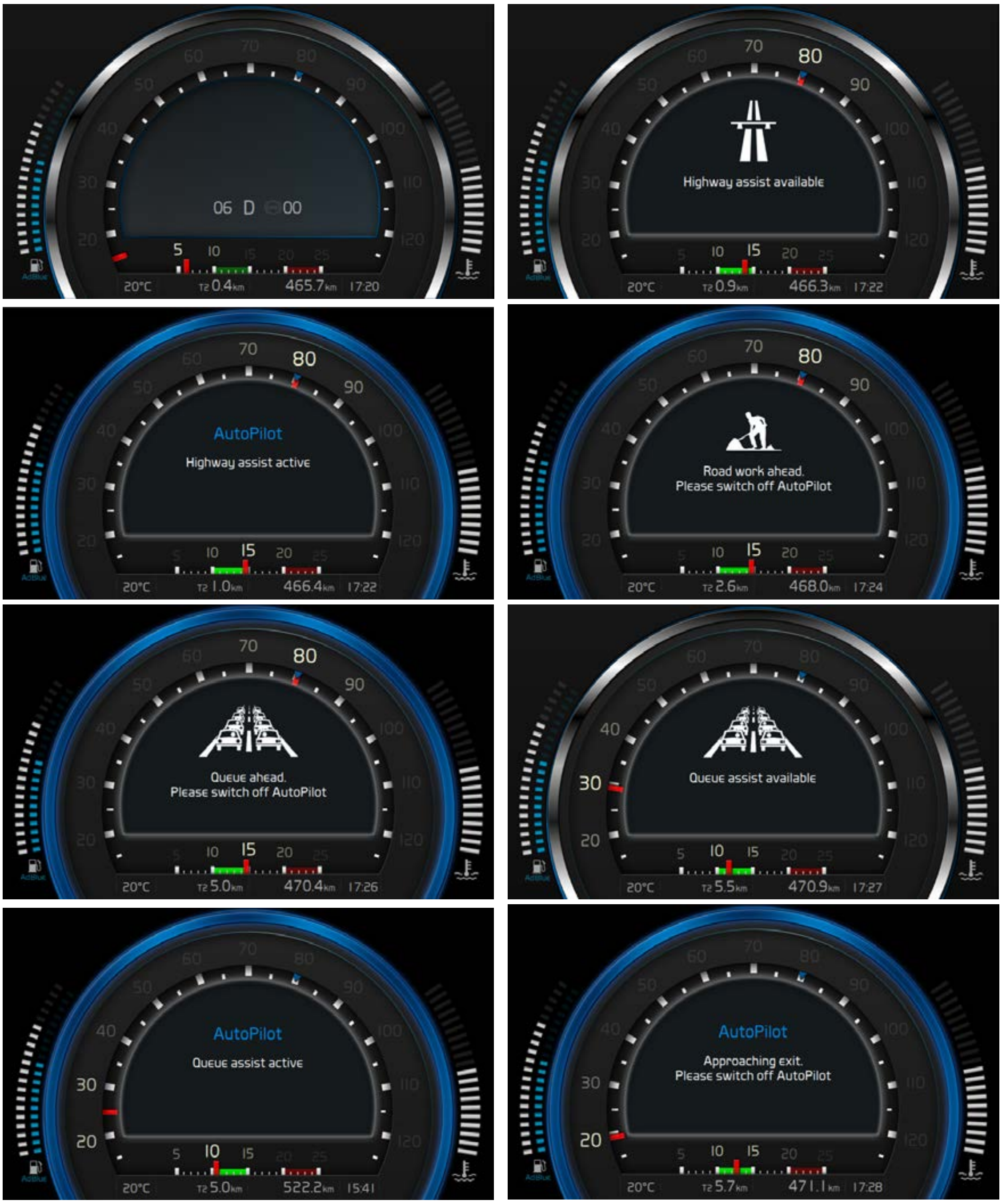


Figure 9: Different cues of the cluster design

The instrument cluster visualizes driving in level 0 of automation with a white-grey circle around the speedometer. When level 3 of automation is activated the instrument cluster visualizes this by switching the colour of the circle to bright blue. Text in the middle of the instrument cluster informs the participants that they are using autopilot and what type of autopilot is activated. When the participants need to switch down to level 0 of automation again the instrument cluster uses a combination of text and figures to notify the participants of the necessary action and the reason for this action. All the information cues are using a sound notification to direct the participants´ attention towards the instrument cluster. When the participants are driving and using the secondary feature of the Final concept the instrument cluster will change to indicate the feature its activation.

SIMULATION 1

Simulation 1 begins in the southernmost part of the simulated road and lets the participants travel in a north going direction, see figure 10.

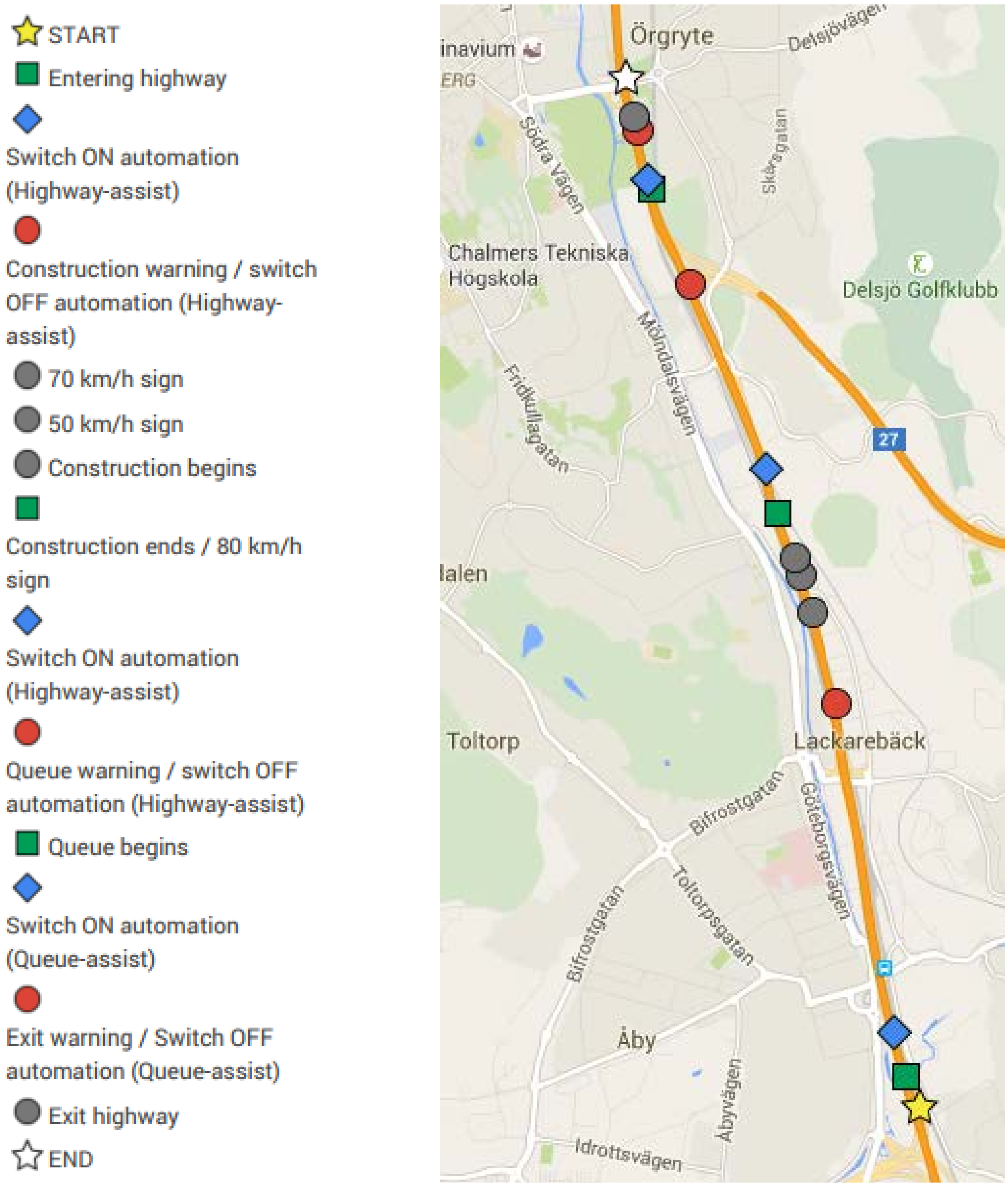


Figure 10: The route of Simulation 1, road E6 between Gothenburg and Möldal (northbound)

The different shapes and colours on the map indicate the different events that are appearing in the segment. The yellow star indicates where the simulation begins while the white star indicates where the simulation ends. The green box shows where the system begins to load towards a higher level of automation (Level 3) and the blue box indicates the when the autopilots can be activated. The red circle indicate where the participants get an indication about an expected switch to a lower LoA (Level 0) and the participants need to resume full control of the system. The grey circles indicate where the participants can´t us the autopilots.

In Simulation 1 a set number of inputs are measured in an effort to decide if the DVS is in- or out-of-the-loop. The measured inputs are decided with help of the BHC and test specific requirement, see table 1.

Table 1: Selected inputs for Simulation 1

Input	What to measure	Input source
The speed of the truck should match (or be lower than) the road signs	Investigate the speed of the truck and compare it with the speed of the road	BHC 124
Always keep at least a 2 seconds distance to the vehicle in front of the truck	Measure distance to other vehicles	BHC 126
Switch to a higher level of automation as soon as possible	Investigate when the driver is switching LoA and compare it to when it is possible to switch	Drive in as high LoA as possible

The "*Inputs*" refer to the law and test specific requirements that are needed for the DVS to operate in a safe and desired manners. The column "*What to measure*" indicates what's measured and the "*Input source*" indicates which BHC law, or test requirement, the input are generated from.

Simulation 1 will take approximately 5.6 minutes to complete and the participants will use the higher LoA for approximately 50% of that time, see figure 11.

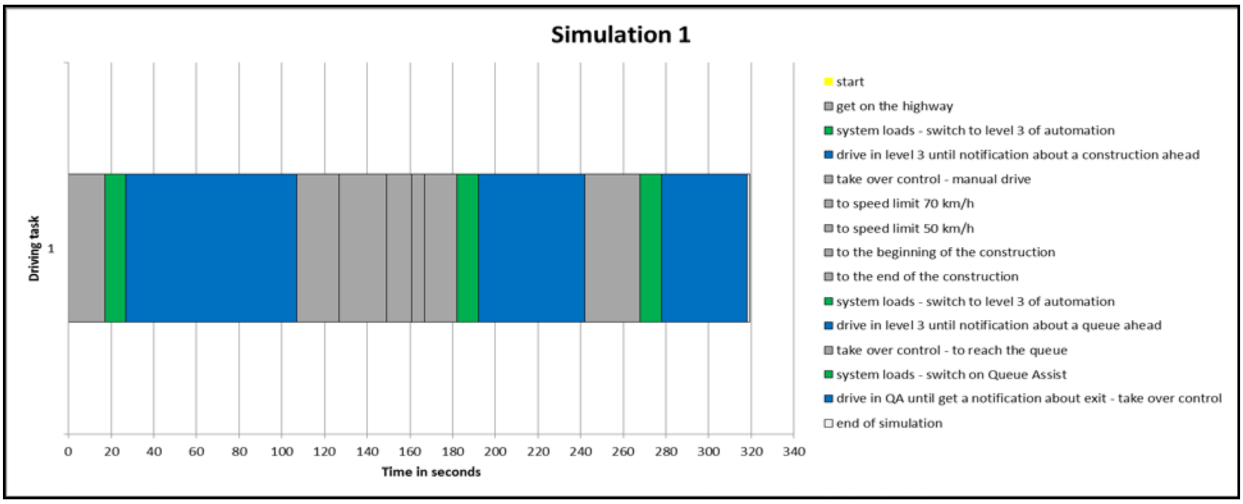


Figure 11: Time plan of simulation 1

SIMULATION 2

The second simulation uses the same road as the first on, but the DVS is traveling in the opposite direction, see figure 12.

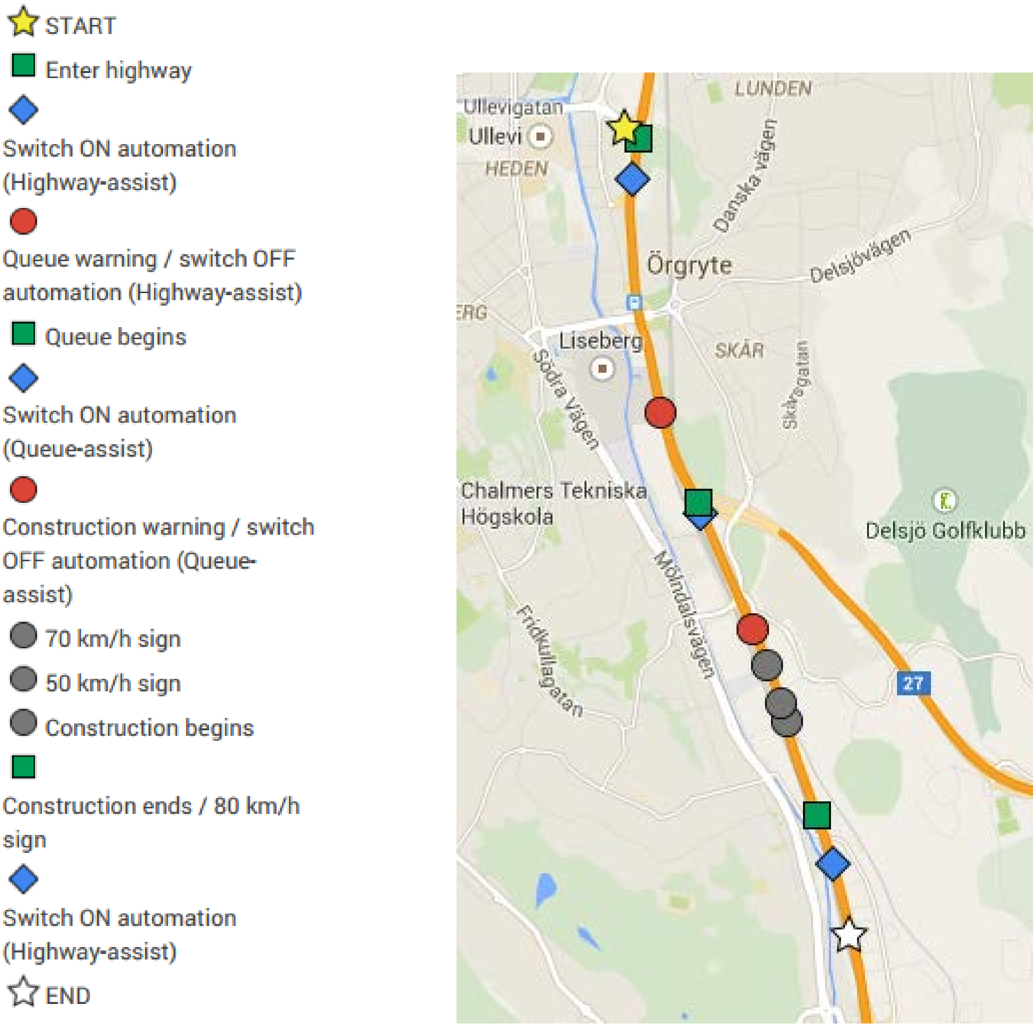


Figure 12: The route of Simulation 2, road E6 between Gothenburg and Möldal (southbound)

The participants will encounter the same type of obstacles, construction site; queue and surrounding vehicles and in Simulation 2 as they do in Simulation 1. The big differences are what type of vehicle the participants are encountering and where the different obstacles occur. In Simulation 2 the queue begins early in the simulation, compared to late in Simulation 1, and the construction site is appearing in the queue instead of on the motorway. This means that the participants need to switch up and down between the LoA while travelling in the queue. To furthermore complicate the queue driving a motorcycle will be the vehicle in front of the DVS in the queue. This demand extra caution from the DVS according to BHC 160 and 288 which states that the motorcycle riders are particularly vulnerable. The inputs measured in Simulation 2 are presented in table 2.

Table 2: Selected inputs for Simulation 2

Input	What to measure	Input source
Don´t slow down unnecessarily	Investigate the speed of the vehicle and compeer it with the speed of the traffic	BHC 282
Give motorcyclist extra space while driving on the road.	Measure distance to motorcycle	BHC 160
Give motorcyclist extra space while driving close to a construction site	Measure distance to motorcycle when driving by the construction site	BHC 288
Switch to a higher level of automation as soon as possible	Investigate when the driver is switching LoA and compeer it to when it is possible to switch	Drive in as high LoA as possible

The length of Simulation 2 is approximately 6.2 minutes and 50% of driving is in a higher LoA, see figure 13.

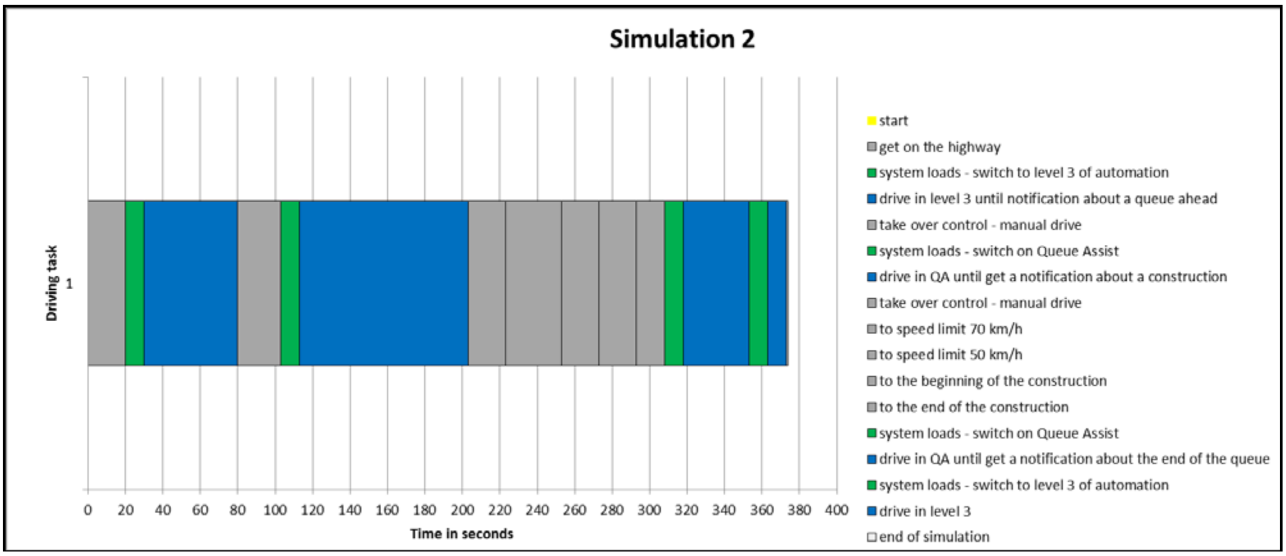


Figure 13: Time plan of Simulation 2

4.3.2 Test setup

A simulation study is conducted with 20 participants, see table 3, and the study takes roughly one hour for each participant. Their experience ratio varied but all of them have been part of a simulator study before. The simulator used in the study is visualised in figure 14.

Table 3: Numbering, gender and age of the participants of the simulator study.

Participant number	Gender	Age
1	Male	27
2	Female	49
3	Male	34
5	Male	48
6	Male	58
7	Female	31
8	Male	28
9	Male	62
10	Male	51
12	Male	33
13	Male	24
15	Male	57
16	Male	34
17	Female	64
18	Male	40
19	Male	26
20	Male	33
21	Male	42
22	Male	31
23	Male	33

Figure 14: The simulator used in the study

The simulator is built-up by three computer screens; one for the windscreen, one for the side mirror and one for the instrument cluster. The seat is a real truck seat and it can be adjusted to the participants' preferences. The steering wheel is a truck steering wheel but only two controllers are activated on it, the turn signal lever and the Autopilot switch. Autopilot switch is the white button down on the left side of the steering wheel and it works both as an *On* and an *Off* switch. The participants get a pair of headset to enclose them from surrounding noise and movable walls are used to remove visual distractions.

In the Result of the Model chapter is where the final version of the theoretical model is presented and its structure and functions is described in details.

5.1 Redefinition of the DVS

In this project is the DVS is seen as a combination of the mechanical vehicle, the human (equals to a Human-Agent) and the automation software (equals to the Automation-System-Agent), see figure 15.

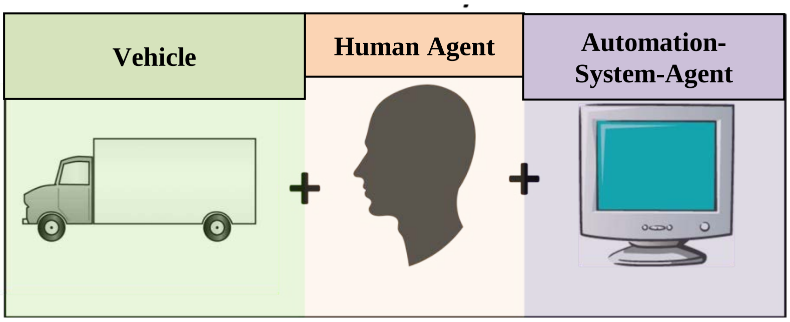


Figure 15: The Driver-Vehicle System

The Human-Agent (HA) and the Automation-System-Agent (ASA) are both defined as drivers of the DVS. The tasks and the roles of the agents in the DVS differ between the different LoA. In lower LoA the HA is the main operator of the DVS while the ASA can help reducing the HA´s workload by taking control over some of the driving tasks. In contrast to this in higher LoA the ASA is the main operator of the DVS and take care of the dynamic driving tasks while the HA operates the strategic driving tasks. The DVS is out-of-the-loop when one of the two agents' cannot perform the assigned driving task. The performance is defined with help of laws and regulations and the two agents are judged equally. Violations of laws and regulations by any of the agents will put the whole DVS out-of-the-loop. This is not dependent on whether the violation is conscious or unconscious. The reasoning behind this is that the DVS is defined as being in- or out-of-the-loop regardless to the different agents' responsibilities because they are seen and judged as one system.

5.2 Adjusted-ECOM

DIL means that a driver plays an active role in the DVS and is involved in the driving tasks. A driver is in-the-loop if the drivers´ involvement produces inputs to the driving-tasks (IHRA, 2011). In contrast to this the driver is out-of-the-loop if the driver does not actively provide these inputs. The Adjusted-ECOM is trying to define when the driver is in-the-loop by defining which inputs the driver needs to produce.

To be able to define the input needed to the system the driving tasks of the system need to be clarified, because the inputs depend on the driving-tasks. The Adjusted-ECOM has a structure of four control-layers, just like the ECOM, (Tracking, Regulating, Monitoring and Targeting) that contains all the driving tasks that are needed to control a road vehicle (Windridge, et al., 2013b), see figure 16. The dynamic driving tasks belong to the Monitoring, Regulating and Tracking control-layers and the strategic driving tasks belong to the Targeting control-layer.

All the different control-layers get inputs and generating outputs. The system uses two different kinds of inputs, System-inputs and Environmental-inputs see table 4. The outputs from the different control-layers are in most cases used within the system, except on the Tracking control-layer where the output goes to the environment, see figure 16. The outputs that are used within the system are thereafter converted into inputs on the receiving control-layers; they are called System-inputs. The System-inputs on the different control layers work with the same hierarchical structure used in the ECOM, where tasks in one control-layer activate and deactivate tasks in the layer immediately below (Windridge, et al., 2013b). With other words, the input of one control-layer activates or deactivates inputs through the control-layers below and ends up as measurable physical inputs to the environment. By measuring these inputs to the environment it is possible to find out if one or more control-layers doesn´t produce input to the system. The second type of inputs is inputs that are generated by the environment and are therefore called Environmental-inputs. Environmental-inputs are information about the surroundings and with that information the DVS is able to place the vehicle in a time and space continuum while fulfilling certain tasks. Different control-layers deal with different driving-tasks so they need different Environmental-inputs with specific information regarding the environment.

Ex:

- **Targeting –** information regarding destination and in what time the destination needs to be reached.
- **Monitoring –** information regarding the orientation of the own vehicle and if it's traveling in the right direction to reach the destination.
- **Regulating –** information regarding the state of other vehicles (vehicle is about to turn) and road sign and signals (red, yellow, green).
- **Tracking –** information regarding velocities and lane position of the own and other vehicle.

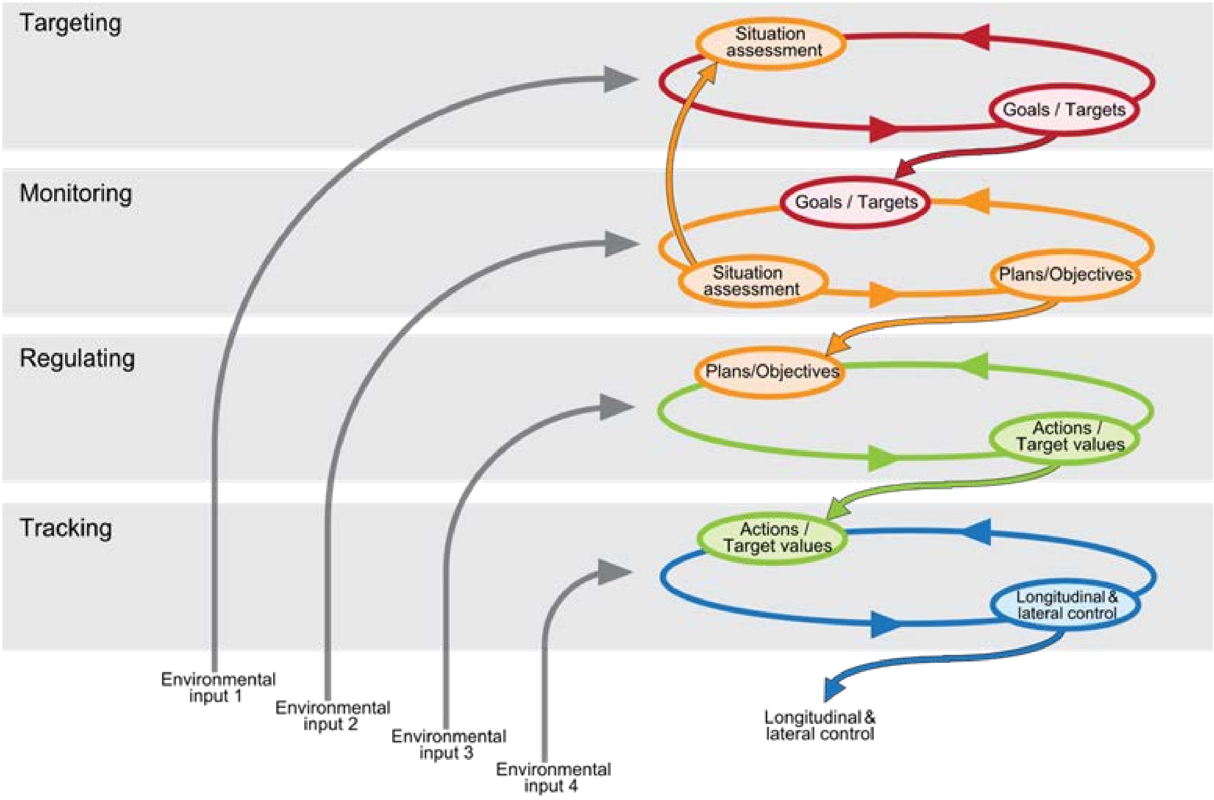
There is one control-layer that works differently than the others and that is the Monitoring control-layer. The Monitoring control-layer produces System-inputs both upwards and downwards in the model. The reason for this is that the *Situation assessment*, which takes place in the Monitoring control-layer, relates and has an effect on the Goals and Targets generated in the Targeting control-layer (Hollnagel, 2015).

Table 4: In- and output in the different control-layers in respect to a road-vehicle system

Information examples	Information	Information type	Control-layer
Every system works properly, fuel level is all right	-Situation assessment (status of the controlled vehicle)	Input	Targeting
Go from Göteborg to Stockholm	-Target locations	Environmental input 1	
Get to Stockholm, fuel efficient, safe drive, keep regulations	- Goals and targets	Output	
Get to Stockholm, fuel efficient, safe drive, keep regulations	-Goals and targets	Input	Monitoring
On a highway, approaching Örebro, end of E20, continue on E18 Every system works properly, fuel level is all right	-Location of the truck (information signs and signals, map/global positioning) -Status of the controlled road vehicle	Environmental input 2	
Every system works properly, fuel level is all right Change from E20 to E18	-Situation assessment (status of the controlled vehicle) -Plans and objectives	Output	
Change from E20 to E18	-Plans and objectives	Input	Regulating
In the merging lane, slow moving traffic	-Position of the truck -State of road signs and signals	Environmental input 3	
Reduce speed, change lane	- Actions and target values	Output	
Reduce speed, change lane	-Actions and target values	Input	Tracking
In the merging lane, reduce speed	-Feedback (relative/absolute orientation, velocities and lane position of the different road entities)	Environmental input 4	
Maintain lane position and headway time	-Longitudinal and lateral control	Output	

The colours represent the different control layers and the information they are generating. The arrows illustrate the origin of the information and which control layer receives the information.

Red: Targeting **Orange: Monitoring** **Green:Regulating**
Blue: Tracking **Grey: Environmental-input**



Environmental input 1 provides information for the Tracking layer about the state of road vehicles (speed, distance and orientation).
Environmental input 2 informs the Regulating layer about a change in the state of road entities (signs and signals).
Environmental input 3 gives data to the Monitoring layer about the controlled road entities´ status and location (positioning, orienting).
Environmental input 4 provides information for the Targeting layer about the location of the target globally.

Figure 16: Adjusted-ECOM with in- and outputs

The colours represent the different control layers and the information they are generating. The arrows illustrate the origin of the information and which control layer receives the information.

Red: Targeting **Orange: Monitoring** **Green:Regulating**
Blue: Tracking **Grey: Environmental-input**

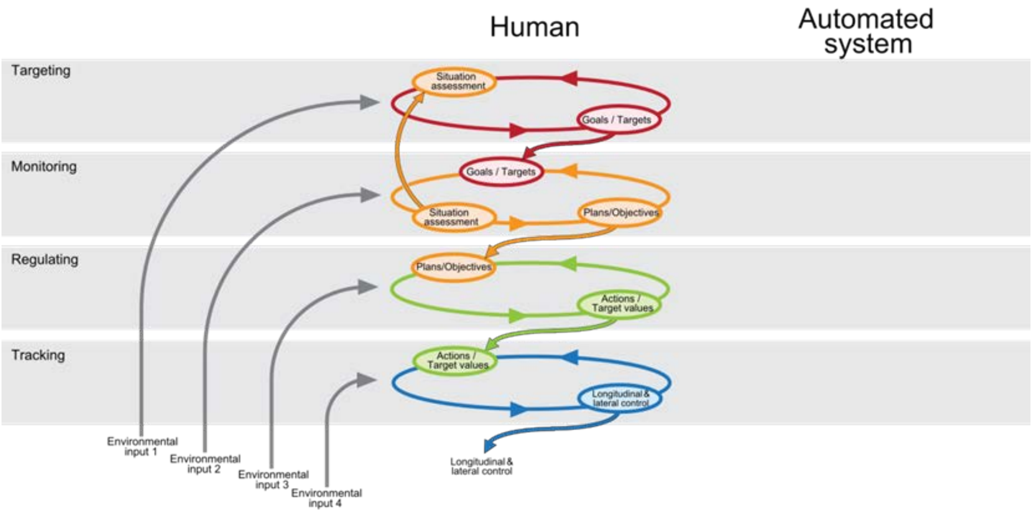
5.2.1 Adjusted-ECOM and Levels of automation

The Adjusted-ECOM is very similar to the ECOM, but when the Adjusted-ECOM is adapted to the levels of automation the difference is revealed. The ECOM functions with only one person who operates the vehicle (Renner & Johansson, 2006) while the Adjusted-ECOM is adapted to a DVS where the tasks (in- and outputs) of the control-layers can be shared between two entities within the system. The Adjusted-ECOM does this by claiming the DVS functions as a heterogeneous Multi-agent system where two agents (the human and the automation-system) collaborate to achieve common goals and individual tasks (Barber & McKay, 1998). The approach to divide the ECOM control-layers between LoA with help of the theory of Multi-agent system is not unique and it has been tested before (Taylor, 2003), see Appendix A. But it has not been adapted to road vehicles neither to their LoA. This is what the Adjusted-ECOM tries to achieve.

The Adjusted-ECOM divides the control-layers between the HA and the ASA in all the six levels of automation of the J3016 standard. This represents which control-layers and assigned tasks on the control-layers belong to the different agents.

LEVEL 0

On Level 0 of automation the Human driver (Human-Agent) takes care of all the driving tasks in all the control-layers, see figure 17.



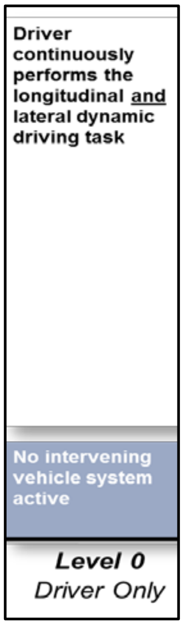
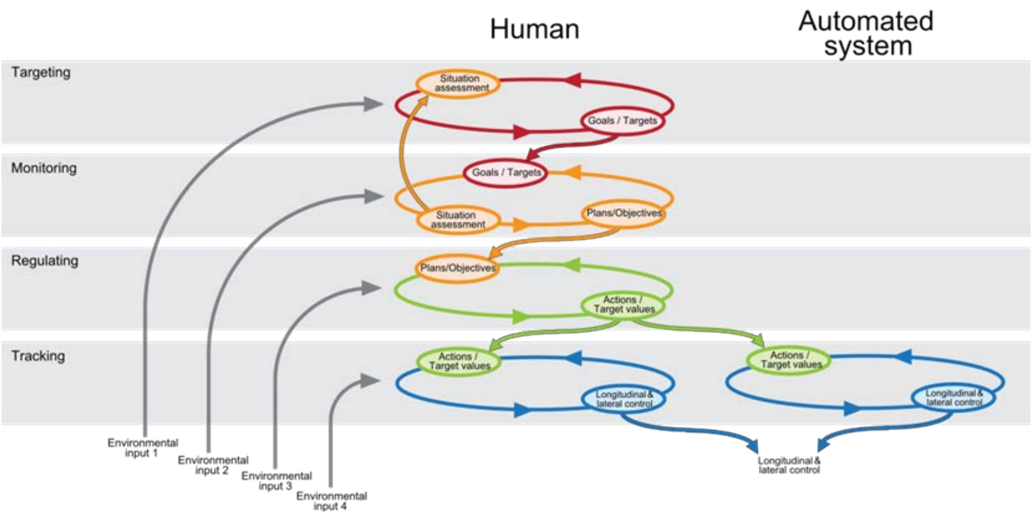


Figure 17: Adjusted-ECOM Level 0

LEVEL 1

On Level 1 the Tracking control layer is shared between the HA and automated driving system (Automation-System-Agent), see figure 18. The reason for this lies in the description of Level 1 which indicates that either longitudinal or lateral control could be handled by the ASA but not both (SAE, 2014).

Scenario: The truck is using Advanced Cruise Control (ACC) while approaching a slower moving vehicle on the highway. The ASA will adapt the speed to the slower vehicle and the HA will initiate the overtake procedure by using the turning signal and the steering wheel.



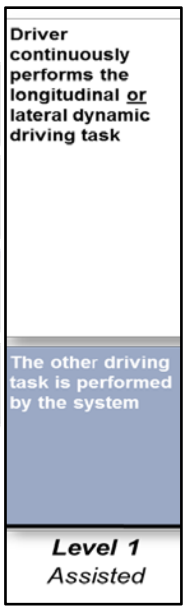


Figure 18: Adjusted-ECOM Level 1

LEVEL 2

The ASA can handle both longitudinal and lateral control on Level 2 so the Tracking control-layer is therefore only controlled by the ASA, see figure 19.

Scenario: The truck is using ACC and Lane Keeping Assist (LKA) while approaching a slower moving vehicle on the highway. The ASA adapts the speed to the slower vehicle and the HA can initiate the overtake procedure by, for instance, using the turning signal.

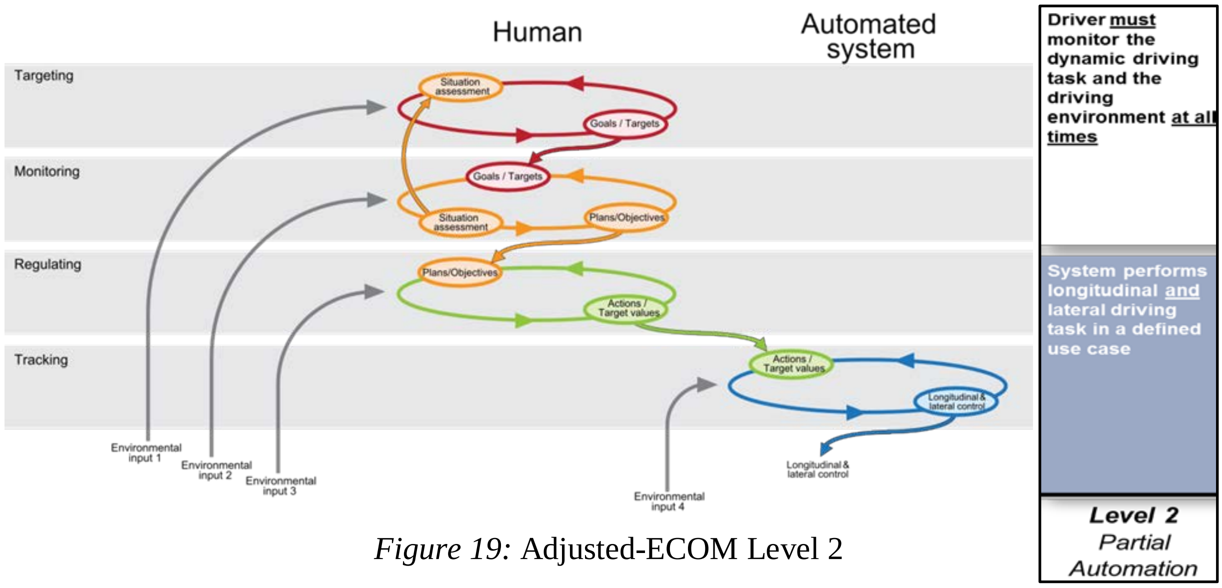


Figure 19: Adjusted-ECOM Level 2

LEVEL 3

On Level 3 the ASA is handling all the dynamic driving tasks which include the Monitoring, Regulating and Tracking control-layer. But the Monitoring control layer is shared between the HA and the ASA because *"the human driver will respond appropriately to a request to intervene"* (SAE, 2014). This means that the Situation assessment generated in the Monitoring control-layer is the HAs´ responsibility, see figure 20.

Scenario: The truck is using an Advanced Driver Assistance *Systems (ADAS) while approaching a slower moving vehicle on the highway. The ASA will adapt the speed to the slower vehicle or initiate and perform the overtake procedure without the HA´s guidance.*

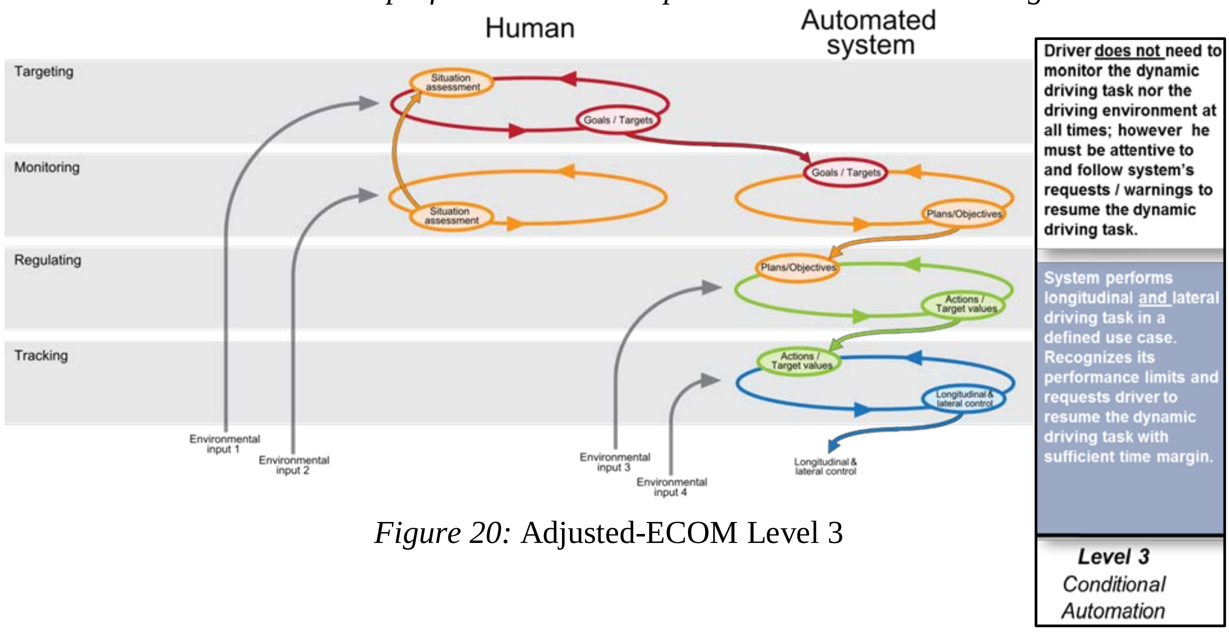


Figure 20: Adjusted-ECOM Level 3

LEVEL 4

On Level 4 of automation the ASA controls all the dynamic driving tasks including the Situation Assessment in the Monitoring control-layer. New Goals and Targets can be created both by the HA, based on Environmental input 1, and by the ASA, based on the Situation Assessment, see figure 21. This information could be for instance new destinations or handling instructions regarding specific cargo.

Scenario: The ASA will take care of all traffic situations on the highway and it will create new Goals and Targets with respect to the Situation Assessment generated in the Monitoring control-layer. The ASA will for instance be able to find and drive to a gas station if the truck is running low on fuel.

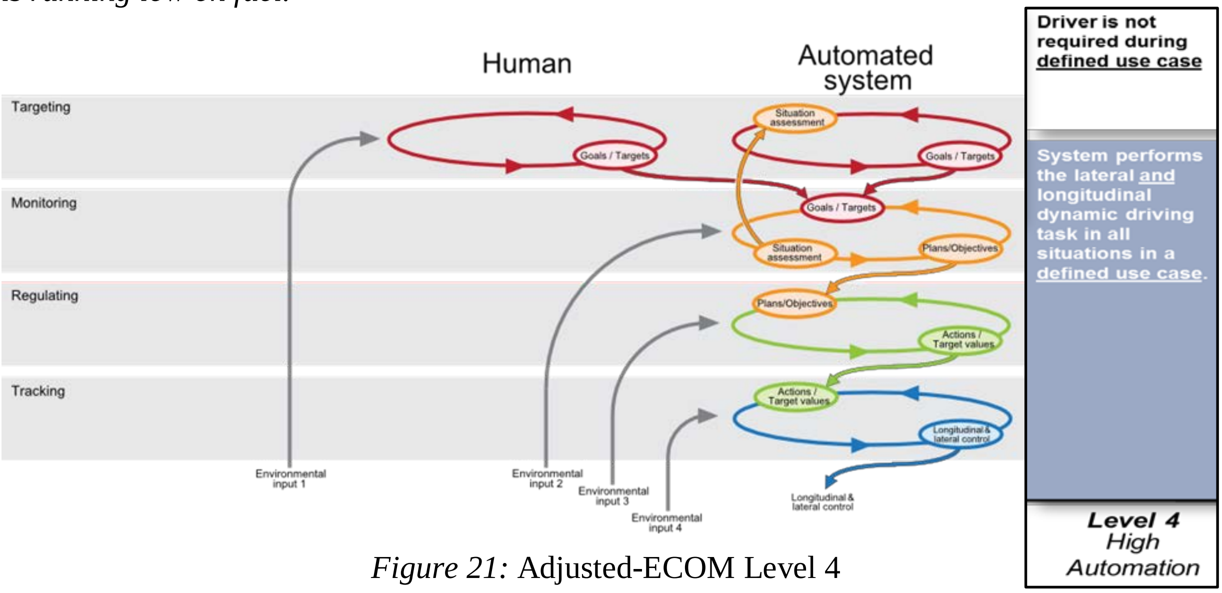


Figure 21: Adjusted-ECOM Level 4

LEVEL 5

On Level 5 of automation all the tasks are handled by the ASA, see figure 22. A compressing between the Adjusted-ECOMs levels of automation is illustrated in figure 23.

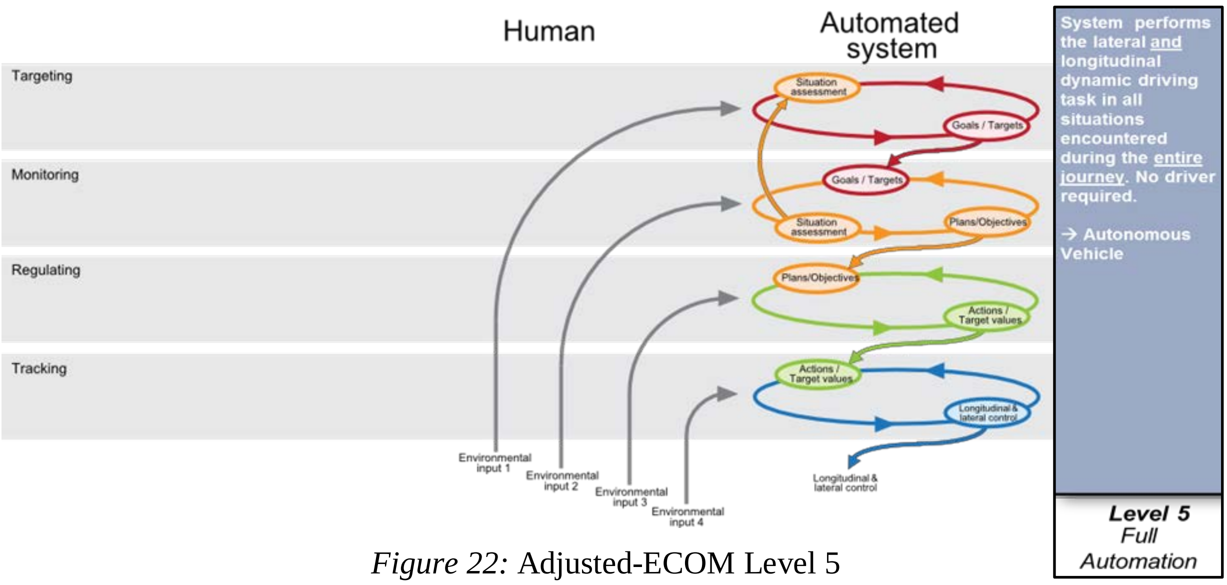


Figure 22: Adjusted-ECOM Level 5

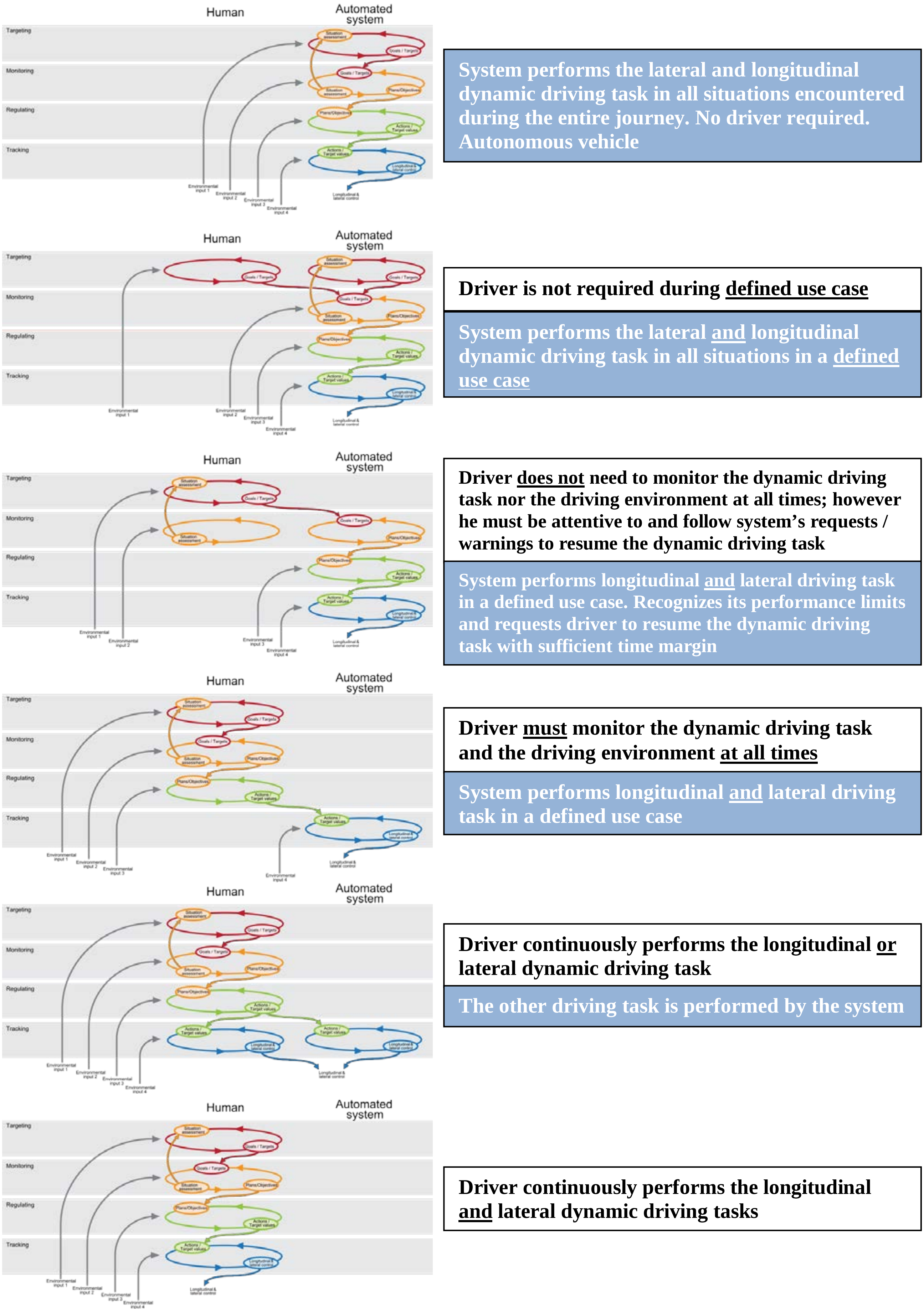


Figure 23: Adjusted-ECOM adapted to the LoA in the J3016 standard

5.2.2 Summary

The Adjusted-ECOM aims to help to measure DIL in road vehicles by connecting the J3016 standard and the ECOM. The Adjusted-ECOM does this by suggesting that the DVS can be seen as a Multi-Agent system with one HA and one ASA where both agents have an active role in the DVS. The Adjusted-ECOM uses the ECOM to determine the driving tasks that are required for the DVS according to the four ECOM control-layers. Which of the two agents that is in charge of a control layer is decided with help of the J3016 standards six LoA. The Adjusted-ECOM suggests that in the lowest LoA the HA is in control of all the control-layers and in the highest level of automation the ASA controls all the control layers. In the levels between the highest and lowest control-layer the management is divided and shared between the two agents. The Adjusted-ECOM proposes that DIL and DOOL can be measured by monitoring the inputs to the different control layers. The control layers need inputs for the driving tasks to be completed; if the agents' cannot provide the required inputs to all the control-layers some driving tasks will be uncompleted. In this case the whole DVS will be out-of-the-loop.

5.3 Result of the simulator study

To examine and validate the Adjusted-ECOM the adaptation of speed to actual speed limits figure 24, and the speed and HWT during manual drive in a queue, showed in figure 25-27 are investigated.

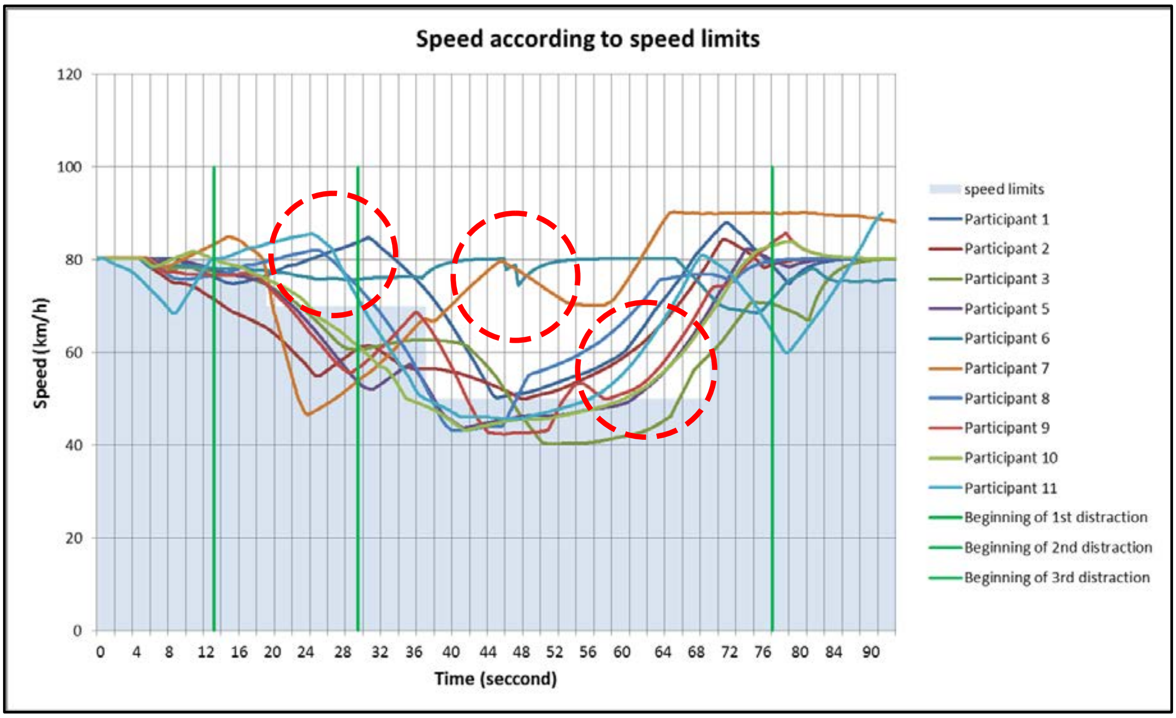


Figure 24: The participants speed according to actual speed limits

Figure 24 shows the participants speed in relation to the actual speed limit during a manual driving area. The speed limit is marked with the light blue area and the speed of the different participants is marked with the coloured lines. The green straight lines are indicating the position of distractions.

Applying the Adjusted-ECOM to situations when the participants drove in a queue in manual mode resulted in three main types of result, in-the-loop, out-of-the-loop and out-the-loop with small occurrence. In the queue situation the driving task are also specified by the BHC. According to the 282th criteria of the BHC the driver must not slow down unnecessarily. Furthermore the BHC says that drivers must give extra space for motorcyclists on the road and near construction sites, see BHC 160 and 288. On diagrams 25, 26 and 27 the speed and headway time of three participants can be seen during manual driving in a queue. The blue line indicates the headway time to the next vehicle in front and the blue dashed line marks the lowest limit of the headway time. The light red area shows the actual speed of the participant and the red dashed line marks the lowest speed of the queue. The green lines mark the start of the distraction tasks.

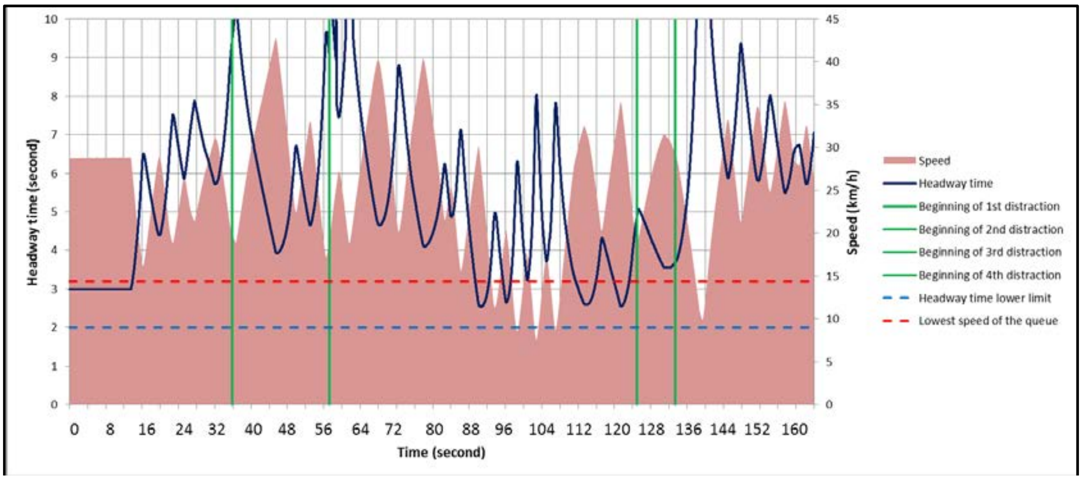


Figure 25: Change of speed and HWT during manual driving in a queue (Simulation 2, Participant 2)

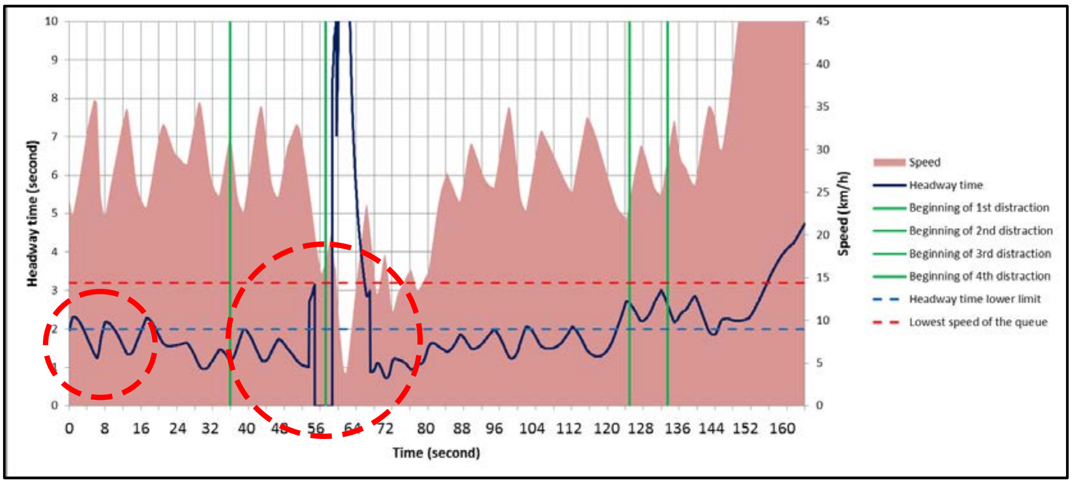


Figure 26: Change of speed and HWT during manual driving in a queue (Simulation 2, Participant 1)

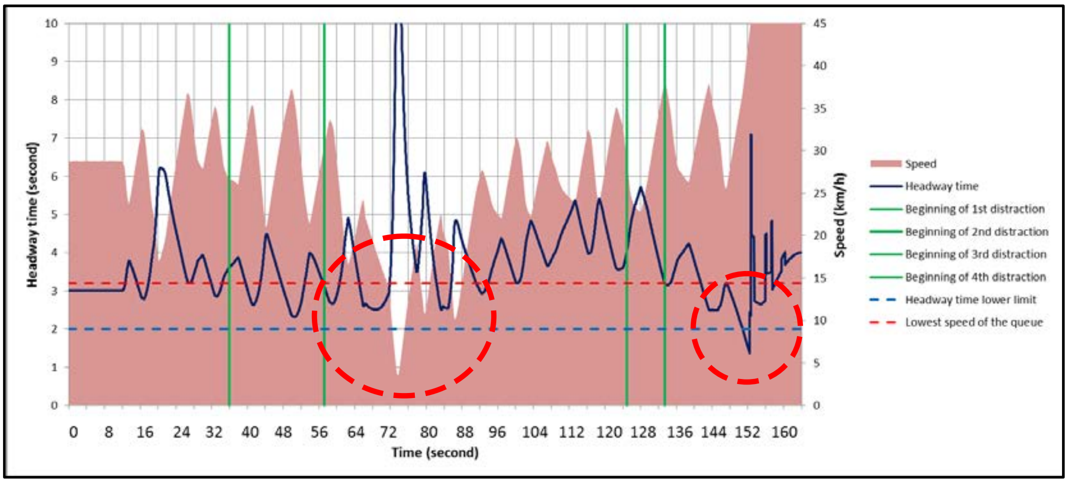


Figure 27: Change of speed and HWT during manual driving in a queue (Simulation 2, Participant 9)

6 ANALYSIS OF THE MODEL

In the Analysis of the model section the outcome of the simulator study is investigated with focus on the model relating hypotheses.

Matching the data of the simulation runs with the pre-set limits enables to point out whether each participant is in- or out-of-the-loop and the reason why. With the help of the 124th criteria of the BHC the current driving task can be specified, which is keeping the speed according to the actual speed limit. According to the Adjusted-ECOM those participants who managed to adapt their speed to the speed limit on time are in-the-loop and those who did not are out-of-the-loop. The analysis shows that a significant amount of the illustrated participants adapted the vehicles speed but there is no one who maintained the speed well during the whole investigated period, see figure 24. Participant 1, 7 and 10 lowered their speed too late, which means that they got out-of-the-loop on the Regulating control layer, indicated with red dashed circle on the left side of the diagram. The distractions, marked with green lines, directed the participants' attention apart from the road thus for instance participant 1, 7 and 10 missed the speed limit sign and entered the area with excessive speed. Before the speed limit ended all participants fell out-of-the-loop on the Regulating control layer as they failed in keeping the appropriate speed and started to accelerate too early, red dashed circle on the right side. The graph also shows that participant number 5 and 6 drove too fast through the examined period that cannot be considered as speed adaptation. These two participants are out of the Targeting control layer because they did not understand and thus did not complete the driving task.

Figure 25 gives an example for a HA being in-the-loop during the queue drive. The analysis shows that the second participant kept the target values; both adapted the vehicle's speed and the HWT properly. However the participant slowed down during a distraction and at the same time increased the HWT, but never stopped the vehicle. According to the Adjusted-ECOM participant number two is in-the-loop.

DVS that are out-of-the-loop provide data that includes continuous bad extreme points. As it can be seen on figure 26, the participant number one kept too small HWT during the whole period. The HA failed the driving tasks on both the Targeting and Regulating control layers. The failure on the Targeting layer is justifiable because the HA kept a too small HWT from entering the queue, indicating a lack of awareness about the relating criteria. By not providing extra space for the motorcyclist the driver broke criteria 160 and 288 of the BHC. The area marked with the red dashed circle on the right shows when the queue slowed down and the distracted driver hit the biker then stopped. In this situation the driver failed on the Regulating layer by not adapting the speed correctly and unnecessarily blocking the traffic, and broke criteria 282. According to the Adjusted-ECOM participant number one is out-of-the-loop.

The third type of participants shows characteristics of small crossings of the target values, but these points used to be rare occurrences, as seen on figure 27. The small marking on the right side of the table points out an occurrence of an insignificant fault. The driver increased the speed too rapidly that ended up in a decreasing HWT for a very short amount of time, which does not mean being out-of-the-loop. But participant 9 stopped for some time marked with the red dashed line on the left, which determines that this participant is out-of-the-loop according to the 282th criteria of the BHC.

Hypothesis 4 and Hypotheses 5 are proven from the result of the objective measurement since it is possible to demonstrate when the DVS is out-of-the-loop and in what control-layer that is responsible.

Hypothesis 4 is confirmed:	The model will help to determine when the participant is out-of-the-loop in the different simulations.
Hypothesis 5 is confirmed:	The model will help to determine on which control layer the participant fails to perform the necessary driving tasks.

7 RESULT OF THE CONCEPT

In the Result of the Concept section the outcome of each development steps of the design process is presented. As the idea was developed further the concept got more detailed and the final concept supposed to answer all related questions that arise during the project.

7.1 Information gathering

Concluding the opinions of the pilots and instructors general requirements can be formulated regarding such automated systems. The autopilot and the functions that it controls needs to be clearer and communicated to the pilots simpler. The claim for clear notification about on-going tasks that are maintained by the autopilot can be described by quoting these average pilot sayings:

“What is it doing now? It is doing the same thing again!”

It should be clear when it is appropriate to take over control manually. Some situations have to/ should be handled manually because it is the most efficient way to handle the situation. The interface has to be intuitive and helping the pilots to maintain tasks, find errors and correct them. A useful feature of the automated system that the pilots introduced is the “Armed” function. Armed in the aviation industry means that when the autopilot controls the aircraft and the plane reaches a certain trigger point (speed, altitude etc.) the autopilot automatically switches to the next pre-programmed action. For instance if the autopilot reaches a certain altitude it switches to the next task and stops pulling up the plane but keeps the altitude.

7.2 Concept generation

PRE-CONCEPT 1

The first pre-concept and the first use-case, see figure 28, take place when the vehicle enters the highway and the system gets ready to operate on a higher LoA. In this case the expected switch is a slow change because it only depends on the HA´s reaction time. The ASA collects information from the environment and the vehicle´s system (sensors, cameras etc.), and communicates it to the HA with the help of HMI, marked with black arrows pointing downwards. The HA has the possibility to endorse these information, marked with the grey dotted arrow. Then the truck indicates to the ASA that the DVS is ready to operate on a higher LoA. As a final step of the use-case the HA switches from Level 0 to Level 3 of automation and gives the control of the dynamic driving tasks to the ASA, marked with blue arrow.

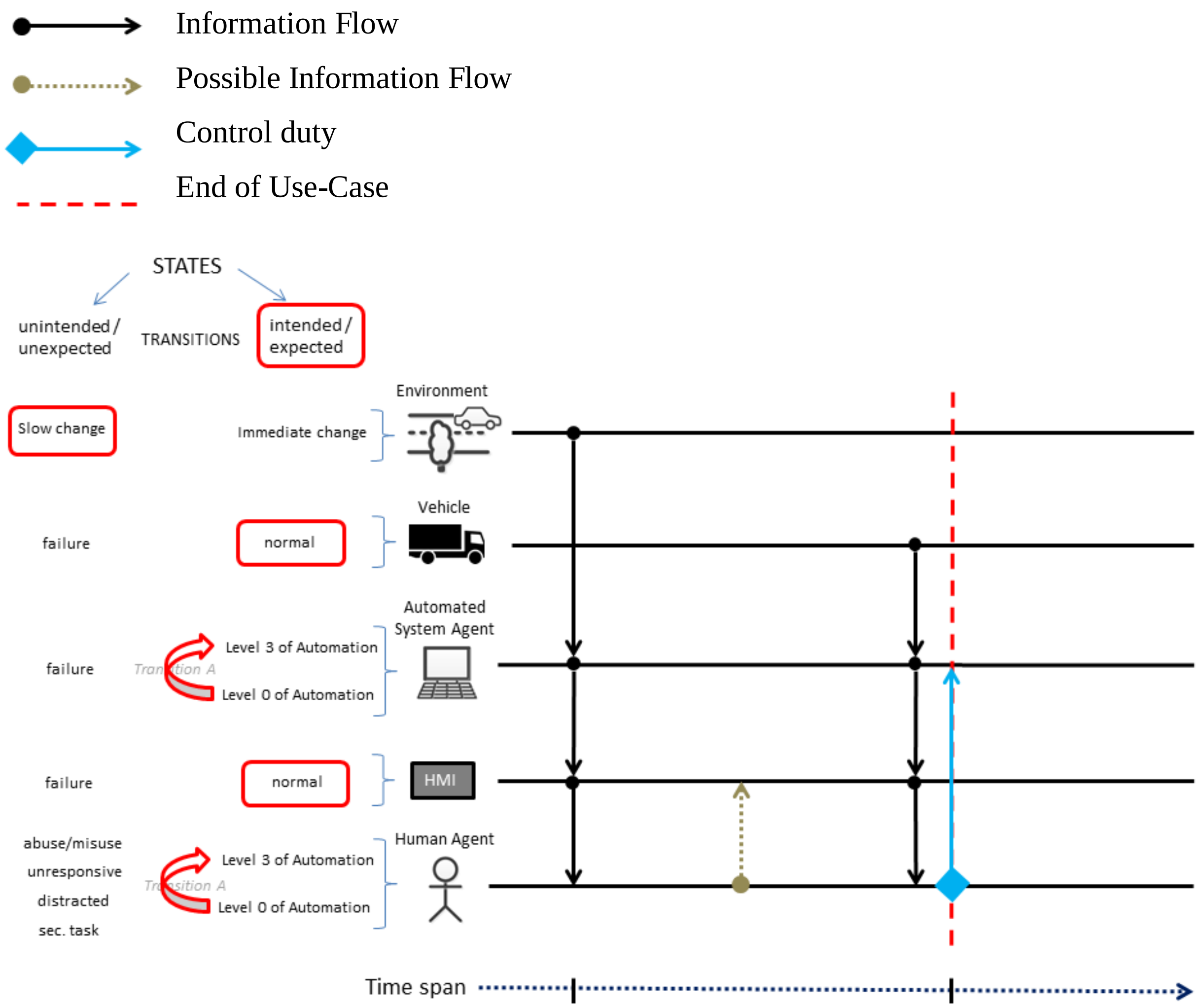


Figure 28: Use-case 1

By connecting the pre-concepts to the Adjusted-ECOM, it can be seen which control layers are maintained by the different agents, why and how. At the beginning of the use-case all control layers of the Adjusted-ECOM are maintained by the HA but after switching to the third LoA, the ASA takes over control of the Tracking, Regulating and partly of the Monitoring control-layers. The HA then has to complete tasks on the Targeting and partly on the Monitoring control-layers afterward.

The first pre-concept, see figure 29, brings the so called "*Armed*" function to the DVS. With the Armed function the ASA will behave like the armed autopilot in aircrafts. The HA sets the trigger points and the type of activation, that can be manual or automated. The ASA investigates the pre-set measurements and starts loading. When the system is loaded the activation will be executed according to the chosen type. In "*manual switch*" the HA will get a notification about the possible switch, while in "*automated switch*" the ASA executes the switch automatically. For instance if the HA is previously set to switch automatically to Level 3 of automation after 200 metres driving on a highway, the ASA executes the intended switch when the vehicle reaches the specific distance. After the ASA have taken over control the interior of the truck will be changed and the control features will be removed. The pedals are folded into the ground and the steering wheel is moved closer to the dashboard to free up more space for the driver. To avoid the transition to the higher LoA the HA can push the "*Decline*" button which breaks the command. A "*Mode Indicator*" helps to clarify for the HA which LoA the truck´s system is operating within and which agent (HA or ASA) that maintain the different driving tasks. The automated system is aided with V2X communication that helps the system to prepare for future acts and manoeuvres relying on shared information with other vehicles in front.

Figure 29: Pre-concept 1

PRE-CONCEPT 2

The second use-case, see figure 30, focuses on keeping the DVS in-the-loop while driving on a highway and both the vehicle and the ASA operates normally on a high LoA. During this use-case there are no transitions between LoA and the DVS operates on Level 3 of Automation. To keep the DVS in-the-Loop the ASA supplies information about the vehicle´s status to the HA continuously during the ride, indicated with the black arrows.

Because of the use-case the second pre-concept operates in level 3 of automation and all system elements function properly. This means that the HA only has to complete tasks on the Targeting and partly on the Monitoring control-layers while the ASA fulfils the tasks on the Tracking, Regulating and partly on the Monitoring layers.

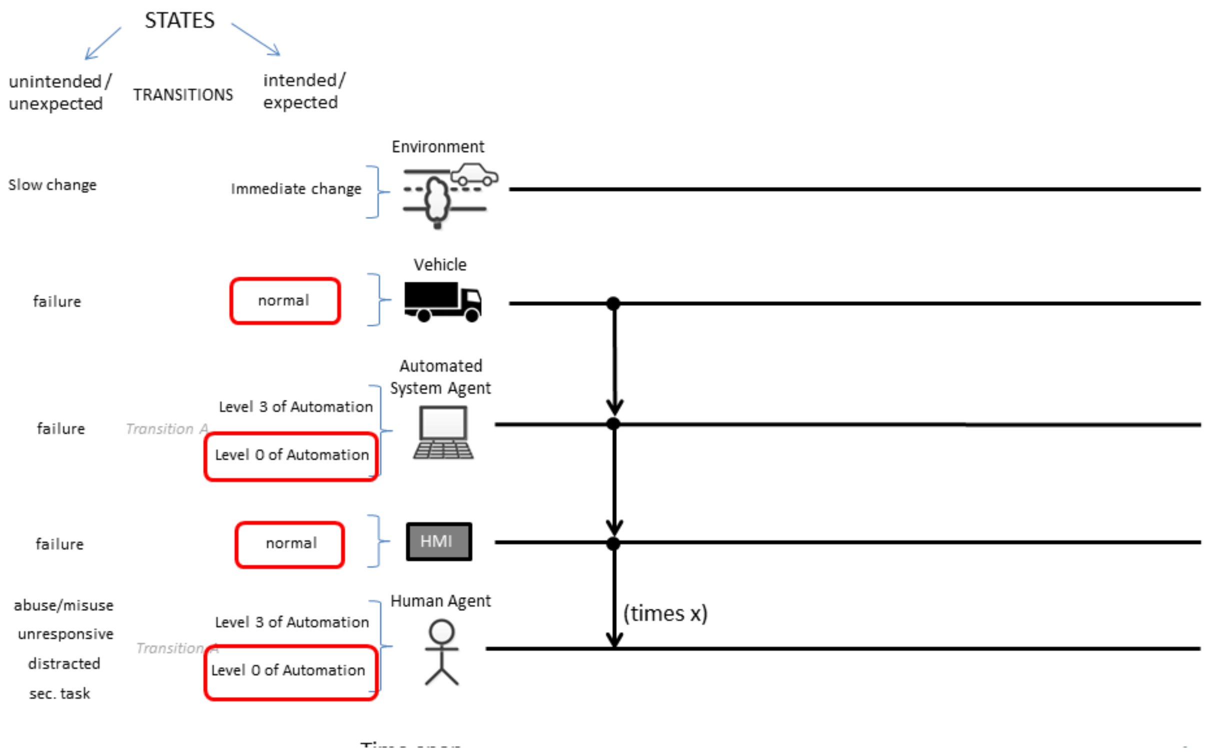


Figure 30: Use-case 2

After a certain amount of time the HA tends to loose attention on driving/monitoring tasks (Bainbridge, 1983). This degradation in awareness may possibly be avoided with the features of Pre-concept 2, see figure 31. Different mode styles help to distinguish one LoA from another by using different cluster design and interaction sources. On Level 0 of automation the cluster design follows the present style with manual instrument panel and physical control buttons. In contrast to this on Level 3 the GPS, trip planner and vehicle status information are displayed on the windscreen by a Head-Up-Display (HUD) and the operations can be controlled by voice commands. The vehicle status information includes data of the vehicle's systems (sensors, cameras picture etc.), current speed, position and distance to other vehicles and set target values. The voices and sounds of the functions and applications differ between the levels enhancing the distinction. The automated system is aided with V2X communication that helps the system to prepare for future acts and manoeuvres by communicating with other vehicles.

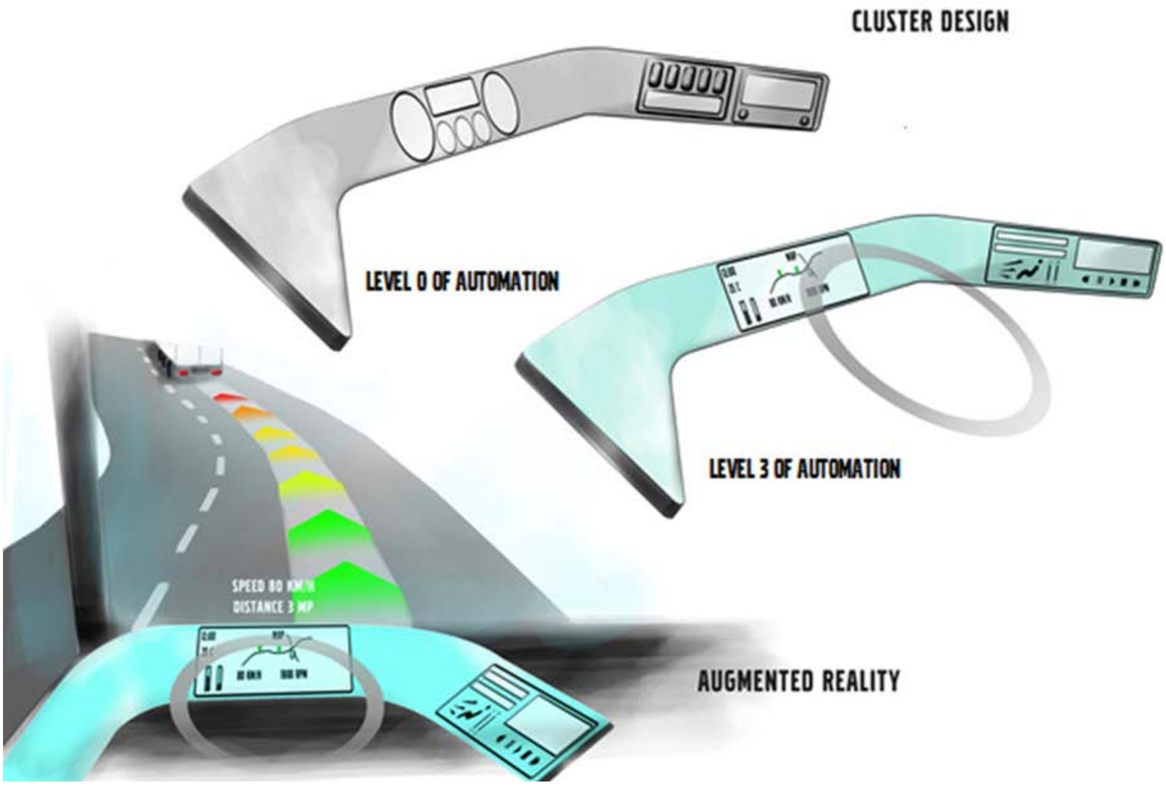


Figure 31: Pre-concept 2

PRE-CONCEPT 3

The third pre-concept and use-case, see figure 32, occurs during an unexpected switch from Level 3 to Level 0 of automation when the vehicle, the ASA and the HMI functions normally but a change in the environment, e.g. heavy rain or fog that blocks the visual sensors, requires the transition. The process starts with information from the environment, communicated by the ASA to the HA via HMI, marked with black arrows pointing downwards. If the HA responds to this notification and confirms the switch to a lower LoA (black arrow pointing upward), the ASA gives the control of all driving tasks to the HA (symbolized by the blue arrow). The ASA keeps informing the HA (grey dotted arrow) about the necessary switch if the HA is unresponsive. If the HA does not switch to Level 0 before the end of the third use-case, the fourth use-case will be executed.

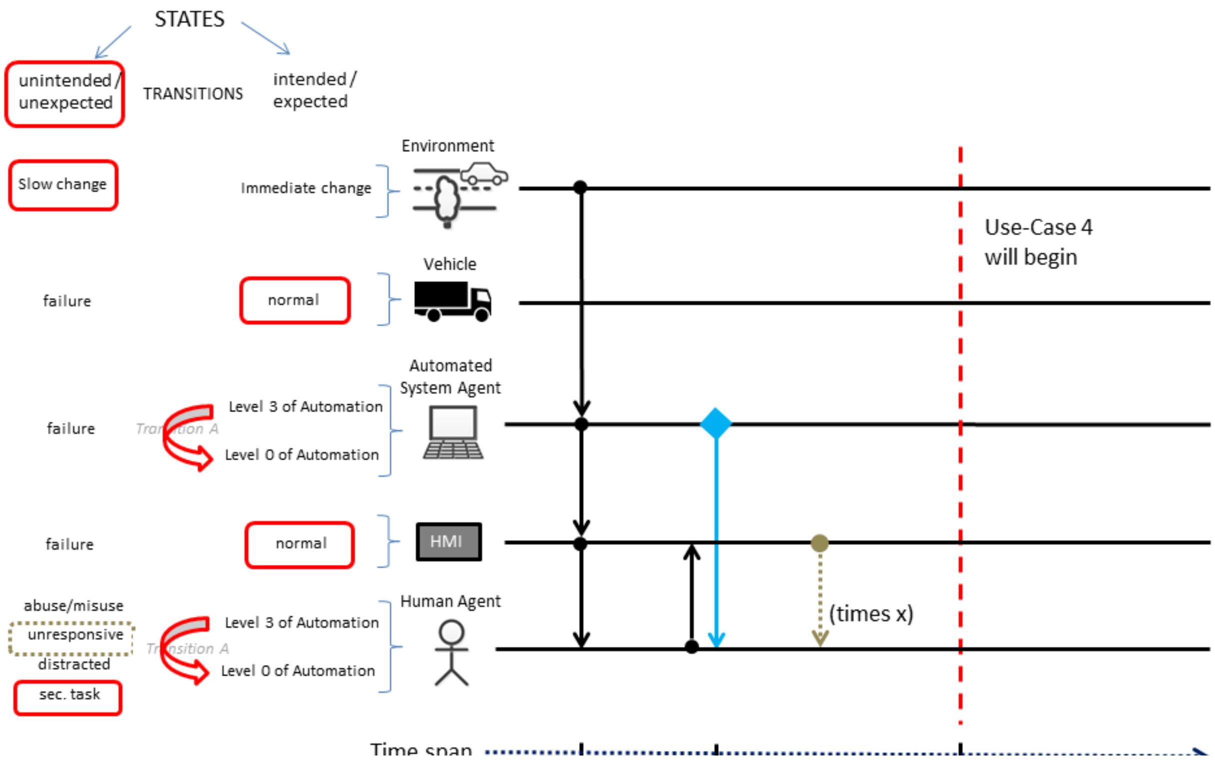


Figure 32: Use-case 3

At the beginning of Pre-concept number three, the HA works on the upper control layers (Targeting and Monitoring) where the driving task only involves setting plans and objectives while the ASA maintains the Tracking, Regulating and partly the Monitoring control-layers. This concept proposes solutions for performing an unexpected but slow (can be measured in minutes) switch to a lower LoA. The aim is to give control of the dynamic driving tasks to the HA by handing over the control of the lower control-layers (Regulating and Tracking).

The features of the third Pre-concept can be seen on figure 33. With the help of the "*Increasing Alarm*" the ASA uses a combination of several types of stimulus to get and draw the HA´s attention to the required direction. The alarm starts with a central visual notification. If the HA does not react to it a peripheral visual stimulus connects to the central visual. If the HA still does not respond sound and vibration in the seat enhances the effectiveness of the alarm system. The desired reaction from the HA is to taking over control of the vehicle. This can be confirmed by "*Visual Handshake*" and "*Physical Handshake*". Visual Handshake means that the HA has to look into check boxes marked on the windscreen and rear-view mirrors by HUD for three seconds ensuring that the HA is aware of the traffic and environmental situations. Physical handshake equals to a physical respond towards the ASA, for instance grabbing the steering wheel, indicating that the HA is ready to take over control. Because the transition between the LoA doesn't require immediate response from the HA there is a time-possibility to do "*Fail Search*". Fail search is a function that reveals problems with the vehicle or the vehicle's system and highlights actions (e.g. Take over control!) and affords solutions (e.g. Go to service, next one is in 10 kilometres!). The arrangement of the cluster elements alters to highlight the most important information, for example when a sensor of the truck is malfunctioning the fail search window is enlarged and the multimedia window is shrunken.

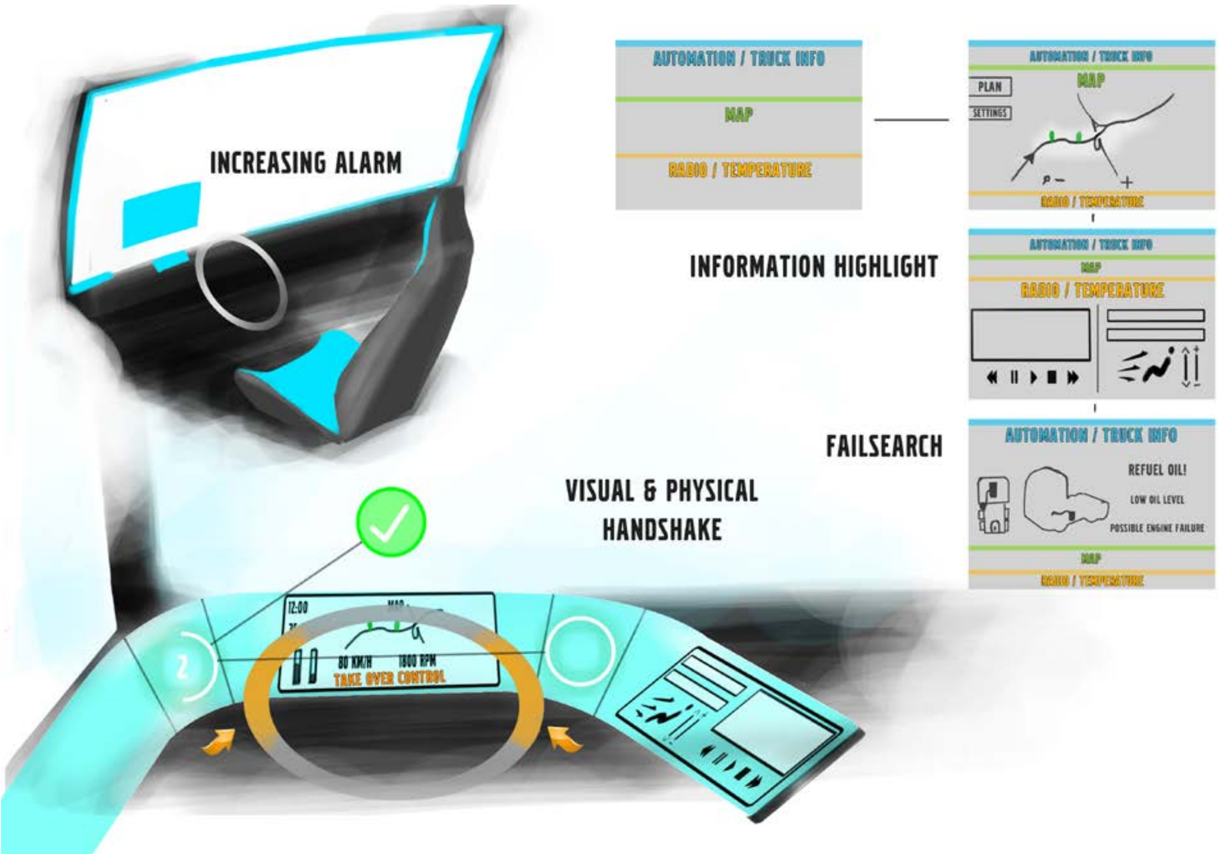


Figure 33: Pre-concept 3

PRECONCEPT 4

Lastly the fourth use-case, see figure 34, deals with an immediate, unexpected transition from Level 3 to Level 0 of automation initiated by failure of the ASA. The fourth situation can be seen as a next step after the third use-case, when after several notification the HA still haven't taken over control. At this point the ASA is no longer capable of maintaining the dynamic driving tasks. Trigger reason can be a loss of sensor inputs, for example the visual sensors loose the lane markings due to heavy rain. The vehicle reports a failure to the ASA that warns the HA about the malfunction (black arrows pointing downward). If the HA responds to this warning immediately (black arrow pointing upward) and confirms the switch, the ASA gives the control of the vehicle to the HA (marked with the blue arrow). But if the HA seems to be unresponsive and does not take over control in a short time, an emergency process, the so called Minimum Risk Manoeuvre (stopping the vehicle safely), will be executed.

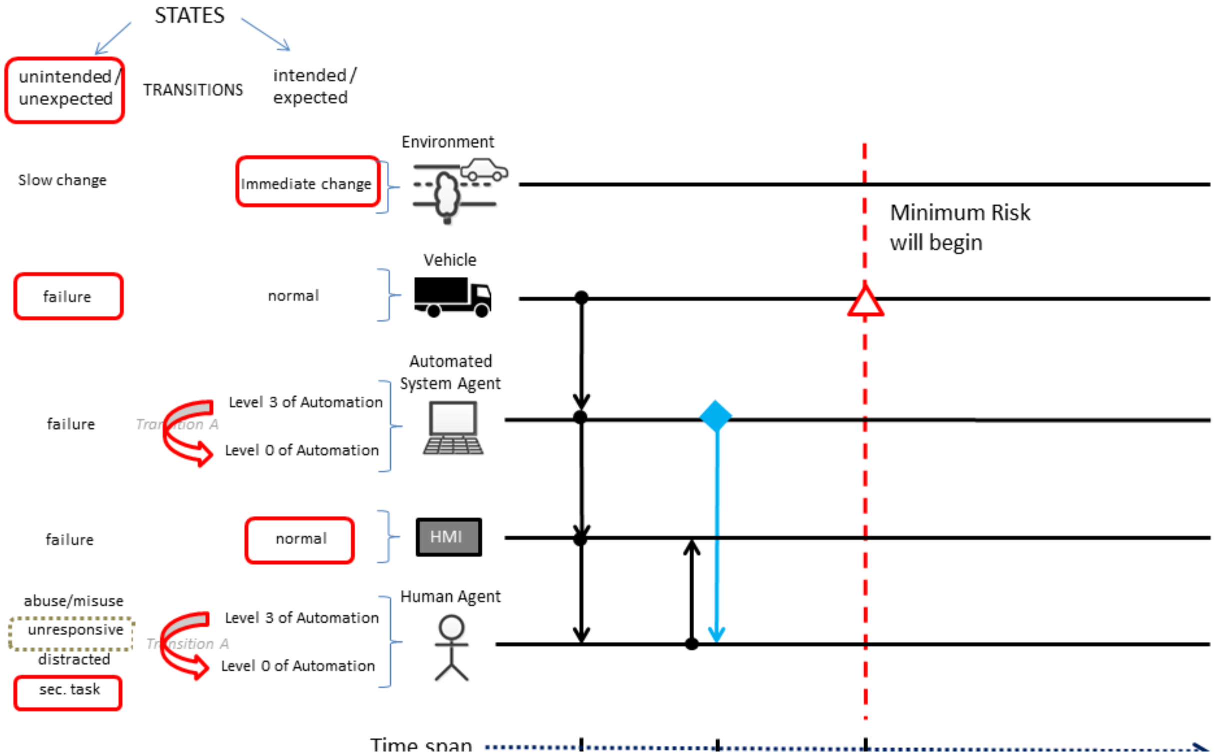


Figure 34: Use-case 4

In the fourth Pre-concept, the HA operates on the upper control layers (Targeting and Monitoring) and the ASA operates on the lower control layers (Tracking, Regulating and partly Monitoring). The vehicle reports an error to the ASA meaning that the ASA is not capable of controlling the lower control layers any more. The aim is to hand over the control of the lower control layers from the ASA to the HA. This use-case can end up in two final states, one is when the HA takes full control over all the control layers and maintain the situation manually or the HA does not take full control and the ASA executes the Minimum Risk Manoeuvre.

The last Pre-concept combines several types of stimulus and ways of information display to get an immediate and appropriate reaction/decision making from the HA, see figure 35. A "*Secondary Task Blocker*" function blocks all the incoming calls, stops the running multimedia system and all the activities that does not relate to the dynamic driving tasks. The Secondary Task Blocker is part of the trucks operating system but it can connect to any device the HA has. The trucks system can not only share data (music, videos, text messages etc.) with the phone but it has the authority of preventing all the incoming phone calls, text messages and all the distracting functions in a hazardous situation. As part of the Task Blocker all the projected information, distracting and disturbing graphic elements of the HUD are removed from the windscreen to make a better visibility. A close auditory stimulus is significantly faster way (than any other types of stimuli) to get someone´s attention (Ho & Spence, 2008). Close sound is operating with speakers mounted in the seat´s headrest close to the ears of the driver. To orient the gaze of the HA a "*Moving Auditory and Visual Stimulus*" runs through the cabin interior towards the front of the cabin. These stimuli are created and driven through several speakers/LED stripes creating a continuous flow of audio and visual stimulus.

Figure 35: Pre-concept 4

7.5 Evaluation II

The second evaluation process made a selection of the pre-concepts to get a satisfying final concept suitable to the set direction and core values. All the participants of the group discussions conclude that one concept feature is more innovative than the other so it is selected for further development. The selected concept feature is the Armed function which will be improved until the final concept. The reason behind this selection is that this function is intended to alter the relation between human and the automated system, which is an interesting area to investigate and test. Currently the automated driving can be switched on manually by the HA when the ASA indicates that it's possible. The Armed functions aims to alter that relation by giving the HA the opportunity to tell the ASA when the transition should occur. When the HA operates the Armed function the DVS shifts to a higher LoA when the vehicle reaches specific trigger points that the HA have decided.

Out of the four use-cases two are selected and further developed. For the Final concept the emergency use-cases are discarded and the focus is put on situations that deal with intended switches between the LoA. The reason is that the emergency situation does not change the human driver's role in performing the dynamic driving task (SAE, 2014). The Final concept will be further developed and presented in the Final Concept chapter.

7.6 Final Concept

The final concept brings the so called “Armed” function (from now on called Armed State) to the DVS which makes it possible for the HA to tell the ASA when it is proper to switch up to Level 3 of automation. This is done by giving the HA the opportunity to select a trigger point where the switch to higher LoA will occur. The trigger point could be either a time, distance or speed that relates to the different autopilots.

The Armed State is combined with a “*Switching Type*” feature. This feature makes it possible for the HA to decide how the transition between the LoA should occur, either manually by a confirmation from the HA or automatically. The automated switching feature aims to decrease the HA´s workload by making the ASA take over control of the dynamic driving tasks as soon as possible. When the automated switching feature is activated an indication is showed on the instrument cluster, see figure 36. When the feature is active the circle around the speedometer will turn to bright yellow while driving in level 0 of automation instead of white-grey. Aside from the different colour on the circle while driving in level 0 of automation the other notifications’ from the instrument cluster are kept the same.

When the DVS reaches the HA defined trigger point the ASA informs the HA about a possible switch or takes over the dynamic driving task depending on the state of the Switching Type feature. In this project the trigger points are pre-set to simplify the simulator study. The trigger point of the HWA is set to 200 meters after entering a motorway and the trigger point of the QA is set to 50 meters after entering a queue.

Figure 36: The instrument cluster visualisation of the Armed State with automated switch activated

The presumed benefit of using the Armed State is that the DVS can switch faster and operate more in Level 3 of automation and by doing so the driving tasks on the Tracking, Regulating and partly on the Monitoring control-layers will be taken away from the HA. The Armed State may reduce the amount of inputs to the Situation assessment by using the automated switch feature. The fewer inputs to maintain could help the HA to operate on the Monitoring control-layer. Compared to the capabilities of the HA, the ASA can predict future actions based on information from the environment, road conditions, infrastructure and traffic elements, and select the most suitable maneuvers/reactions to them. With this prediction ability the DVS might be able to reduce the fuel consumption. Another assumed benefit is the increased safety due to the decreased influence of the human factor, involving issues such as being distracted or fatigued.

7.7 Result of the simulator study

7.7.1 Objective

The first objective analysis investigates the difference between the Armed State with the automated switch feature and manual switch feature. The automated switch feature always activates the higher LoA independent of distractions. The objective data, illustrated in figure 37, illustrates the activation point of Level 3 of automation after a distraction when the manual switch is activated. The diagrams show a time period of 12 seconds after a notification sent about a possible activation of autopilot. The notification is marked with blue line. A distraction (secondary task) has already begun when the notification was sent and ended at the black line marking. The green lines indicate the beginning of the second distraction and the black lines after them mark the end of the second distraction. The red dots mark the time when each participant activated the autopilot.

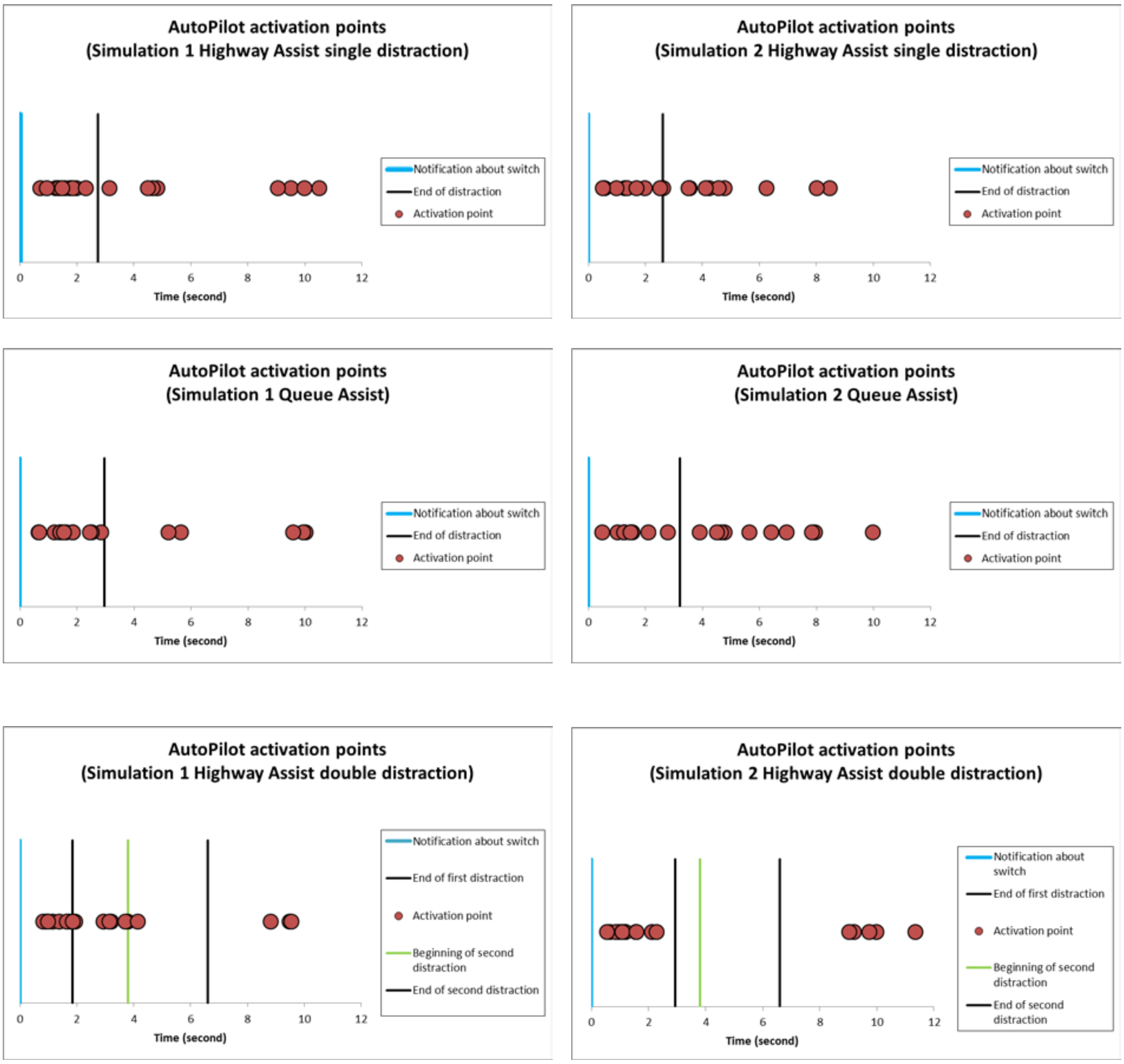


Figure 37: Activating points of the Autopilot

The results show that quite many of the participants didn't activate the autopilot before the second distraction was completed. The percentage of the switches that occur after the distraction task was over:

- Percentage of late activation of Highway Assist: 50%
- Percentage of late activation of Queue Assist: 42%
- Percentage of late activation during double distractions 1_{st}; 2_{nd}: 53%; 33%

The second set of objective data relates to the Armed States usefulness from a safety and fuel efficiency point of view. It compares how the participants are operating the truck regarding speed, see figures 38-39, and HWT, see figures 40-41, with and without automated switch function activated.

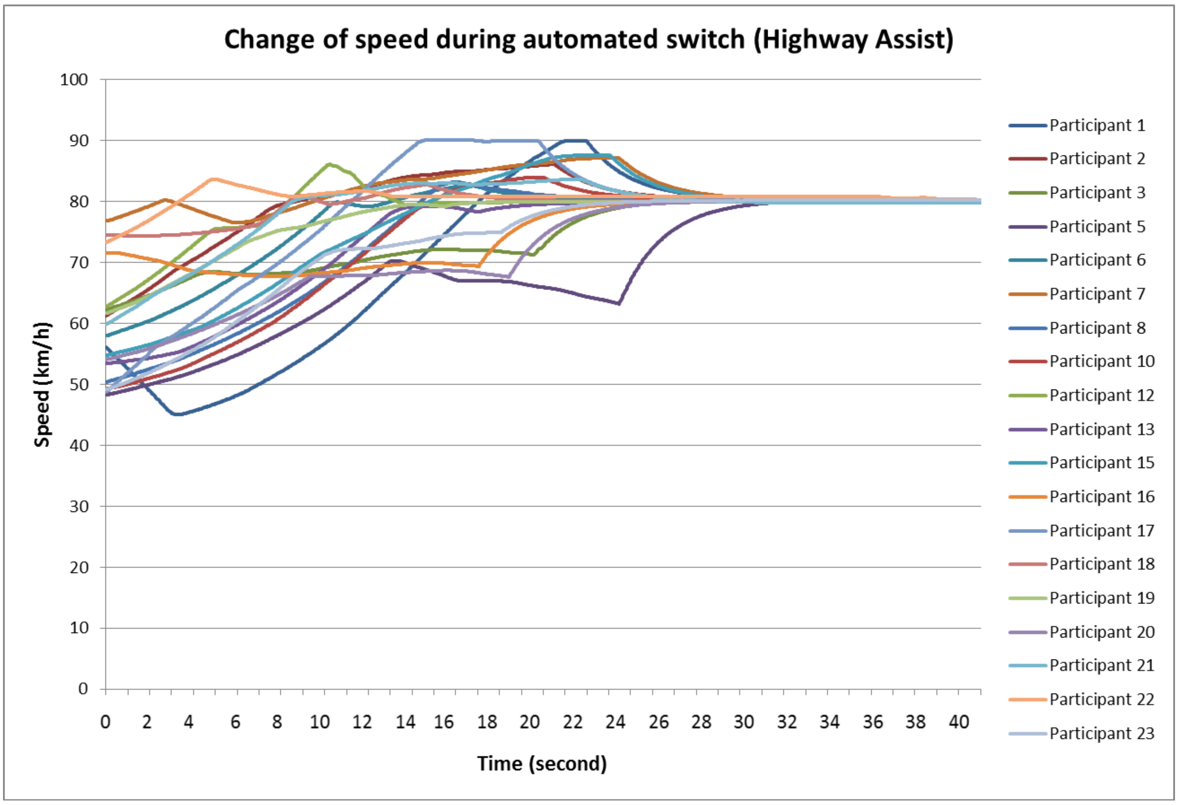


Figure 38: Change of speed during Armed State (Highway Assist)

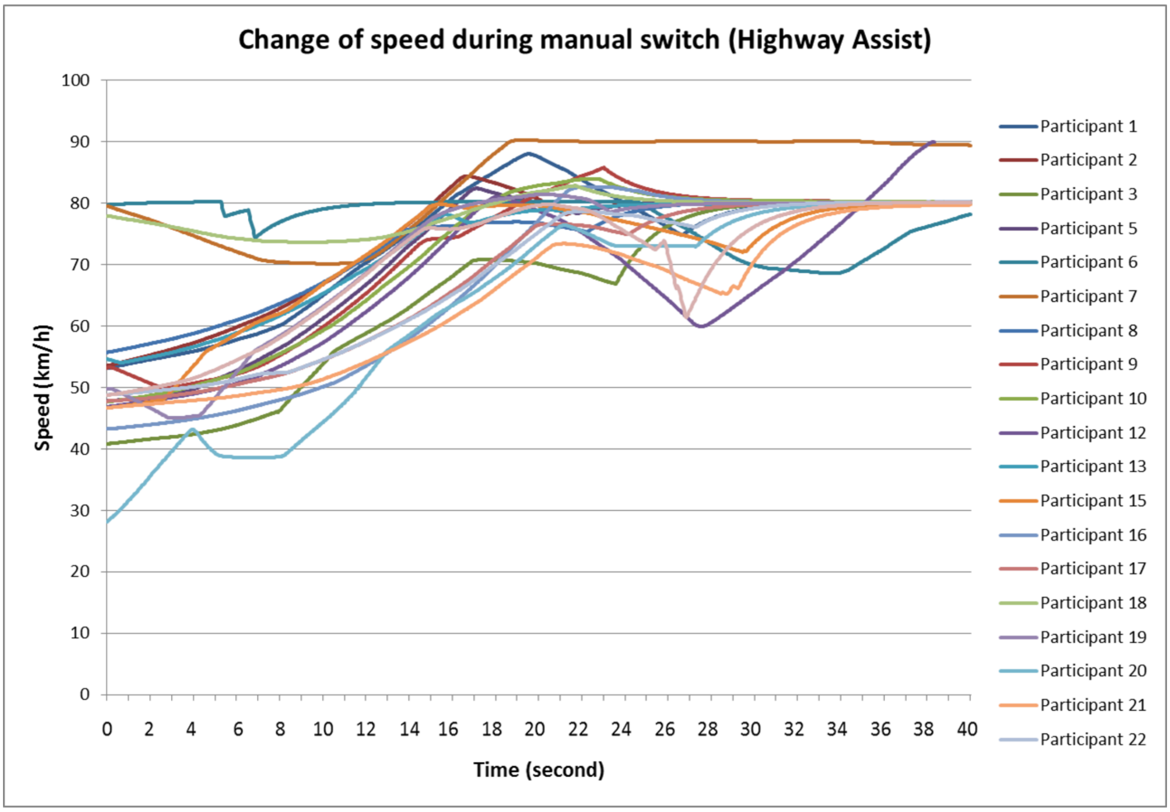


Figure 39: Change of speed during manual switch (Highway Assist)

In figure 38 and 39 the change of speed of each participant was investigated during the activation of HWA. The investigated time period is 40 seconds. In figure 38 the change of speed is shown while using Armed State automated switch and in figure 39 while using Armed State manual switch.

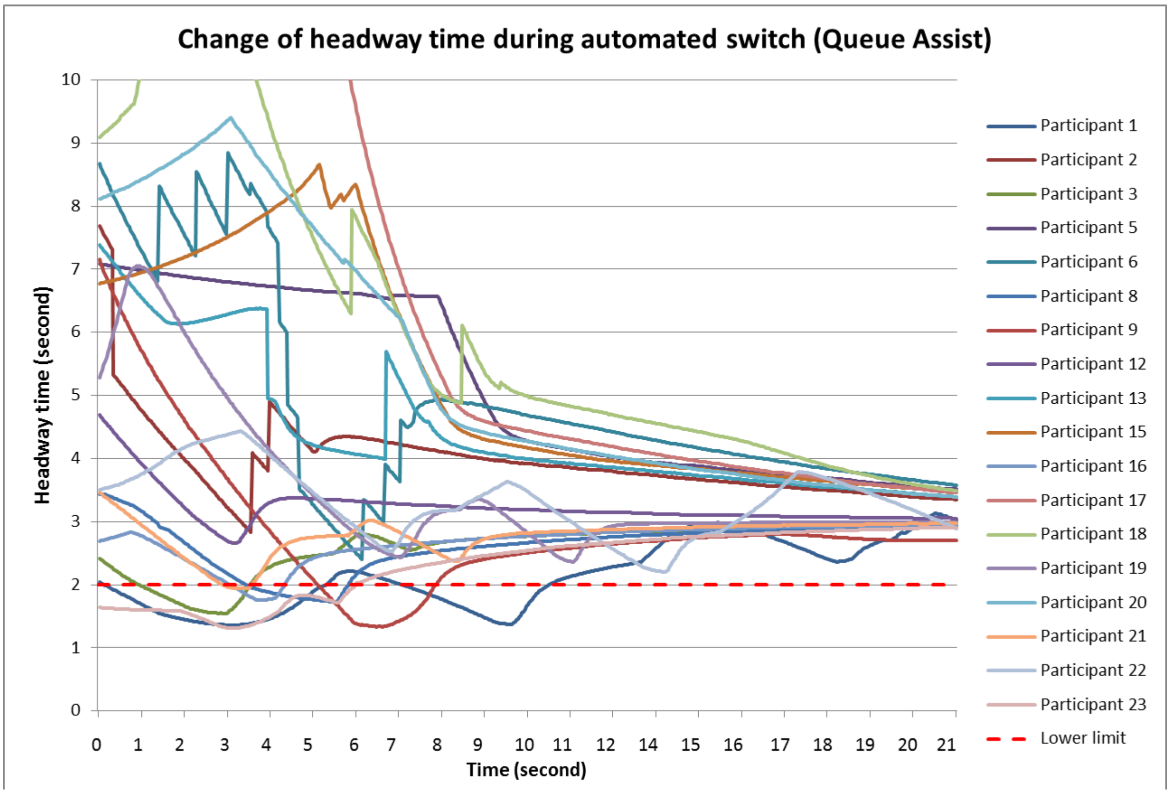


Figure 40: Change of HWT with Armed State activated (Queue Assist)

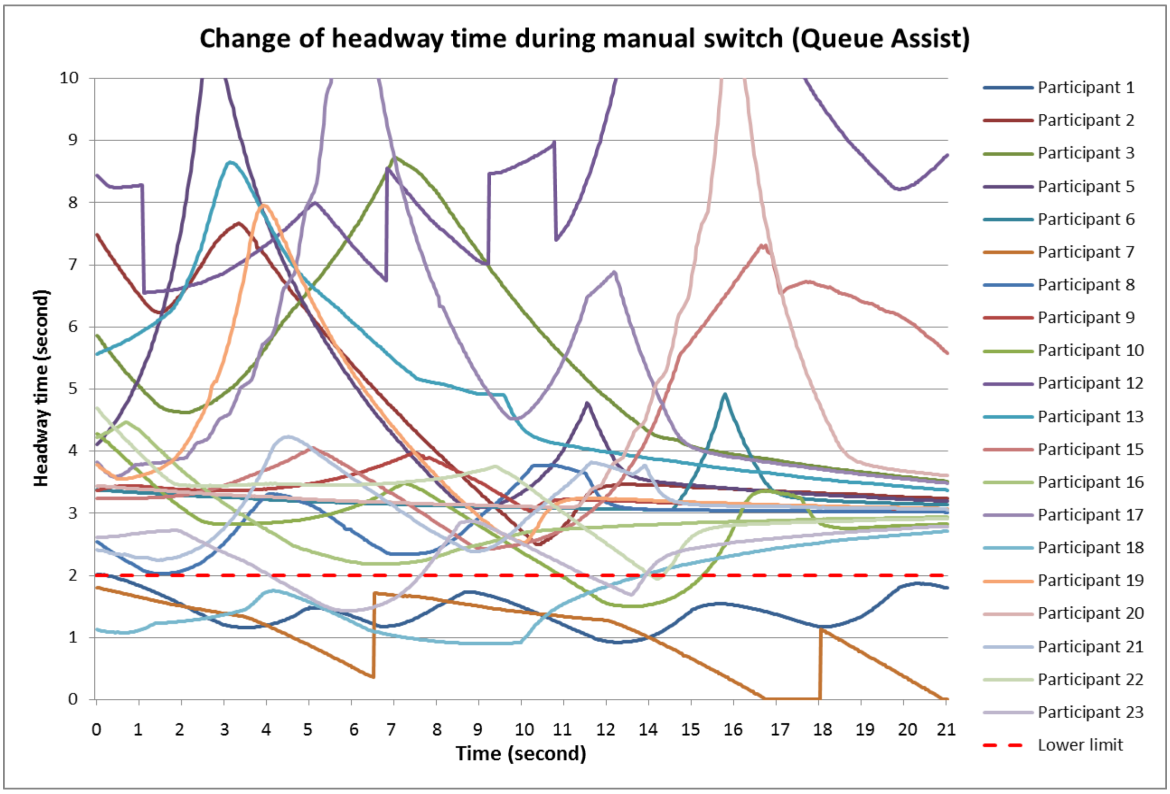


Figure 41: Change of HWT during manual switch (Queue Assist)

Figure 40 and 41 visualize the change of HWT of each participant during the activation of QA. The investigated time period is 20 seconds. In figure 40 the change of headway time is displayed while using Armed State automated switch and in figure 41 while using Armed State manual switch.

7.7.2 Subjective

The Van Der Laan measurement compares rate of satisfaction and usefulness between the HWA, QA and Armed State with automated switch, see table 5. The Van Der Laan model scores usefulness and satisfaction according to a scale from +2 to -2 (positive to negative) from 9 different parameters. The usefulness is measured as the mean of the 1+3+5+7+9 parameter and satisfaction is the mean of 2+4+6+8.

Table 5: Participants opinion about the different driver aiding systems

	Van Der Laan HWA		Van Der Laan QA		Van Der Laan Armed	
Participant	Usefulness	Satisfaction	Usefulness	Satisfaction	Usefulness	Satisfaction
1	0,2	0,25	1,6	1,25	0,8	-0,25
2	-0,2	-0,25	0,6	0,75	0	0,25
3	0,4	0	1	1	0,4	0,5
5	2	2	2	2	2	2
6	1,8	2	1,8	2	-1,4	-1,75
7	1,6	1,5	1,6	1,5	1,8	1,5
8	1,8	1,5	1,6	1,25	1,8	2
9	1,8	2	1,6	1,5	1,8	2
10	1,8	2	2	2	2	2
12	1,2	1,5	1,4	1,5	0,2	0
13	1,2	1,25	1,8	2	1,6	0,75
15	1,2	0,25	1	1	0,4	0,25
16	1,4	2	1,4	2	1,8	2
17	2	2	2	2	2	2
18	0,6	1	0,6	1,5	0,4	1
19	1	1,25	1,6	1,25	1,4	1,25
20	1,4	1,5	2	2	1,8	1,75
21	1,2	1,5	1,8	1,5	1,2	1,5
22	1,6	2	1,6	2	1,6	2
23	1	1,25	1,4	1,75	0,8	0,5
Mean:	**1,25**	**1,33**	**1,52**	**1,59**	**1,25**	**1,21**

7.7.3 Simulator study verification

For the simulator study verification a subjective investigation was conducted regarding to the participants´ understanding of notifications and the usage of the simulator, see figure 42. The questioners aim to give an understanding about the participant opinion of the instrument cluster and the hardware of the simulator.

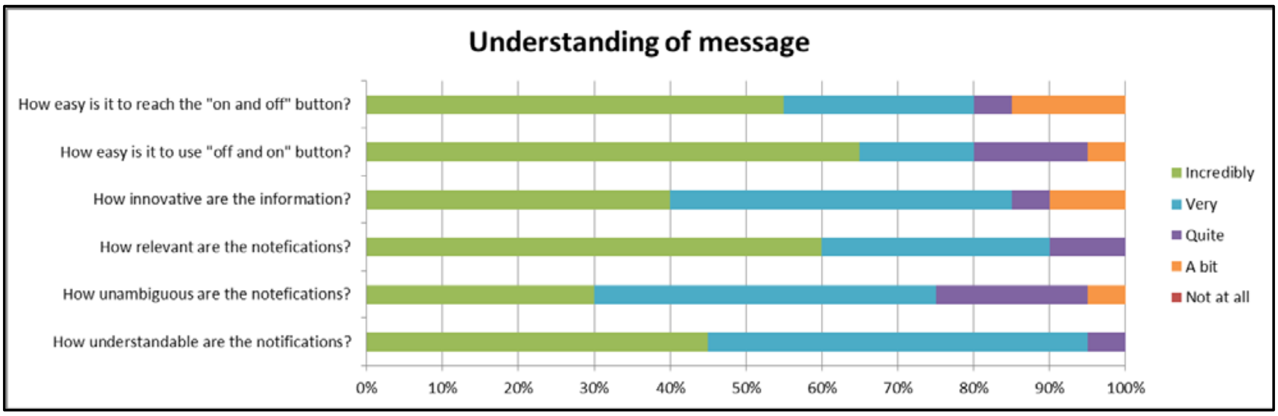


Figure 42: Understanding of cluster messages

8 ANALYSIS OF THE CONCEPT

In the Analysis of the concept section the data of the simulator study is investigated with a focus on the final concept and the relating hypotheses.

8.1 Objective

Analysing the activation point of both the HWA and QA, see figure 37, resulted in a significant amount of the participants activated the autopilot after the secondary task ended. This can be an indication that the participants experience a higher workload because of the distractions (Durso & Dattel, 2004). In contrast to this if the participants use the Armed State with automated switch the activation of the HWA and QA will be executed instantly thus reducing the inputs to the Situation assessment in the Monitoring control-layer, proving Hypothesis 1.

On diagrams 38-39 the moderation of speed is in the focus of investigation. On diagram 38, during Armed State with automated switch the moderation of speed happened in a more controlled and equal way than on diagram 39 when the switch was manual. However the impact of the Armed State´s two different types of switches is less visually striking when observing the speed change. A bigger difference can be seen when measuring HWT in QA activation. Illustrated in figures 37-38 it is easy to see that the trend lines go much smother much faster when the automated switch is activated in comparison with when it’s not activated. This partly proves Hypothesis 2 because the results illustrate the safety benefits while driving in higher traffic situation like a queue. But it’s hard to state that the Armed State will have any kind of fuel efficiency effect.

Hypothesis 1 confirmed:	The Final concept can make a significant difference in reaction time when the participant is distracted.
Hypothesis 2 partly confirmed:	The Final concept is meaningful from a safety, but probably not fuel efficiency, point of view.

8.2 Subjective

The analysis of the Van der Laan tables resulted in that the QA got the highest mean value for both usefulness and satisfaction. The HWA got a bigger satisfaction value than the Armed State but they both got the same mean value with regard to the usefulness. The red marked data in the Armed State Van Der Laan was excluded from the mean calculation. The reason for that was that participant number 6 had a lack of understanding of the Armed State and the settings of the simulation study. This resulted in an unfair evaluation of the Armed State which therefore was removed. As illustrated by the results in the Van Der Laan evaluation Hypothesis 3 is confirmed where the perceived usefulness of the Armed State is at the same mean value as the perceived usefulness of the HWA.

Hypothesis 3 confirmed: The Final concept is seen as useful.

8.3 Simulator study verification

The Simulator study verification questioner's main purpose was to ascertain that the participants didn´t have any problems regarding the setup of the simulator that could affect the objective results of the simulation. The result of this subjective investigation shows that the participant had a high understanding of the information presented by the instrument cluster and that they didn´t see any physical problems with the setup if the simulator. With this result it's concluded that if the participants had any problems regarding simulator study it was not derived from the HMI.

9 DISCUSSION AND CONCLUSIONS

9.1 Discussion

The basic structure of the ECOM have been used together with the theory of Multi-agent system in development of automated vehicles before (Taylor, 2003), but not in the area of road vehicle. This tested ECOM structure is used and adapted to road vehicles during this project and it resulted in the Adjusted-ECOM. With the help of the Adjusted-ECOM and additional laws and regulations the driving tasks can be determined and divided between the four control layers. During an investigation the performance of the whole DVS is investigated. The current role of the different agents in the DVS, the responsibility for the driving tasks, can be defined. How the agents operate the vehicle and how they share the different driving tasks and perform transitions between LoA can all be investigate with the Adjusted-ECOM.

The Adjusted-ECOM is built upon ECOM which is a well proved method but basically not developed for in-the-loop measurements. The ECOM has a logical structure which in the current study is combined with the J3016 standard which is adapted for road vehicle and is internationally used in big research projects. Another LoA standard developed by the NHTSA is to great extent identical to the J3016 standard. This study investigates transitions between level 0 of automation and level 3 of automation. The definitions of these two levels are identical between these two standards which means that the used standard in the Adjusted-ECOM does not matter for the result of this project.

The Adjusted-ECOM is a newly developed model and it is not yet proven that it actually works. The model needs to be thoroughly tested and the first studies using this model could encounter many possibilities for failure. From false understanding of structure of the model, misinterpret the driving tasks and their position in the control layers to incorrectly chosen measurements, many variables can affect the outcome of the simulations and the validation. Another issue could be that Hollnagel's ECOM model not at all is suited to measure if a DVS is in- or out-the-loop.

During the course of this project vivid discussions have been held between different project stakeholders regarding the definition that says the HA is out-of-the-loop if traffic laws and regulations are violated. People are reluctant to say that the HA is out-of-the-loop when he/she consciously doing a violation. According to the Adjusted-ECOM the HA isn’t necessarily out-of-the-loop when a violation occurs. The HA could create new Goals and Targets in the Targeting control-layer that relates to breaking the law. But if we state that ignoring laws and regulations is a possibility for the HA then we need to state that that is a possibility for all the entities in the traffic situation, making laws and regulations obsolete. If this is the case it’s actually impossible to define a traffic situation. Furthermore the ASA was never deemed to not be out-of-the-loop if it violated laws and regulations. So when the DVS is seen as one entity, and doesn’t have a break down structure of the control-layers, it always needs to follow the laws and regulations because it’s uncertain what control-layers the ASA is responsible for.

Some complications could occur because the BHC is adapted for British traffic and the participants of the study are Swedish citizens. This means that some laws and regulations are not necessary applied to the country that the study is conducted in. For instance in the BHC 103 it is stated *“keep at least a 2 seconds distance to the vehicle in front of the truck”*. This is law does not exist in Sweden but a recommendation can be found regarding a 3 second distance to the vehicle in front. It would be beneficial to use the laws and regulations from the specific country the study is conducted within. But most of the laws and regulations that exist within these compilations regard common driving logic and behaviour. It is presumed that the BHC can function like a source of general traffic laws and regulations that are independent of the country in question. We used the BHC to find set values to investigate, but it could also be used for guidance instead of absolute limits.

Armed State seems to have some beneficial aspects. From the result it's possible to see that the Armed State combined with the automated switch feature helped the participants to maintain speed and distance in a good manner. The simulator study reveals that a significant amount of participants were not able to press the button to activate the Autopilot while they were occupied with secondary tasks, the automated switch feature in the Armed State is a possible solution for that problem. The Armed State helps the HA to handle the tasks in the Monitoring control-layers forced upon the HA by the Targeting control-layer by reducing the operations in the Monitoring control-layer.

By giving the HA the possibility to use a function that alters the behaviour of the DVS in a later stage of the drive the relation between the human and de machine have been significantly altered. Armed State makes it possible for the HA to activate a driving aid somewhere else in time which as we know it never have been done in road vehicles before. By arming the vehicle the HA changing the interaction between the HA and the ASA in such a way that situations where a higher LoA should be activated but isn't could be avoided

The Armed State could work as a safety feature in situations where distractions fast can result in accidents. It seems to have fewer benefits when it's investigated from an economic beneficial point of view. The Armed State will only increase the driving in higher LoA on motorway with a couple of seconds during the transitions between the LoA and this doesn't occurring that often. But the biggest benefit of the Armed State might not lay in fuel efficiency or increased safety but in convenience.

The Armed State is a very simple function that operates in a very complex system. This makes it sometime a bit hard to explain because its simplicity needs to be combined with the complexity of a DVS that operates in a higher LoA. This has resulted in some misunderstandings and/or misinterpretations of what the Armed State is supposed to do. This have resulted in participants thinking that Armed State means that the autopilot is on all the time or that the queue assist will activate instantly resulting in participants driving straight through a queue in high speed. These incidents usually only meant small loss of data during one of the four runs but the misunderstanding once generate a very negative subjective review. Participant 6 had a very faulty understanding regarding the functionality of the Armed State with resulted in the bad scores given in the subjective measurement. These scores for the Armed State are not calculated into the finals result because they were so completely different in comparison with other participants with similar scores. It´s concluded that the subjective scores from participant 6 depend on a misunderstanding and it wouldn't be an honest assessment if these scores for the Armed State were retained.

During the simulator study creating the test routes, calibrating the controllers and the capabilities of the technical components all pose a risk. However the driving tasks are predetermined but if the switching points and the distractions are not placed correctly the simulations will not provide good test results. For instance the badly planned queue in the Simulation 1 was realized when some participants simply overtook the queue and continued driving. This resulted in loss of data about the QA. The performance of the technical components reached their limit many times, causing lagging and crashing simulations. Loss of data and in extreme cases loss of whole runs happened due to these hardware issues. Problems with the controller calibration occurred during test runs. A practice run is provided for the participants before the actual simulation run, still not all of the participants were able to get used to the simulator settings regarding the sensitivity of the steering wheel and the pedals. The dynamics of the driving felt inappropriate as well, caused by sounds and noises, which don´t matched the speed or vibrations. Participants who didn't complain about the unusual parameters of the simulator usual have had the opportunity to participate in these kinds of studies many times before and understood difficulty in creating a realistic environment.

The literature study, which was conducted in this project, wasn't able to find a model, method or tool to measure DIL and as a direct result of that a new DIL measurement tool was created in this report. This doesn't mean that a model that can measure DIL doesn't exist and the literature study could simply have missed it. But if a model exists it can be conclude that it is not as well used or discussed in the area of automated road vehicles as it should with respect to the research questions asked by the different global organisations, especially by the European AdaptiVe project.

9.2 Conclusions

After analysing the data from the simulator studies both the hypotheses regarding the Adjusted-ECOM is confirmed. The model is able to the help the investigator to determine when the DVS is out-of-the-loop during different traffic situations. Furthermore the model helps to determine on which control layer the DVS fails to perform the necessary driving tasks.

The Armed State with the automated switch makes a difference when the HA is distracted from a safety point of view. It doesn't provide significant economic benefits but is considered to be useful by the potential users.

10 RECOMMENDATIONS AND FUTURE WORK

10.1 Recommendations

The Adjusted-ECOM will help developers to create more efficient and adapted driving aid systems that can be incorporated in future vehicles. It's possible with help of an Adjusted-ECOM investigation to conclude in what control layer the HA fails to perform the correct driving tasks. If the investigation can state in what control-layer the problem is located then it is possible for the developers to create an aid to help with that control-layers specific driving tasks.

The amount of being in- and out-of-the-loop tends to be is very individual. Some participants have a high tendency to fall out-of-the-loop while other can stay focused during a whole study. To be able to find out-of-the-loop trend it's recommended to do a quantitative investigation. It's also recommended to use simple measurement so it's easier to see which control layer the participants are failing to complete. It's important to have a well-constructed traffic situation and specific target values that is relevant for that specific situation.

10.2 Future work

The Adjusted-ECOM hasn't been tested before and because the lack of other DIL measurement models can it only be compared with results generated by itself. This makes the validation of the Adjusted-ECOM a bit unsorted and more tests need to be conducted to verify the result of the model. The Adjusted-ECOM is not a final model, it's more in the beginning of its development, and it is expected to change quite much when it getting subjected to more extended investigations. The Adjusted-ECOM can be improved by investigating the effect of the Environmental inputs. This future work can be based on the thought that the Environmental inputs (vibrations, sounds etc.) always effects the HA but the inputs aren't necessarily used.

The Adjusted-ECOM uses the J3016 standard and the main reason for this is that the J3016 standard is adapted for road vehicle and it is internationally used in big research projects. This doesn't mean that this is the final defined description of the LoA and it could evolve to other scales when more research is being done. The Adjusted-ECOM is dependent on a good definition of the LoA. If the J3016 standard rescales the Adjusted-ECOM needs to rescale with it or change to another definition of LoA.

The Armed-State seems to have some aspects that are appealing for the participants in the simulation study. The result of subjective study indicates that the participants think that the Armed State can be a useful feature in a highly automated road vehicle. The subjective measurements are however based on a small scale investigation and more investigations needs to be conducted to determine if Armed State with certainty is a desirable function.

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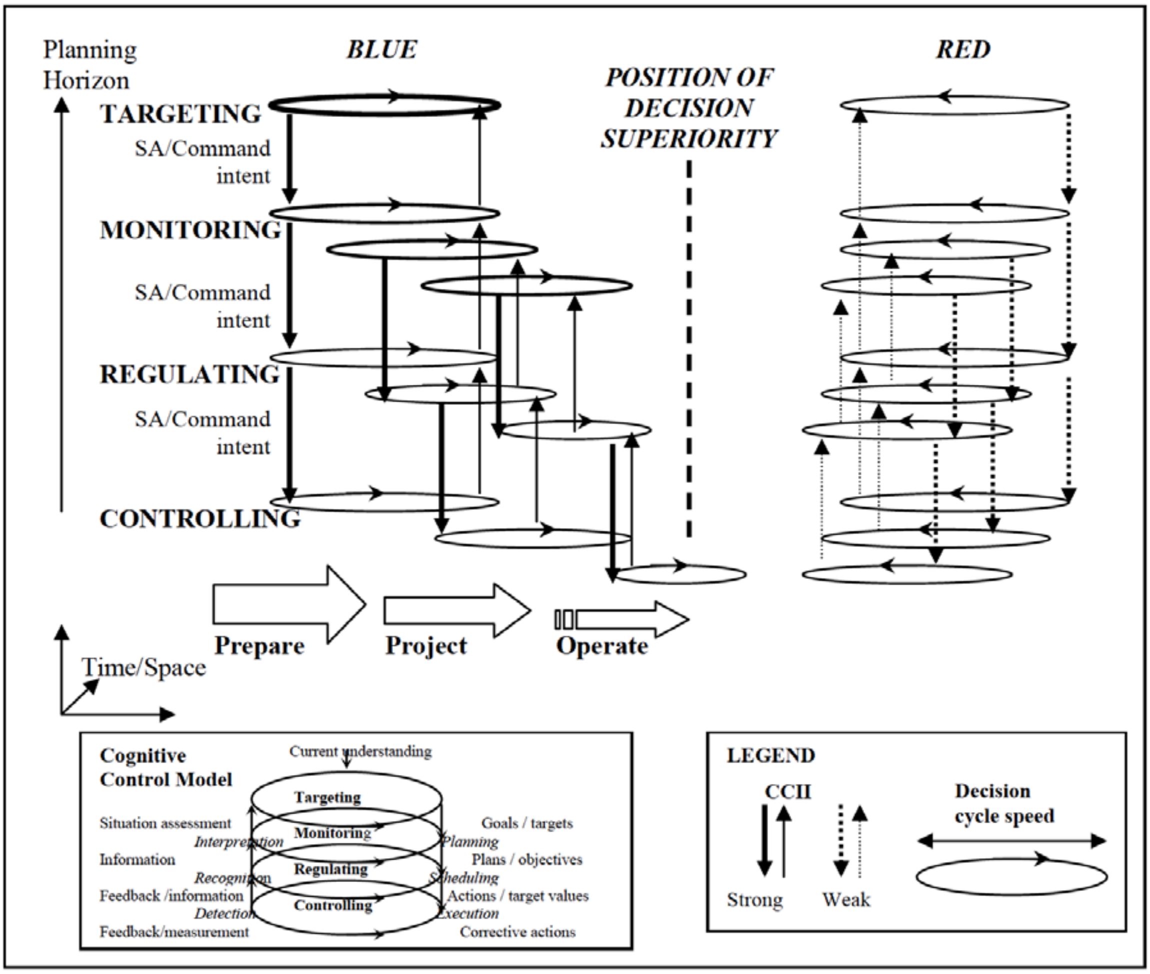
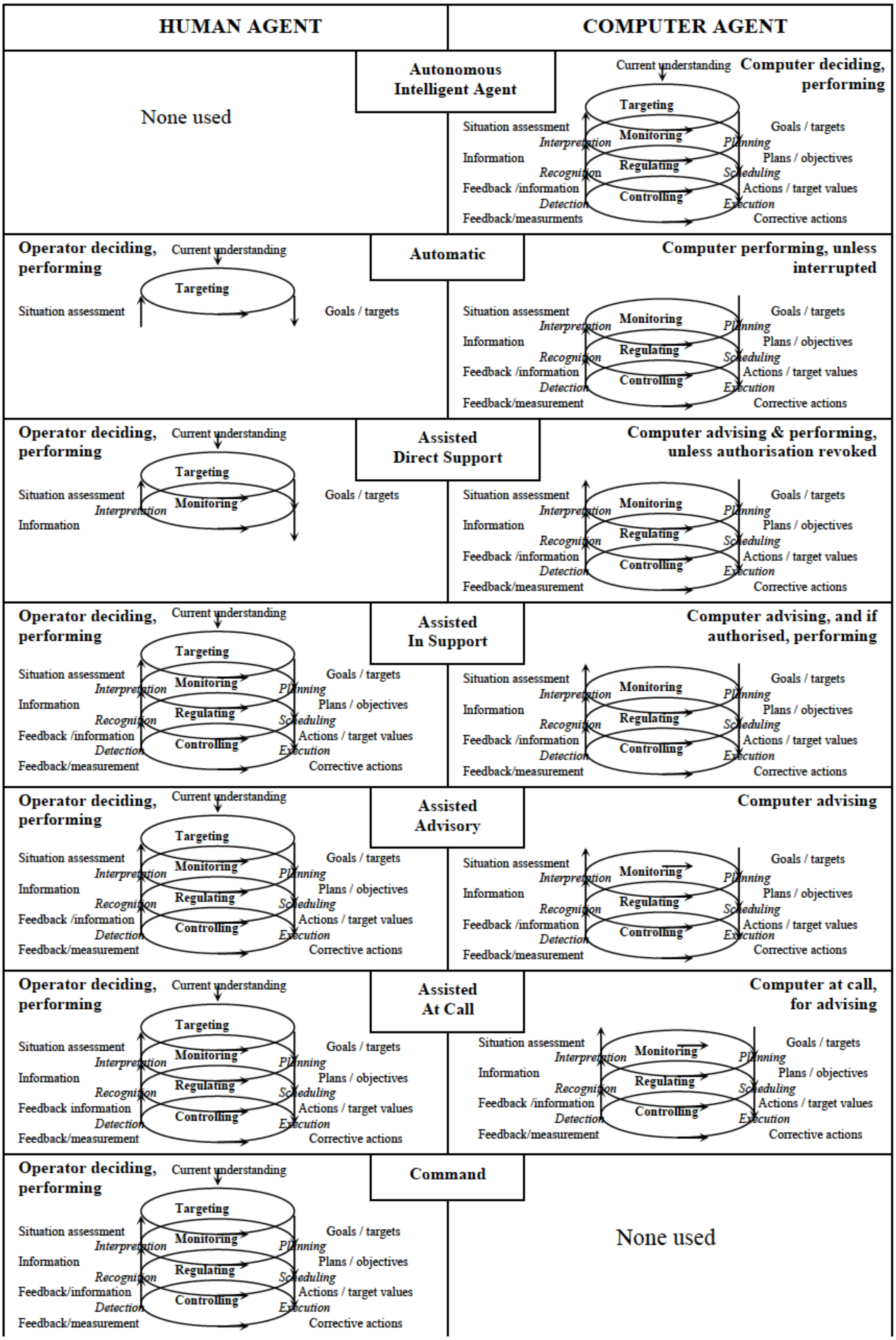
APPENDIX A: SUPPLEMENTARY INFORMATION



Appendix A: Decision Agility through Cognitive Command and Control (Taylor, 2003)



Appendix A: Levels of Autonomy within the Extended Control Model Framework (Taylor, 2003)

APPENDIX B: SUBJECTIVE MEASURMENT

Ref.		
DE1	Ålder?	….. år
DE2	Kön	□ man □ kvinna
DE3	Nationalitet	
DE4	Antal år som lastbilsförare?	………..år
DE5	Typ av körkort?	
DE6	Hur ofta kör du lastbil?	□ dagligen □ 5-6 dagar/vecka □ 3-4 dagar/vecka □1-2 dagar/vecka □ mindre än 1 dag i veckan
DE7	Vilken typ av lastbil kör du mest?	
DE8	Vilken typ av transport kör du mest?	❒ distribution ❒ Fjärr ❒ Konstruktion ❒ Annat
DE9	Antal mil i arbetet per år	❒ mindre än 3000 mil ❒ 3000 – 7000 mil ❒ 7000 – 15000 mil ❒ 15000 mil eller mer
DE10	På vilken typ av vägar kör du? Ange i procent (ungefär)	… % stad, tätort … % landsväg … % motor väg
DE11	Vilken typ av växellåda kör du mest?	□ Manuell □ Automatisk □ halv-automatisk
DE12	Vilken typ av gods kör du mest?	□ Stycke gods □ Bulk

		☐ Timmer ☐ Livsmedel ☐ annat:_________________
DE13	Hur stor last brukar du köra?	☐ mindre än 2 ton ☐ 2-5 ton ☐ 5-10 ton ☐ 10-20 ton ☐ 20-40 ton ☐ 40-60 ton ☐ mer än 60 ton
DE14	Har du gått någon kurs/utbildning i att köra bränsleeffektivt *(eco-driving, sparsam körning)?*	☐ Nej ☐ Ja, för lastbil, När?_______________ ☐ Ja för bilförare, När?________________
DE17	Har du någon erfarenhet av system som stöder din körning? *(Farthållare, Adaptive Farthållare (ACC), Filbytesassistans (LCS), Filhållningshjälpen (LKS), Hel eller halvautomatisk parkeringshjälp etc.)* *Om "Nej" hoppa över DE18*	☐ Nej ☐ Ja I personbil ☐ Ja i lastbil, vilket system?______________
DE18	Hur länge har du kört/körde du med detta system?	☐ mindre än 3 månader ☐ 3-6 månader ☐ 6-12 månader ☐ mer än 12 månader

Formulär 1: Uppfattning av AutoPilot

Detta är ett mått på hur du uppfattar de olika automationernas användbarhet och ditt gillande av dessa. Du fyller igenom att kryssa i en av rutorna för varje ordpar. Exempel:

AutoPilot är **mycket** användbart:

		1	2	3	4	5	
1	Användbart	**X**					Oanvändbart

AutoPilot är användbart:

		1	2	3	4	5	
1	Användbart		**X**				Oanvändbart

AutoPilot är **lite** användbart:

		1	2	3	4	5	
1	Användbart				**X**		Oanvändbart

AutoPilot är **helt** oanvändbart:

		1	2	3	4	5	
1	Användbart					**X**	Oanvändbart

AutoPilot **är varken eller**:

		1	2	3	4	5	
1	Användbart			**X**			Oanvändbart

Vad är din bedömning av AutoPilot på motorväg (Highway Assist) som du nyss har kört med?

Min bedömning av functionen som helhet							
		1	2	3	4	5	
1	Användbart						Oanvändbart
2	Behagligt						Obehagligt
3	Dåligt						Bra
4	Tilltalande						Störande
5	Gör nytta						Onödigt
6	Irriterande						Angenämt
7	Stödjande						Värdelöst
8	Önskvärt						Icke önskvärt
9	Stimulerande						Tröttande

Vad är din bedömning av <u>AutoPilot i kö</u> (Queue Assist) som du nyss har kört med?

Min bedömning av systemet som helhet							
		1	2	3	4	5	
1	Användbart						Oanvändbart
2	Behagligt						Obehagligt
3	Dåligt						Bra
4	Tilltalande						Störande
5	Gör nytta						Onödigt
6	Irriterande						Angenämt
7	Stödjande						Värdelöst
8	Önskvärt						Icke önskvärt
9	Stimulerande						Tröttande

Vad är din bedömning av <u>funktionen</u> (Armed-State + automated switch) som du nyss har kört med?

Min bedömning av functionen som helhet							
		1	2	3	4	5	
1	Användbart						Oanvändbart
2	Behagligt						Obehagligt
3	Dåligt						Bra
4	Tilltalande						Störande
5	Gör nytta						Onödigt
6	Irriterande						Angenämt
7	Stödjande						Värdelöst
8	Önskvärt						Icke önskvärt
9	Stimulerande						Tröttande

Ref.	**Förståelse av meddelanden (symbol+text)** Understanding of message	1= Inte alls	2= Sådär	3= Ganska	4= Mycket	5= Väldigt
UM1	Hur förståeliga är meddelandena som presenteras?	☐	☐	☐	☐	☐
UM2	Hur entydiga är meddelandena som visas?	☐	☐	☐	☐	☐
UM3	Hur relevant är informationen som presenteras?	☐	☐	☐	☐	☐
UM4	Hur mycket kräver informationen från systemet att jag agerar?	☐	☐	☐	☐	☐
UM5	Hur intuitiv är informationen som presenteras?	☐	☐	☐	☐	☐
UM6	Hur lätt är det att använda *”av och på”* knappen?	☐	☐	☐	☐	☐
UM7	Hur lätt är det att nå *”av och på”* knappen?	☐	☐	☐	☐	☐

Övriga tankar angående instrumentpanelen:____

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