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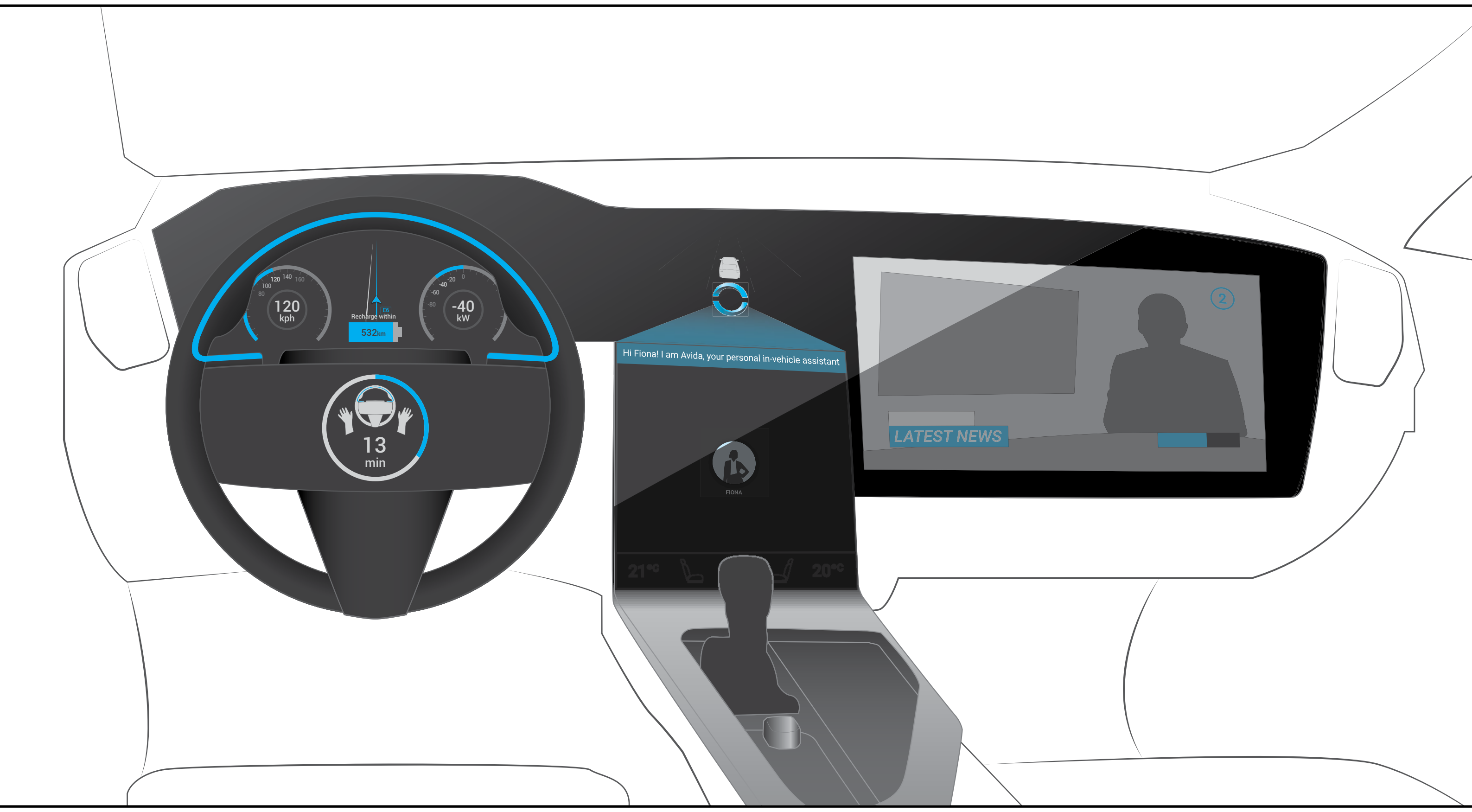

AVID - Autonomous Vehicles' Interaction with Drivers

An investigation of the embodiment of vehicle-driver communication and development of an HMI concept

M.Sc. Thesis in Industrial Design Engineering

ERIK AREMYR
MARTIN JÖNSSON

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2017

Department of Product- and Production Development
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Master of Science Thesis

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MARTIN JÖNSSON

SUPERVISOR: HELENA STRÖMBERG
EXAMINER: LARS-OLA BLIGÅRD

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Chalmers University of Technology
SE-412 96 Göteborg, Sweden
Telefon +46(0) 31-772 10 00

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PREFACE

This master's thesis presents a project covering 30 ECTS credits, which was conducted between September 2016 and February 2017. The project was conducted by two students at the Industrial Design Engineering programme at the division of Design and Human Factors, department of Product and Production Development, at Chalmers University of Technology.

Many people have helped us during the course of this project. First of all, we would like to thank all the experts within the fields of HMI, HRI, and autonomous vehicles, who aided us in the research phase to understand the complexity surrounding the introduction of autonomous vehicles. A special thanks to Annie Rydström at Volvo Car Corporation and Victor Lundgren at Viktoria Swedish ICT who aided us in the preparations for the user test.

We would also like to thank the participants who volunteered in the user test. We are especially grateful for the support of Sofia Larsson and Sophie Challis, who acted as pedestrians during the test and relentlessly withstood rain and wind to aid us, and Kristian Erskog, who gave life to one of the test conditions. Furthermore, we want to thank Maksim Hansén Goobar, Jonas Isaksson, Filip Oscadal and Kamil Dolezal, for bringing inspiration and positive energy into the project and for helping us perform at our highest level when needed.

Lastly, we want to direct our deepest thanks to the researchers at the division of Design and Human Factors at Chalmers. Thank you Fredrick Ekman and Mikael Johansson for taking your time to discuss ideas and advise us during the project. Furthermore, we want to thank you Lars-Ola Bligård, examiner of the project, for sharing your thoughts regarding our work and for helping us in the HMI concept ideation. Last but not least, a special thanks to our supervisor and project owner, Helena Strömberg, for guiding us through the process and for always making time for us in your busy schedule - without your dedication, this project would not have been possible.

ERIK AREMYR

MARTIN JÖNSSON

ABSTRACT

Background: Within the next five years, several major car manufacturers are expected to release their first generation of highly automated vehicles (HAV). The success of autonomous driving (AD) technology is highly dependent on user acceptance - and if the users do not perceive its benefits, it will not be utilised. Previous studies have identified trust as a major factor affecting user acceptance and that trust can be affected by using anthropomorphism (humanlikeness) as a human-machine interaction (HMI) design tool. However, few studies have investigated which variables, apart from trust, that affect user acceptance of HAV and how these relate to anthropomorphism.

Aim: This thesis aimed to explore how anthropomorphism can be used in HMI design to facilitate the creation of user acceptance of HAV.

Method & Process: The project included a literature review aimed to create a theoretical framework for an in-vehicle user test, which was conducted on a test course using ten subjects and three conditions based on different degrees of anthropomorphism. The results from the theory and the user test were synthesised in HMI design guidelines, which were used to create an HMI concept.

Results: The literature review indicated a correlation between anthropomorphism, trust, and user acceptance. However, no significant difference in levels of trust between the three conditions could be found in the user test. Instead, it was found that anthropomorphism, as part of the interface characteristics, indirectly through perceived usefulness and perceived ease of use, affects user acceptance. This finding resulted in a proposed model for vehicle-driver (V2D) communication strategies, named AVID Model. Furthermore, an example concept named Vision AVID was created to illustrate the model's utility in HMI development.

Implications: The proposed HMI concept could be used to aid HMI designers and researchers in creating HMI concepts that increase user acceptance of HAV.

Keywords: *Autonomous vehicles, Human-machine interaction, Embodiment, Anthropomorphism, User acceptance, Trust, Vehicle-driver communication*

ABBREVIATIONS

AD Automated Driving

DVS Driver-Vehicle System

HAI Human-Automation Interaction

HAV Highly Automated Vehicle

HMI Human-Machine Interaction

HRI Human-Robot Interaction

Contents

1 INTRODUCTION

The introduction presents a background on the development of highly automated vehicles (HAV) in relation to human-machine interaction (HMI) as well as the aim, objectives, and delimitations of the project.

1.1 Background

The development of highly automated vehicles (HAV) is rapidly progressing and within a few years, several of the major car manufacturers are expected to release their first generation (Muoio, 2016). Automation in vehicles is predicted to improve road safety, decrease the need for parking space and add comfort to the driver (Goodall, 2014; Litman, 2016). However, there is still a lack of understanding regarding the effects of automation on human behaviour in the context of HAV. This applies in particular to the case of the first generation, in which the driver may be expected to resume manual control whenever the vehicle is incapable of controlling itself (Cunningham and Regan, 2015). Hence, it is important to fully understand the relationship between driver and highly automated vehicle in order to design an human machine interaction (HMI) that clearly communicates the capabilities and limitations of the system to the driver.

A part of this relationship concerns user acceptance. Cunningham and Regan (2015) state that user acceptance is crucial for the future of HAV technology. Without user acceptance, the technology and its associated benefits will not be utilised. To define user acceptance, Ghazizadeh, Lee and Boyle (2011) propose an Automation Acceptance Model (AAM) that builds on the Technology Acceptance Model (TAM) by Davis et al. (1989). TAM suggests that technology acceptance is affected by perceived usefulness and perceived ease of use as well as external variables, and AAM states that automation acceptance includes these factors, but is also dependent on trust and task-technology compatibility. Evidence of the relationship between trust and acceptance can also be found in a recent survey of public opinion about HAV, including 1,533 persons in the U.S., U.K. and Australia. The survey aimed to gain insights into what the general public are most worried about regarding HAV and clearly indicated that trust is a major factor affecting acceptance (Schoettle and Sivak, 2014).

Previous research has investigated which variables affect trust in HAV. For instance, Waytz, Heafner and Epley (2014), investigated how anthropomorphism affects trust in autonomous vehicles. Anthropomorphism can be described as the "process of inductive inference whereby people attribute to nonhumans distinctively human characteristics, particularly the capacity for rational thought (agency) and conscious feeling (experience)" (Gray, Gray and Wegner, 2007). In their study, Waytz, Heafner and Epley (2014) concluded that anthropomorphic features such as name, gender, and voice, used in vehicle-driver communication, correlated positively with increased trust in the vehicle's ability to perform competently. They suggested that by blurring the line further between human and nonhuman by utilising anthropomorphism, the driver's willingness to trust technology in place of humans would increase. Anthropomorphism has also been subject to investigation as a variable affecting the efficiency of HMI performance in other research areas. For instance, previous research conducted within the field of Human Robot Interaction (HRI) has shown that humans prefer human-like verbal interaction with intelligent service robots (Khan, 1998). Although research from different areas seems to be congruent in suggesting a positive correlation between anthropomorphism and trust, further user tests need to be conducted to fully validate the results in an HAV context. Also, there is a need for further investigations regarding which variables, apart from trust, affect user acceptance of HAV and how these relate to anthropomorphism.

1.2 Aim

This thesis aims to explore how anthropomorphism can be used in HMI design to facilitate the creation of user acceptance of HAV.

The following research questions are addressed in the thesis:

RQ1: Which variables affect user acceptance for HAV?

RQ2: How are these variables influenced by HMIs based on different degrees of anthropomorphism?

1.3 Objective

The objective of the thesis is to make the findings from the two research questions tangible in the form of an HMI concept.

The objective is achieved by:

1. Defining probable scenarios and identifying events during the interaction between driver and HAV which are critical for assessing variables affecting acceptance.

2. Based on the identified events, developing and evaluating function models based on different degrees of anthropomorphism.

3. Based on the evaluation of the function models and HMI theory, developing an HMI concept for the first generation of HAV.

1.4 Delimitations

- The thesis focuses on SAE level 4 autonomy only.
- Only automated vehicles expected to be available within five years from now were considered in the HMI concept development.
- The thesis only considers autonomous driving (AD) mode.

1.5 Report Disposition

In figure 1.1, the report disposition is shown, along with the different phases of the project process. The report is divided into eight chapters, which are described briefly below:

1. **Introduction** - Here, the background, aim, objective, and delimitations of the thesis are presented.
2. **Theory** - This chapter presents the theoretical concepts and research related to the topics handled in the thesis.
3. **Methodology** - This chapter describes the methods used in the project and functions as an encyclopaedia for the reader.
4. **Process** - This chapter describes the process for each phase of the project.
5. **User Test** - This chapter presents the results from the user test.
6. **HMI Design Guidelines** - This chapter presents a set of design guidelines based on theoretical and empirical findings.
7. **HMI Concept** - This chapter presents a model for vehicle-driver communication and a vision for an HMI in HAV.
8. **Discussion** - The final chapter discusses the contributions, results, and process of the project. It ends with a recommendation for future work.

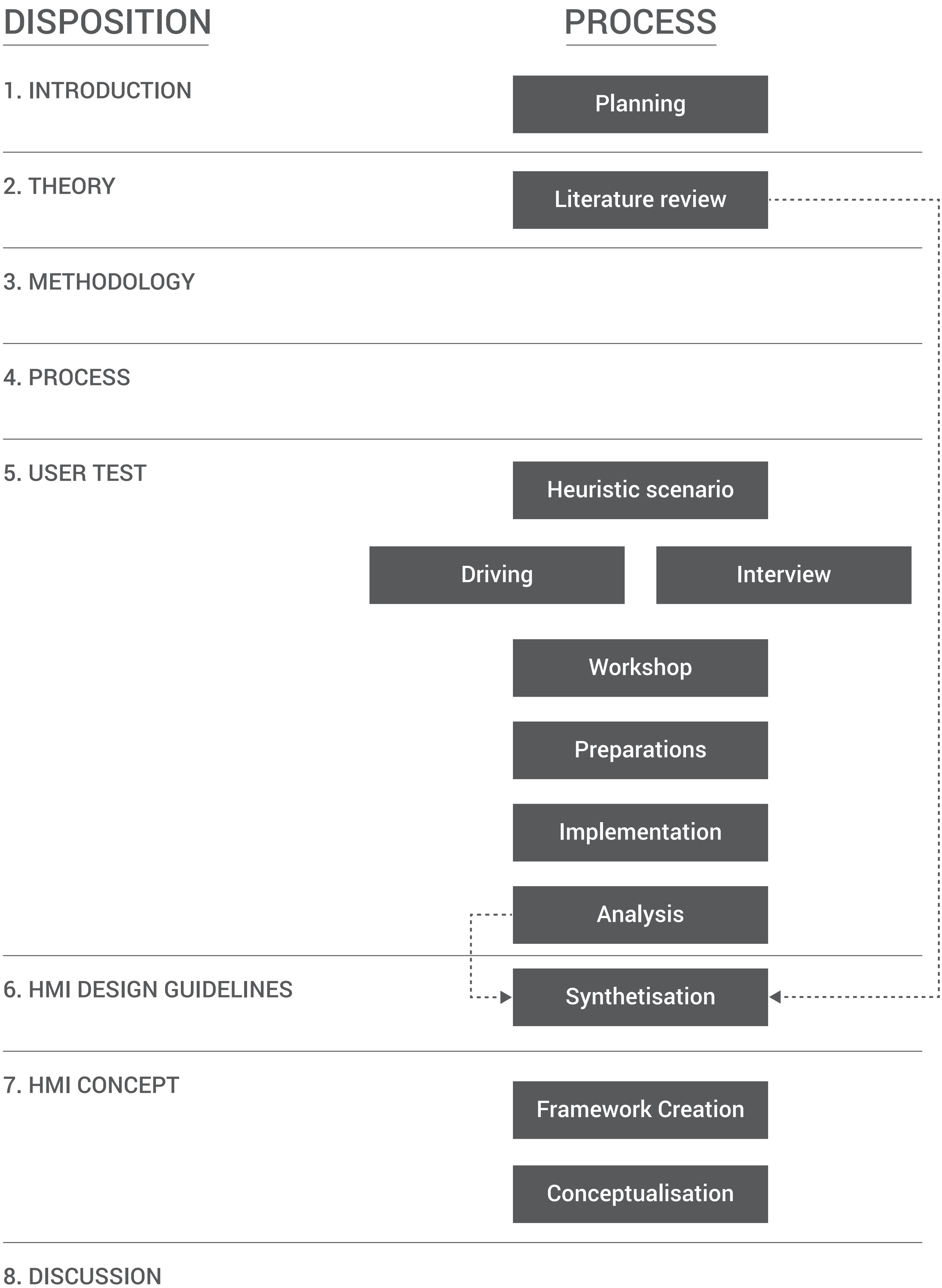

Figure 1.1: Report disposition and project process.

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THEORY

This chapter includes theory regarding automotive automation, the driver-vehicle system, HMI, and finally a description of the relationship between acceptance and anthropomorphism. This is in order to give the reader an understanding of concepts and research within fields relevant to the project. After this, recommendations for HMI design are summarised, followed by a summary of the theory's implications on the thesis work. The theory forms the basis for the user test and HMI concept development.

2.1 Automotive Automation

In this section, the basic definitions, classifications, and taxonomies of automation are described and related to the automotive context. Benefits and issues with automation are then discussed. This is in order to give the reader an understanding of the concept of automation and how it may affect users.

2.1.1 Classifications & Taxonomies

Automation can mean everything from automating one task in a large process to automating the whole process. A machine that is a part of automation has a level of autonomy, which exists on a continuum between no autonomy and full autonomy (Beer, Fisk and Rogers, 2014). However, it is hard to meaningfully define levels of autonomy on a continuum, and so a classification or taxonomy can help create an understanding of what is meant when discussing different levels of autonomy. Worth mentioning is that much of the literature refers to a machine with some degree of autonomous capabilities as a robot, and much of the research about interaction between humans and automation has been conducted within the field of HRI.

Beer, Fisk and Rogers (2014, p. 77) define autonomy as:

> The extent to which a robot can *sense* its environment, *plan* based on that environment, and *act* upon that environment with the intent of reaching some *task-specific goal* (either given to or created by the robot) without external *control*.

Based on this definition, they propose a taxonomy of levels of robot autonomy consisting of ten levels ranging from manual control to full autonomy. Each level is described in terms of which agent (human or robot) senses, plans, and acts in order to reach a task-specific goal, and is exemplified with literature.

Applying the definitions for levels of robot autonomy on vehicles can be done by comparing these to the SAE J3016 standard, which defines levels of driving autonomy (see figure 2.1) (SAE International, 2016).

This project is delimited to only consider vehicles on SAE level 4 “High Automation” (SAE International, 2016, p. 2), which is defined as follows:

> The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene.

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* (“system”) monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Figure 2.1: SAE Automation level classification (SAE International, 2016).

At level 4, the system is only capable of performing in some contexts, e.g. AD authorised roads. SAE level 4 autonomy loosely corresponds to the "Executive control" level in the taxonomy proposed by Beer, Fisk and Rogers (2014). On this level, the human provides the robot with an abstract high-level goal, while the robot autonomously senses the environment, sets the plan, and implements action. This means for instance that in AD mode, the driver has the responsibility to set navigation goals, while the HAV has the responsibility create a plan on how to reach the destination and then perform all driving activities necessary to reach it.

2.1.2 Benefits & Issues of Automation

In terms of automotive automation, the previous decade of HAV development has focused on increasing not only comfort and efficiency, but also to support the driver and mitigate the risks of driving-related tasks (Large and Burnett, 2014). According to the World Health Organization (WHO), 1.25 million people died as a result of traffic crashes in 2015 (World Health Organization, 2016). If HAV are designed appropriately, many of these accidents may be prevented in the future. In addition to the safety benefits HAV provides, Bazilinskyy and de Winter (2015) predict that gas emissions, fuel consumption and traffic congestions may be significantly reduced. Litman (2016) share these predictions and adds an infrastructural perspective, claiming that the introduction of HAV will lead to more efficient parking, convenient use of car sharing, narrower lanes, and reduced intersection stops.

In relation to automotive automation, there are a number of issues to take into consideration including security and privacy concerns, induced vehicle travel by increased convenience, and social equity concerns (Litman, 2015). Ethics relating to autonomous vehicles is an area with many critical issues. Since the vehicle is responsible in AD mode, human ethics may need to be translated into algorithms for the vehicle to act on, and this is a great challenge (Bonnefon, Shariff and Rahwan, 2016). Certain traffic situations may force the vehicle to choose between several ethically incorrect actions, as exemplified by Lin (2016). Although these ethical aspects pose great challenges in terms of HAV design, they fall outside of this project's scope and will therefore not be further discussed.

2.2 Driver-Vehicle System

In order to describe how the driver-vehicle system (DVS) operates, e.g. its components, goals, and actions, a system model is used. Firstly, the system as defined in this thesis contains a vehicle with SAE level 4 autonomous capabilities and a human driver, as can be seen in figure 2.2 (Strömberg, 2017). The driver and the vehicle form a joint system driving goal and communicate with each other through one or more

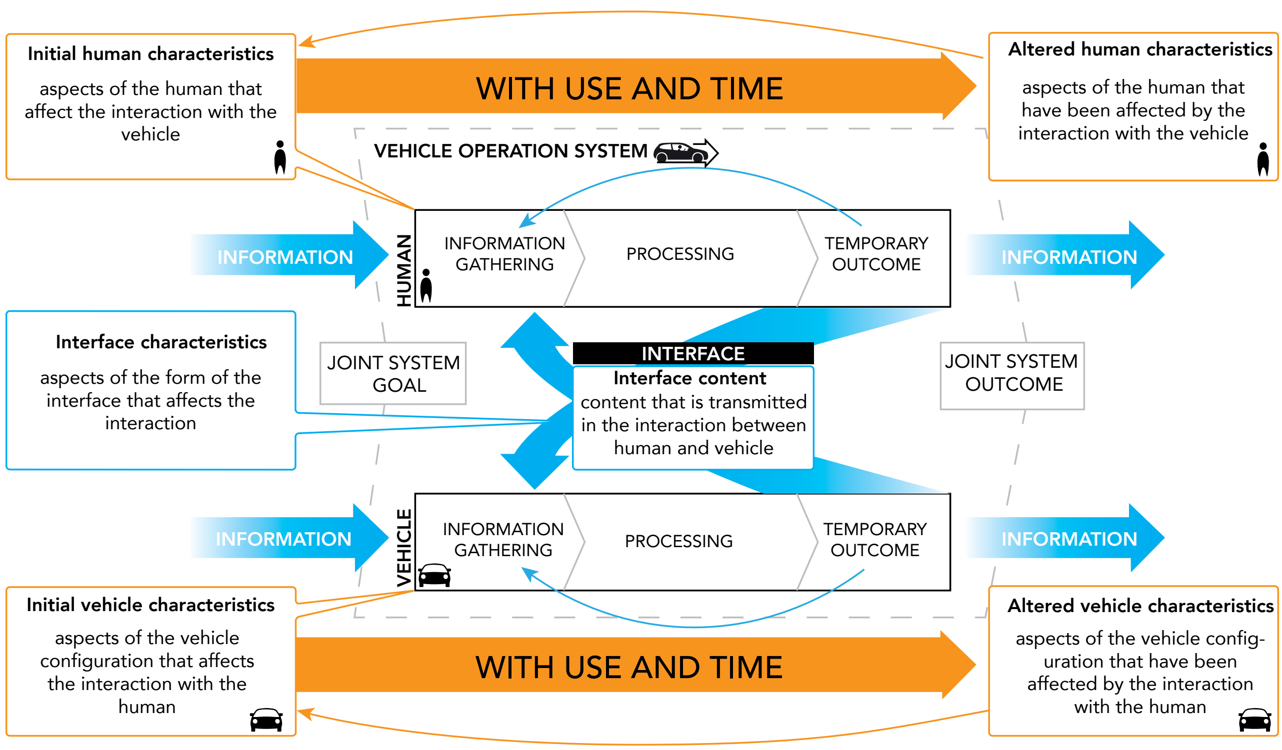

Figure 2.2: Driver-Vehicle System (Strömberg, 2017)

interfaces in order to reach this goal. The joint system goal is to effectively, safely and comfortably transport the driver to a destination. The DVS operates within a context and has two continuous outcomes during the operation - movement forward and situation awareness (SA). It is important to note that the SA mentioned in this context refers to the system SA, which is not to be confused with human SA. Both the driver and the vehicle gather and process information, and make decisions to act and create temporary outcomes and states. This process can be compared to the *sense*, *plan*, and *act* process described by Beer, Fisk and Rogers (2014), where sense corresponds to information gathering, while plan and act correspond to processing.

For the driver, information gathering consists of intake of sensory information and the perception of its meaning. The processing of this information may lead to decision-making, adaptations, and/or mental model development (see mental models, section 2.2.3), and the temporary outcomes may consist of different levels of workload and mode awareness as well as emotional reactions. The vehicle gathers information through its sensors, e.g. LIDAR, GPS, and cameras, and processes this information with the use of complex algorithms and acts according to rules and commands. The temporary outcome created is the qualities of the vehicle's movement.

In order to understand the interaction between driver and vehicle, the components of an HAV interface are described below.

2.2.1 Interface Components

Automotive HMI can be divided into two major categories based on the direction of the communication: primary components and secondary components (Gáspár, Szalay and Aradi, 2014). Both primary and secondary components can make use of visual, auditory, and haptic inputs and outputs in order to establish an effective and efficient communication between driver and vehicle. This project aimed to investigate the driver's trust in a HAV in AD mode. Hence, the driver is not expected to intervene in safety critical tasks. Therefore, the focus of this project was limited to mainly consider the output devices.

Primary HMI Components

Primary HMI components are characterised as those associated with the operation of the vehicle's basic functions and allow the driver to control the movement of the vehicle. Primary HMI components include both input devices, such as steering wheel, pedals, gear shift lever, and parking brake, and output devices, such as the driver information module (DIM) and head-up display (HUD). The DIM is situated in the dashboard, in front of the steering wheel, and is responsible for providing the driver with information regarding the operation of the vehicle (see figure 2.3). Information presented commonly includes vehicle speed (speedometer), rotational speed of the engine (tachometer), and feedback for performed tasks such as indicator signals, warnings, and error messages. In autonomous vehicles, the DIM is expected to provide information about the current level and state of the automation as well as the driving situation. The HUD consists of information projected onto the windscreen, in order to provide the driver with information without having to look away from the road. The HUD commonly displays some of the information from the DIM, such as vehicle speed and urgent warnings. Except for the previously mentioned visual interfaces, the vehicle may also include auditory output interfaces, such as beepers or speech messages communicating safety warnings. Auditory inputs include for instance voice control, which is a recognition-based input technique for controlling several in-vehicle functions, such as using the phone.

Figure 2.3: DIM, HUD, and CSD.

Secondary HMI Components

Secondary HMI components are defined as those associated with comfort and infotainment. Components include input devices such as buttons and touch screens around the centre stack display (CSD), as well as output devices such as screens.

The interface components together form the vehicle's interface towards the driver, which allows for driver-vehicle interaction.

2.2.2 Driver-Vehicle Interaction

As previously mentioned, the driver and vehicle communicate through one or more interfaces within the vehicle (Strömberg, 2017). The human may provide the vehicle with explicit commands and also monitor the explicit and implicit information communicated by the vehicle, such as intentions and current state of automation. Both the driver and the vehicle also gather information about traffic, road and weather conditions from the surrounding environment in order to take this into account in the decision-making process.

The driver, vehicle, and interface all have certain characteristics that affect the interaction, which in turn affects the operation as well as the joint system goals and outcomes. Driver characteristics may include attitudes such as trust in automation as well as knowledge and driving skills, and these characteristics are continuously altered through use of the vehicle over time. Vehicle characteristics may include sensing capabilities, programming, and experience (machine learning), and these characteristics are also altered with use over time through driving experience as well as wear and tear on the vehicle.

The interface can be divided into two distinct parts - content and characteristics. The content represents the information that is conveyed through the interface, and differs depending on the level of automation. The characteristics refer to how this information is communicated, i.e. the aspects of the interface form which affect the interaction. This may for instance include different modalities and types of embodiment.

From the aspects mentioned, modalities, acceptance, trust, embodiment, and especially anthropomorphism are considered central to the aim of the project, and are described in their own sections. However, several other aspects relating to HMI and human cognition are necessary in order to understand the results. Hence, these aspects are described below.

2.2.3 HMI and Cognition

There are a number of HMI aspects related to the limitations of the human cognitive processes which all affect the performance of the driver-vehicle system. The aspects which are discussed include behavioural adaptation, usefulness, situation awareness, driving skills, mental workload, and trust.

Behavioural Adaptation

Many issues that may arise in relation to automotive automation and human cognition depend on behavioural adaptation, which in this thesis refers to unintended behaviour that appears after a change to the road traffic system (Martens and Jenssen, 2012). OECD (1990) defines behavioural adaptation as "Those behaviours which may occur following the introduction of changes to the road-vehicle-user system and which were not intended by the initiators of the change." One example is the introduction of Anti-lock Brake System (ABS), which increased road safety by preventing wheels from locking when braking to avoid uncontrolled skidding. However, an unintended change in behaviour arose in users, as they started to keep a shorter distance to the car in front of them, knowing about the safety benefits of ABS and so reducing their safety margin (Sagberg, Fosser and Sætermo, 1997). This type of behavioural adaptation is unintended, but will inevitably occur, and so it is important for designers to take into account when designing or changing a system (Martens and Jenssen, 2012).

Usefulness

Usefulness consists of two quality attributes: utility and usability (see figure 2.4) (Nielsen, 2012). Utility is decided from whether the technology provides the features needed to perform a task. Usability can be defined as "...a quality attribute that assesses how easy user interfaces are to use" (Nielsen, 2012) and is commonly divided into five quality components: learnability, efficiency, memorability, errors, and satisfaction.

Figure 2.4: The definition of usefulness according to Nielsen (2012).

Learnability assesses how easy a user can accomplish a basic task the first time the design is encountered. Efficiency refers to, as the name indicates, how rapidly the user can perform the task after being introduced to the design. Memorability refers to how easy the user can re-establish efficiency after a period away from the design. Errors represent a quantitative measure of the number of errors the user makes, as well as a qualitative measure of the severity of those errors and how easily the user can recover from them. Lastly, satisfaction is defined as how pleasant the design is to use. Based on this definition, usability may be considered as an important HMI aspect. According to Weir (2010), usability is one of the most important aspects to consider during HMI development. In relation to HAV, usability is highly linked to the transparency of the interface, i.e. to which degree the processes underlying the automation is presented (Tofetti et al., 2009). This is in accordance with the argument that the overall performance of the driver-vehicle system might be enhanced by designing interfaces and training in such a way that the information regarding purpose, process and performance of the automated functions are clearly communicated to the driver (Lee and See, 2004).

Mental Models

Mental models, which can be defined as a person's mental representation of hypothetical, imaginary or real situations, are important to consider when designing a driver-vehicle system since it defines how well the user understands the system. There are two types of mental models: functional mental models refer to a person's knowledge regarding a product's functionality, for instance that the car will start if the key is twisted. Structural models are more elaborate and require knowledge regarding the components of a product and their relationships, for instance why twisting the key triggers the vehicle to start. The mental models that designers want the users to have are referred to as conceptual models. The user can acquire the "proper" conceptual model by going through training, documentation or simply by interacting with the system. However, to facilitate the creation of conceptual models with little means, designers may use metaphors. A metaphor uses existing conceptual models to facilitate the formation of mental models and might hence be used as a powerful design tool to describe novel use situations to a user (Hudson, 2003).

Situation Awareness

Situation Awareness (SA), is according to Endsley (1995, p.36) defined as "...the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future."

In terms of a driver-vehicle system, SA may refer to either the driver or the system as a whole, where this thesis uses the latter. SA therefore refers to drivers' ability to receive internal and external input from the surroundings, understand what is happening around them, and ability to foresee potential consequences of the vehicle's actions. SA is an important aspect to consider in the design of HMI for HAV, since lack of SA may have severe consequences. It has been shown that diverted attention may lead to automation surprises, which may lead to slower and less competent manual control recoveries by the driver. It is hence important to design the user interface (UI) in a way that communicates the limitations of the automated functions, so that the driver is helped back in-the-loop and can regain SA before resuming manual control. This design aspect is especially crucial to consider when it comes to control transitions between manual and AD mode, since decreased SA can lead to mode confusion (Cunningham and Regan, 2015). Mode confusion refers to the mismatch between the driver's mental model of how the vehicle operates and the actual operation of the vehicle (Cummings and Ryan, 2014). In terms of autonomous vehicles, the driver may for instance be confused about which level of automation that is currently active and hence make incorrect assumptions about the system's current limitations. However, these hazardous situations can be mitigated by providing the driver with timely and comprehensive information regarding the vehicle's status and intentions (Merat et al., 2012).

Driving Skills

Use of autonomous vehicles, especially of SAE level 4 and 5, may lead to a loss of driving skills. This phenomenon is known as skill degradation (Cunningham and Regan, 2015) and can be divided into short-term and long-term loss of skill. Short-term loss of skill is directly related to an insufficient SA, and affects the driver's ability to control the vehicle after a transition between levels of automation. Long-term loss of skill is a product of continuous use of HAV, as drivers may not make use of their manual driving skills over long periods of time (Parasuraman, Sheridan and Wickens, 2000). This may cause drivers to lose manual control skills through a degraded psychomotor dexterity and cognitive skills, as they rely on the automation for a major part of the driving. The phenomenon may become a problem when vehicle automation and regulations have advanced to a point where a majority of driving can be done by automation.

Mental Workload

A general description of mental workload is the relation between the mental resources needed to perform a task and the mental resources that the driver can supply (Parasuraman, Sheridan and Wickens, 2008). In general, HAV will lower the mental workload of the driver during periods of automated driving, as the driver does not need to be involved in the driving or the monitoring of the environment. However, if the vehicle is designed so that it requires a high level of supervision from the driver, it might instead increase the mental workload (Wickens et al., 2010). If the mental workload of supervising the driving is very low, the driver may get distracted by secondary tasks, as shown by Merat et al. (2012). Their simulator study showed that drivers of an HAV who were distracted by a secondary task when prompted to retake control performed worse than drivers who were not distracted by a secondary task. Low workload may also lead to a boredom, which might induce hazardous driver behaviour as the level of vigilance is decreased (Cunningham and Regan, 2015).

To mitigate the negative effects of insufficient or too low or too high mental workload, as well as sudden changes in workload, one can design interfaces so that drivers receive the information they need at the right time (Parasuraman, Sheridan and Wickens, 2008). This way, the driver has a greater chance of being able to evaluate the information presented by the system in order to make informed decisions about the driving task. To achieve this, the information presented must be highly accessible and understandable to the driver, so that the mental workload required to process the information is as low as possible. Dekker and Woods (2002) suggest among other things that information presented should be future-oriented and pattern-based, so that the driver can get support in knowing what changes to anticipate, communicated in a way that facilitates quick scanning of the information without a high cognitive workload.

2.3 Modalities in Interaction

Important aspects of the interface characteristics include the use of modalities. In this section, the auditory, visual, and haptic modalities, as well as multimodal interaction are described from a driver-vehicle interaction perspective.

2.3.1 Basics

In order to process information, the sensory organs need to register and mediate stimuli to the brain. This is done via the human modalities, which from a traditional perspective include; the visual, auditory, haptic, olfactory, and gustatory modality (Bohgard, 2009).

The visual modality is often mentioned to be the dominant sense since it accounts for nearly 80 percent of the total sensory perception (Bohgard, 2009). However, in terms of HMI in HAV, research suggests that the auditory and haptic modalities have great potential in terms of providing feedback to the driver. In a study by Bazilinskyy and de Winter (2015), it was concluded that auditory feedback in partially automated vehicles has great potential, due to its omnidirectional characteristics and its ability to complement the perceived visual information. Furthermore, when comparing different combinations of modalities in interfaces to support safe driving in their driving simulator study, Adell et al. (2008) found that participants preferred a haptic interface to avoid rear-end collisions.

Campbell et al. (2007) present guidelines for the development of collision warning systems (CWS) based on best practice within human factors. The report presents elaborate guidelines specific to auditory, visual, and haptic warnings, and despite the guidelines being specific for CWS, the information presented is useful for the development of HMI for HAV. With a collision warning, it is the driver's responsibility to intervene, often within a very short period of time, in order to avoid the collision. When designing for interface communication in AD mode, it is important to keep in mind that if a driver fails to intervene, it is still the automated function's responsibility to safely manoeuvre the vehicle.

2.3.2 Auditory Displays

Campbell et al. (2007) suggest that auditory warnings are good for capturing drivers' attention when they are distracted or looking away from a visual warning, and for information that is time critical. They also argue that auditory displays are good for short messages of low complexity and high priority. Auditory warnings are also beneficial in non-time-critical situations where they can augment visual displays. However, auditory displays are bad for use in frequent warnings and continuous information as they can be obtrusive and cause annoyance. Worth noting is also that environments with auditory noise can mask auditory displays.

There are four types of auditory displays presented in the report (Campbell et al., 2007). *Simple tones* consist of one or more frequencies presented simultaneously, and *earcons* are abstract musical tones that can create messages by being used in structured combinations. These displays should be used when immediate driver intervention is required. *Auditory icons* are sounds that are familiar to the user in the context and intuitively present information about what they represent (e.g. skidding tyre sounds), and are good for collision warning applications where a short reaction time is crucial. *Speech messages* are voice messages that convey information through language, and can be used for non-time-critical informational or status messages.

2.3.3 Visual Displays

Campbell et al. (2007) argue that visual warnings should be used in situations where it is not critical that the visual display captures the driver's attention, and that visual displays are good for providing discrete and continuously available information. They are also good for situations where a large number of messages need to be displayed, and when messages are long and complex. However, visual displays are not good for presenting time-critical information or with poor lighting conditions.

Four types of visual displays are presented. *Analog displays* convey graphical representations of continuous information, *discrete displays* provide binary (on/off) information, and *icons* are simple graphical representations symbolising some information. These displays may be appropriate in providing cautionary warnings as long as they do not distract from more time-critical information by visually cluttering the display. *Alphanumeric displays* present full or abbreviated information and should be used for non-time-critical and complex messages.

2.3.4 Haptic Displays

Campbell et al. (2007) state that haptic displays should be used in time-critical situations where it is unlikely that auditory displays would be effective. This includes situations where the driver has an auditory overload, such as when ambient noise is high or when other systems use auditory warnings. Haptic displays are good for capturing attention as an obtrusive and omnidirectional display and providing simple information in appropriate contexts. However, information provided by a haptic display may be ambiguous and will only be effective if the driver is in physical contact with the source of the display.

The type of haptic display presented in the report that may be of interest for HAV is *seat vibration*. This is because the seat is the only interface that the driver is guaranteed to be in contact with during AD mode. A seat vibration is a non-directional or directional vibration applied either to the entire driver's seat or a part of it, and may be good to capture attention when a part of the driver's body is in contact with and sensitive to vibrations of the vibrating part of the seat.

In table 2.1, visual, auditory, and haptic displays are listed and exemplified. Furthermore, the parameters frequency, intensity, and placement further illustrate the design space of interface design. For instance, the visual modality can make use of an oil lamp icon, displayed continuously with medium intensity, and be located in the DIM.

2.3.5 Multimodal Interaction

Many studies have also concluded that the use of multimodal communication, i.e. the use of several modalities in parallel, have benefits in terms of driving safety. For instance, when studying the effectiveness of different HMI characteristics during a take-over request from an SAE level 2 automated vehicle, Blanco et al. (2016) found that multimodal alerts resulted in a faster reaction time and a faster time to regain control compared to unimodal alerts. Large and Burnett (2014) state that there is an overwhelming consensus that using the auditory modality is less distracting for drivers than interacting visually with a display during route guidance. A potential explanation to the reason for advantages of using multimodal interaction is suggested by Jonsson, Harris and Nass (2008), who rationalise that it is due to the fact that drivers better can distribute their attention cross-modally rather than intra-modally. Their theory is aligned with Wickens' (2002) multiple resource model, which states that mental resources allocated within one modality are more likely to interfere with each other than mental resources within different modalities.

Table 2.1: Modality displays based on Campbell et al. (2007) and interface components.

Modality	Display	Examples
Visual	Analog	God-view, battery charge meter
	Discrete	Check oil, fill antifreeze, check engine
	Icon	Oil lamp, queue icon, place of interest
	Alphanumeric	"System check complete", "Change route to save time?"
	Video	Instructional video or tutorial
Auditory	Simple tone	Square wave
	Earcon	One or two-tone "dings" or chimes
	Auditory icon	Sound of a horn or skidding tyres
	Speech	"Checking systems", "Resume manual control"
Haptic	Vibration	Non-directional, directional

Frequency	Intensity	Placement
Low	Low	A-pillar
		DIM
		HUD
Medium	Medium	CSD
		Headrest
High	High	Backrest
		Seat
		On the gearshift
		On the steering wheel
		On the pedals
Continuous		Omnipresent

Haas and van Erp (2014) argue that multimodal displays such as visual-auditory and visual-tactile ones can be considerably more effective in enhancing user performance than visual displays on their own. They also provide guidance for the use of multimodal warnings, of which some are highly relevant to the context of autonomous vehicles:

- Multimodal displays reduce the risk of a user overlooking a message and can be used in situations characterised by high mental workload.

- Auditory and tactile displays are useful for capturing attention both non-directionally and directionally, especially when there is a high workload on the visual modality. They can be used both for redundancy and as a supplement to visual information.

- To avoid overloading the user, multimodal displays should only provide necessary information. If this is done successfully, it can help improve user performance and reduce the risk of a high cognitive workload and visual sensory overload.

2.4 Acceptance

In order for technology to be used, it is paramount to create user acceptance. Without acceptance for the technology, it will not be used, as Waytz, Heafner and Epley (2014, p. 116) pointed out: "Even the greatest technology, such as vehicles that drive themselves, is of little benefit if consumers are unwilling to use it."

Introducing automation leads to a change in how tasks are structured and the creation of new tasks and responsibilities, such as monitoring and coordination of activities between human and automation (Sarter, Woods and Billings, 1997). For this to be possible, the automation in itself must be performing at a high level, but also be cooperative and allow the user to rely on it to an appropriate extent. How users are enabled to appropriately rely on automation and accept it depends on several interrelated factors described by researchers within cognitive engineering as well as researchers within information systems (Ghazizadeh, Lee and Boyle, 2011).

In order to explain which factors affect acceptance in technology in general, as well as automation more specifically, the relationships are described using the Technology Acceptance Model (Davis, Bagotti and Warshaw, 1989) which has been augmented by Ghazizadeh, Lee and Boyle (2011) to assess automation in the Automation Acceptance Model.

2.4.1 Technology Acceptance Model

The Technology Acceptance Model (TAM) was introduced by Davis, Bagotti and Warshaw (1989) and is built on the Theory of Reasoned Action by Fishbein and Ajzen (1975). In TAM, perceived usefulness and perceived ease of use are the two main determinants of the attitude to use (see figure 2.5). This attitude predicts the behavioural intention to use and the actual use of the system.

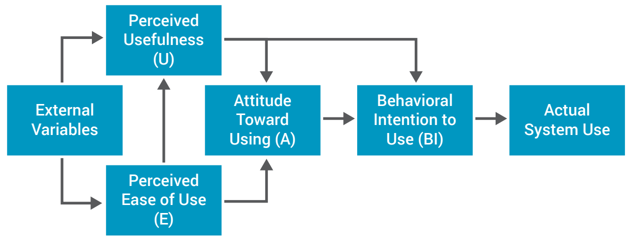

Figure 2.5: Technology Acceptance Model (Davis, Bagotti and Warshaw, 1989).

Perceived usefulness corresponds to the degree a user believes that the technology will help perform a task, while perceived ease of use corresponds to the perceived effort of a user to use the automation. This is closely related to Nielsen's definition of usefulness, where utility corresponds to perceived usefulness and usability to perceived ease of use. TAM has been used to assess user acceptance in several domains and provided quantitative measures of relationships between external variables, user perceptions and user attitudes and intentions (Ghazizadeh, Lee and Boyle, 2011). Using TAM, both the perceived usefulness and perceived ease of use of an HAV can be affected by HMI design. In order for the user to assess whether the HAV has all features needed to perform the task of driving, the HMI must provide information about this. Similarly, the HMI design affects how easy and pleasant said features are to use. However, TAM is built on research from the field of information systems only, and does not account for all variables affecting user acceptance of HAV.

2.4.2 Automation Acceptance Model

The Automation Acceptance Model (AAM) aims to combine research from the fields of information systems and cognitive engineering to create an integrated view of automation acceptance (Ghazizadeh, Lee and Boyle, 2011). As can be seen in figure 2.6, the light areas correspond to TAM created by Davis et al. (1989), which has been expanded to include compatibility and trust as factors directly affecting perceived usefulness and perceived ease of use. Trust is also seen as directly affecting the behavioural intention to use, just like the perceived usefulness. Compatibility and trust are in turn directly affected by external variables, and feedback mechanisms have been added to show how the actual system use in turn affects these factors in a loop.

Task-technology compatibility, or compatibility for short, has been found to be an important factor affecting automation acceptance within cognitive engineering (Ghazizadeh, Lee and Boyle, 2011), and it does so by indirectly affecting the behavioural intention to use through perceived usefulness and perceived ease of use. Compatibility can be assessed by how well the functions that the technology can perform match the needs of the task it is to perform within a specific context. More specifically, it suggests that it is not enough for a vehicle to have high performance AD functions, but that the users considers these functions to benefit them compared to manual driving.
According to Ghazizadeh, Lee and Boyle (2011), cognitive engineering research has also found trust to be a major factor affecting automation acceptance. More specifically, it can be described as a dynamic of trust and reliance, where trust can be described as an attitude that affects the behaviour of reliance (Lee and See, 2004). The definitions and dynamics of the relationship are discussed further in the following section.

2.5 Trust

It is reasonable to assume that most people have some general notion of what trust is. This notion is commonly based on previous experience from interpersonal relationships, and usually reflects the degree of confidence that an individual has in other people. However, trust is not limited to the domain of social psychology, but can also be applied to automation - and is often referred to as the concept of trust in automation (Hoff and Bashir, 2015). In this section, the concept's fundamentals, affecting factors, and consequences are described and discussed.

2.5.1 Fundamentals

In this thesis the definition of trust provided by Lee and See (2004) acts as a reference point due to its applicability to the focus of the project, i.e. the driver-vehicle interaction.

Components

According to the systematic review done by Hoff and Bashir (2015), containing 127 studies regarding empirical research of trust, three components or bases need to be present in order for trust to be established. The first component includes a *trustor* to give trust, a *trustee* to accept trust, and something that is at stake.

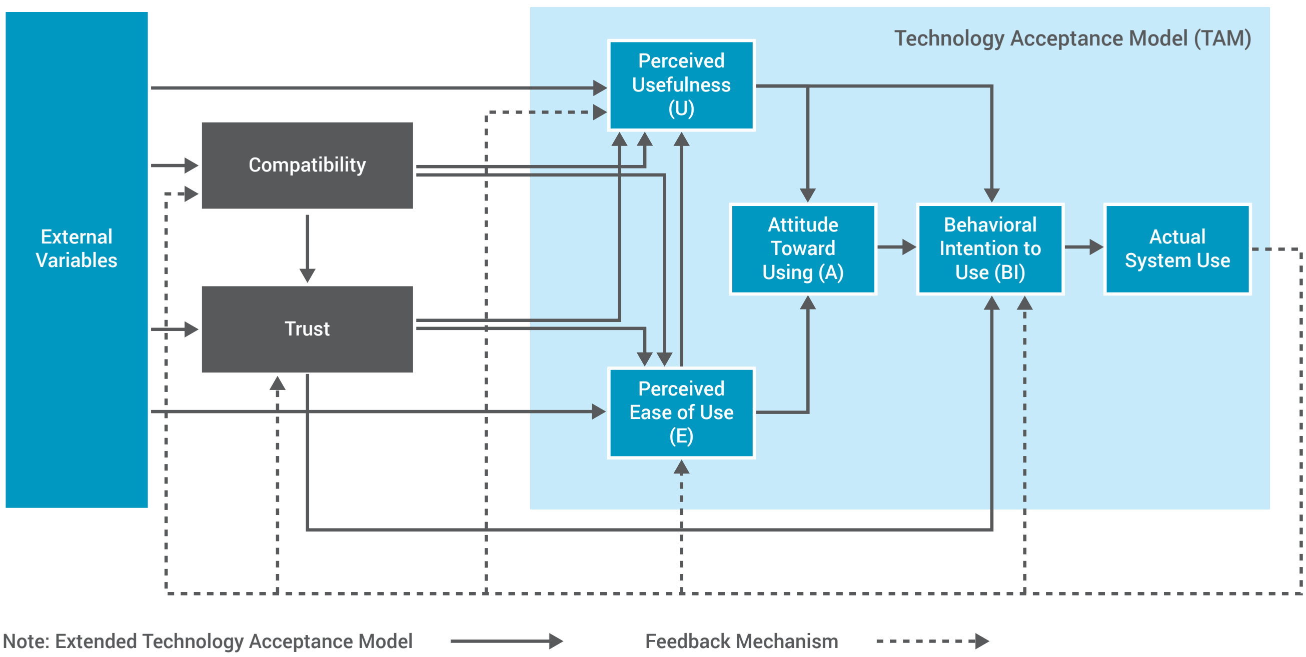

Figure 2.6: Automation Acceptance Model (Ghazizadeh, Lee and Boyle, 2011)

Secondly, there must be an *incentive* to trust from the trustor's side. In terms of technology, the incentive is commonly represented by the designer's intended use of the system. Lastly, the task performed by the trustee should be associated with some kind of uncertainty or risk (Hardin, 2006). In terms of HAV, the vehicle can be seen as the trustee, the driver as the trustor, and the HMI design intent as the incentive. The risk of system failure or driver misuse can be seen as the uncertainty and risk associated with the use of HAV.

Formation
As with interpersonal trust, trust in automation does not form instantly, but rather progressively over a longer period of time. Based on the work of Barber (1983), Muir (1987) presented a model which attempts to explain human-automation trust formation in three stages. Trust develops through the three stages: faith, dependability, and predictability. Research has for instance shown that humans tend to exhibit a positivity bias towards new automated systems (Dzindolet et al., 2003). In other words, people tend to overtrust novel technology in their first encounter with it. Hoff and Bashir (2015) suggest that people base their trust on faith initially, because they believe that since automated functions are supposed to replace human control, they are perfect. These unrealistic expectations tend to fall apart as soon as people interact with the automated system, and the remaining trust formation will instead be based on dependability and predictability. In terms of HAV, people may, based on this theory, initially have an overtrust in the system - assuming that the automated functions can handle more than they actually can. But after a short period of interaction with the system, they will revise and adjust their trust to more accurately match the system's limitations. An initial overtrust in the system can also be counteracted by providing proper training or instructions (Lee and See, 2004).

Basis
As the components and formation of trust have been defined, the next logical question to pose should be: How does trust grow? Research on human-human relationships has shown that there are three dimensions which are particularly important for trust to grow. Mayer, Davis and Schoorman (1995) summarised these dimensions as ability, integrity, and benevolence. Ability refers to the skills and competencies that make the trustee able to influence the domain. Integrity reflects how well the trustee sticks to principles which are accepted by the trustor. Lastly, benevolence represents how well the intents and motivations of the trustee reflect those of the trustor. Translated into the domain of human-automation interaction (HAI), Lee and See (2004) define three dimensions: performance; process; and purpose. These three dimensions are aimed at describing the basis of trust in the interaction between a human and a machine. The performance dimension refers to, similarly to the ability dimension, the operations of the machine and is measured in terms of predictability and reliability. Secondly, the process dimension reflects the extent to which the automation is appropriate to achieve the human's goals. Lastly, the purpose basis of trust reflects the degree to which the design is used according to the designer's intent. Research has shown that if trust is based on several dimensions, it will become more stable and robust, whilst if it is only based on one it will be fragile (McKnight, Cummings and Chervany, 1998). Lee and See (2004, p.61) highlight the implications for the design of HMI, stating: "Designing interfaces and training to provide operators with information regarding the purpose, process, and performance of automation could enhance the appropriateness of trust."

Trust as an Attitude
Even though people indicate that they trust an agent, such as an autonomous vehicle, they may not always act in accordance to their statement. Hence, it is important to differentiate between trust as an attitude, and reliance as a behaviour. In their conceptual framework "A Dynamic Model of Trust and Reliance on Automation", Lee and See (2004) describe the processes that govern trust and explain their effect on reliance (see figure 2.7). The main idea is that trust and automation interaction affect one another in a dynamic closed-loop process - i.e. that the user's interaction with the system will affect the user's trust in the system, and vice versa. Their model shows the complex interrelations between automation, interface, context, and user and divides the formation of a user's action into four consecutive steps: belief formation, trust evolution, intention formation, and reliance action. In the first step, the user forms beliefs about the automation based on available information, such as interface features. This step is important for trust to grow, since it relies heavily on the observability of the automation behaviour. If information is insufficient, trust will not grow and the system is less likely to be used. If trust grows, the user may combine other contextual factors, such as workload, perceived risk, and effort to engage to form an intention to rely on the automation. This reliance intent, combined with external factors such as time constraints and configuration errors, will thereafter guide the user's actions and behaviour in the interaction with the system. This model is structured similarly to AAM, which further supports the process in which attitudes transform into behaviours.

In sum, it is important in the design of HMI for HAV to consider the mediating effect that trust may have on reliance, as well as the importance of information availability and automation observability in order for the user to be able to make a decision to rely on the automation. Most importantly, it is essential to remember that trust is not to be confused with intention or behaviour, since these are also influenced by other human factors such as workload, SA and self-confidence (Lee and See, 2004).

Analytic processes refer to the rational thinking and conscious evaluation of the trustee's characteristics. The analogical cognitive processes on the other hand, are based on societal norms and rules defined by others to decide trustworthiness. Lastly, the affective processes are closely associated with the emotional response to the "...violation or confirmation of implicit

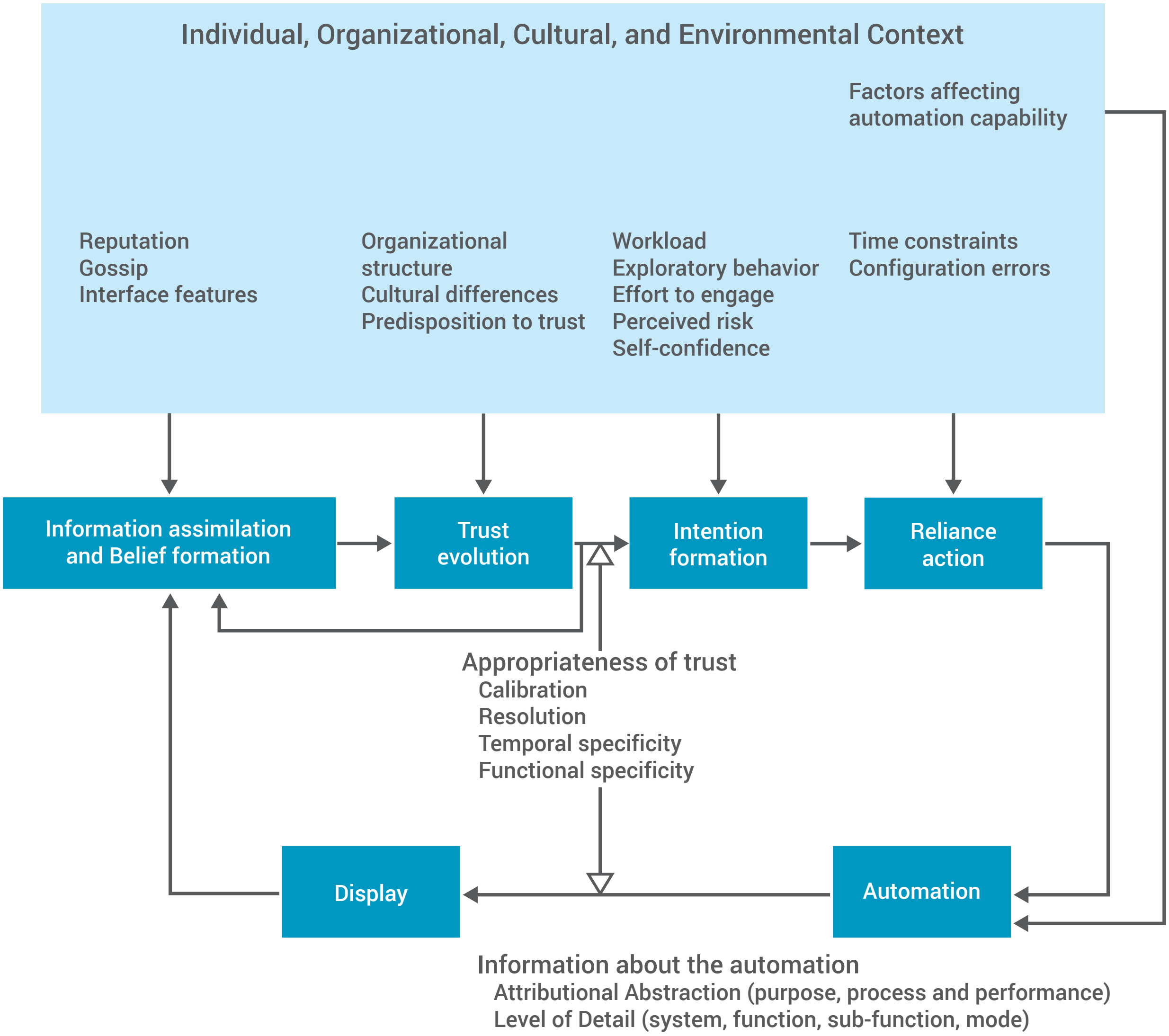

Figure 2.7: Framework by Lee and See (2004, p. 68) describing how trust as an attitude may influence reliance as a behaviour.

Governing Processes

As can be seen in AAM, trust-induced behaviour, e.g. reliance, in automation is closely related to the user's view of the system rather than the actual system capabilities. Subsequently, it is of great importance to study the mechanisms which Wickens (1984) associated with the perception stage in his information processing model.

The assimilation processes that represent the underlying cognitive mechanisms of trust can be summarised in three different ways. Lee and See (2004) propose a model which describes the interplay between the analytic, analogical, and affective processes of a human.

expectancies" (Lee and See, 2004, p. 61). Depending on the cognitive resources available and the evolution of the trustor-trustee relationship, people will use different assimilation processes. For example, if large cognitive resources are available, people tend to use analytic processes, while if the resources are insufficient, they tend to rely on analogical and affective processes. This implies that trust ultimately is an affective response, partially influenced by analytic and analogical processes, as indicated by the bold lines in figure 2.8 (Lee and See, 2004). In terms of design of HMI for HAV, this means that one must carefully consider the instant subjective emotional response to an HMI experience and therefore carefully select how information is displayed.

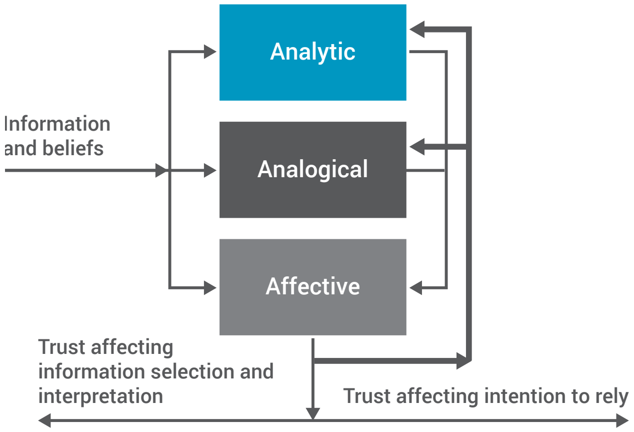

Figure 2.8: Interplay between assimilation processes underlying trust.

2.5.2 Factors Affecting Trust

Up to this point, trust has been described as a relatively abstract construct and a universal phenomenon, in which formation, bases, and assimilation processes apply to the same extent under all conditions. In the real world however, these models do not always apply in the same way for everyone, and one needs to take into account the inherent variability linked to factors associated with the user, environment, and the automated system.

Through their systematic review of empirical research on trust in automation, Marsh and Dibben (2003) created a conceptual model of a three-layered variability in human-automation trust. The model describes variability from three layers; dispositional trust, situational trust, and learned trust (see figure 2.9).

Dispositional trust refers to a person's general long-term tendency to trust automation, independent of environment or particular system. According to Hoff and Bashir (2015), there are four primary sources of this layer of trust, including: culture, age, gender, and personality. Cultural aspects include differences in tendencies to trust between ethnicities, countries, and religions. Age plays a significant role in trusting automation. For example, Pak et al. (2012) showed that by adding a picture of a physician to a diabetes management application interface, young participants trusted the system more. At the same time, older participants did not place any more trust in the system's advice. Differences in gender have been shown in HRI studies, such as Tung (2011), which suggested that the responses to appearance and communication styles in automation differ between males and females. The last source of variability is personality, which is an enduring trait of persons that determines their tendency to trust in others. Research has shown that people with high levels of dispositional trust are more prone to trust reliable systems, but less likely to trust systems after failures (Hoff and Bashir, 2015).

Situational trust is, according to Marsh and Dibben (2003), defined as trust dependent on the context of a specific interaction. Hoff and Bashir (2015) reveal two primary sources of variability within situational trust; the internal and the external. External variability refers to factors which affect a user's trust in an automated system, including system characteristics and environment. It has been found that people tend to rely less on a system when the context of use is hazardous, for instance using a GPS while driving (Perkins et al.,

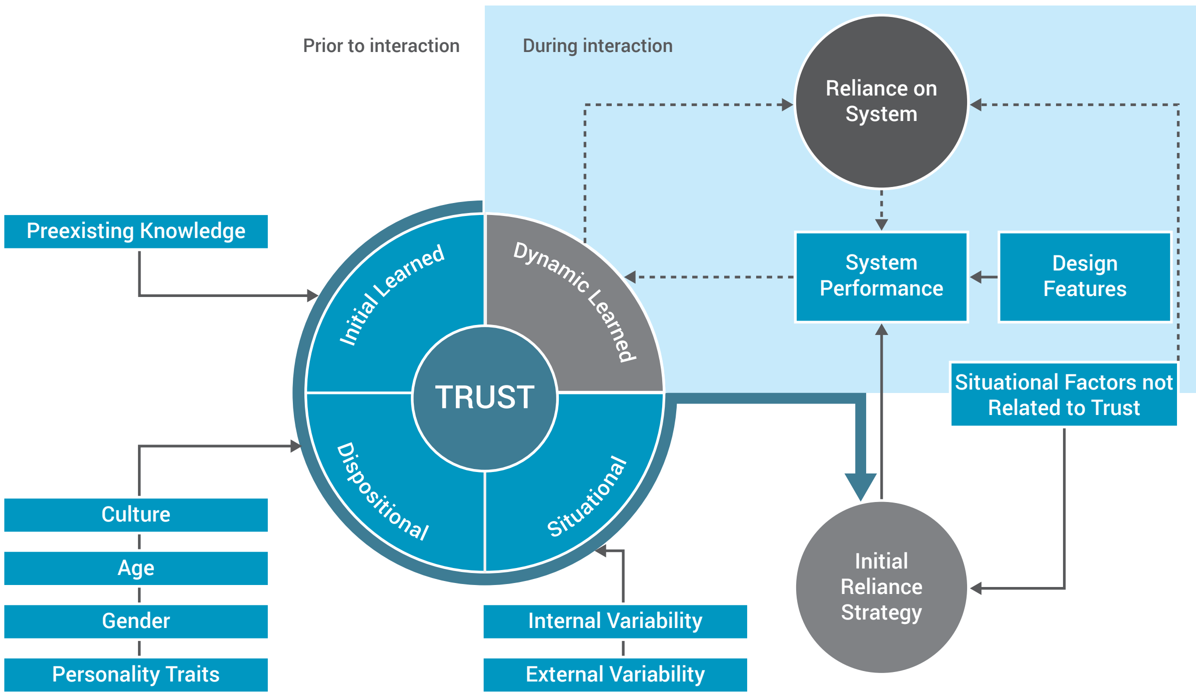

Figure 2.9: Model of three-layered variability in trust in automation (Hoff and Bashir, 2015).

2010). Second, internal variability refers to the traits of the user which, contrary to those of personality, may vary over time. Self-confidence is a typical example of a trait that may direct trust formation. For example, it has been shown that when trust is high and self-confidence low, automation will be more frequently used. The opposite effect could also be observed when trust was low and self-confidence high (de Vries, Midden and Bouwhuis, 2003). Lee and See (2004) have shown that some factors related to situational trust have a particular impact on the strength of the relationship between trust and reliance, including complexity of automation and novelty of situation. Hoff and Bashir (2015) add two more factors (see figure 2.10), including the user's ability to compare automated performance to manual, and the user's degree of decisional freedom. The model shows the relationship between trust and reliance will be stronger, the more complex the system is, the more frequent unplanned events occur, the higher ability the user can evaluate the performance of the system, and the more control the user can exert.

a significant impact on the trust formation processes and decisions by the user (Hoff and Bashir, 2015).

In terms of HAV, this model of trust variability is highly applicable in order to discern patterns between behaviour in the driver-vehicle interaction, general attitudes, and specific context dependent subjective responses of trust. It further complement the AAM by Ghazizadeh, Lee and Boyle (2011) by explaining the components affecting trust formation in a more detailed manner and thus clarifies the relationship between contextual factors and driver behaviour.

2.5.3 Calibration, Resolution, and Specificity

As described in section 2.5.1, misuse and disuse of automation depend on if the user overtrusts or distrusts the automation to perform specific functions, and so rely on the automation inappropriately (Parasuraman and Riley, 1997). This relationship is dependent on how well the user's trust matches the true capabilities of the automation according to Lee and See (2004). Just as supporting appropriate trust is important for facilitating effective human-human relationships, it is important in avoiding misuse and disuse of automation (Wicks, Berman and Jones, 1999). Lee and See (2004) propose a relationship between calibration, resolution, and automation capability to define appropriate trust in automation, as shown in figure 2.11.

Calibration of trust in relation to automation capability is directly related to misuse and disuse when describing appropriate reliance (Lee and See, 2004). Here, good calibration is represented by a diagonal line, where the user's trust in the automation corresponds to its actual capabilities. This means that overtrust is poor calibration

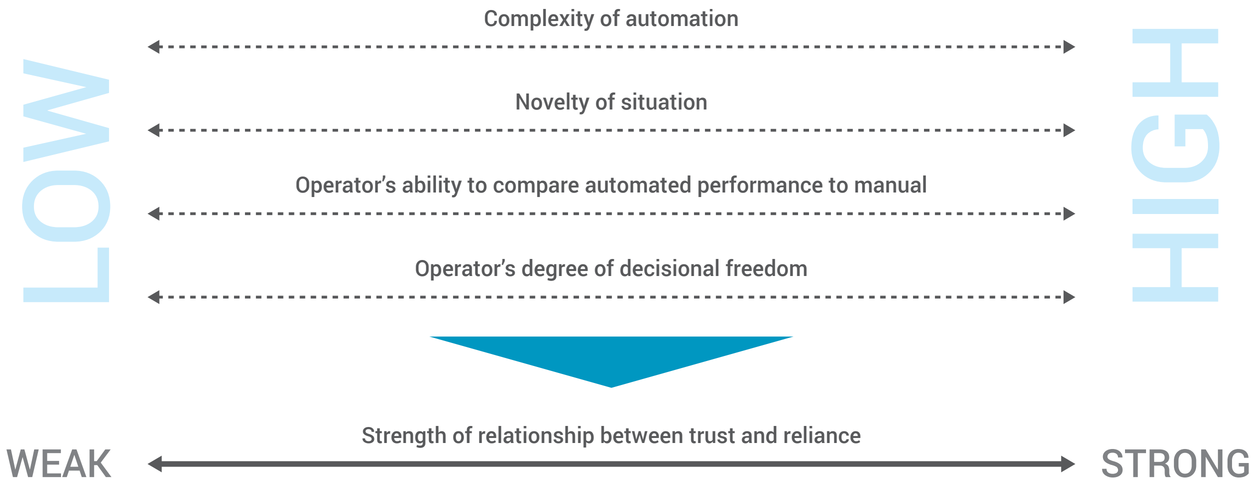

Figure 2.10. Environmental factors affecting the strength of the relationship between trust and reliance in automation.

Learned trust is the last layer of trust and is defined by Marsh and Dibben (2003) as the evaluation made by a user of a system based on past experiences or current interaction. Hoff and Bashir (2015) identify two sources of variability: initial learned trust and dynamic learned trust. Initial learned trust includes pre-existing knowledge regarding the system, for instance a mental model of it, and is characterised by influencing trust prior to interaction with the system. Dynamic learned trust, on the other hand, refers to the trust that is influenced during the interaction with a system. During the interaction with the system, the user may change reliance strategy, and by that influence the overall performance of the system. Hence, the factors of dynamic learned trust, system performance, and reliance are interdependent. Research has shown that learned trust, in particular initial learned trust, may have

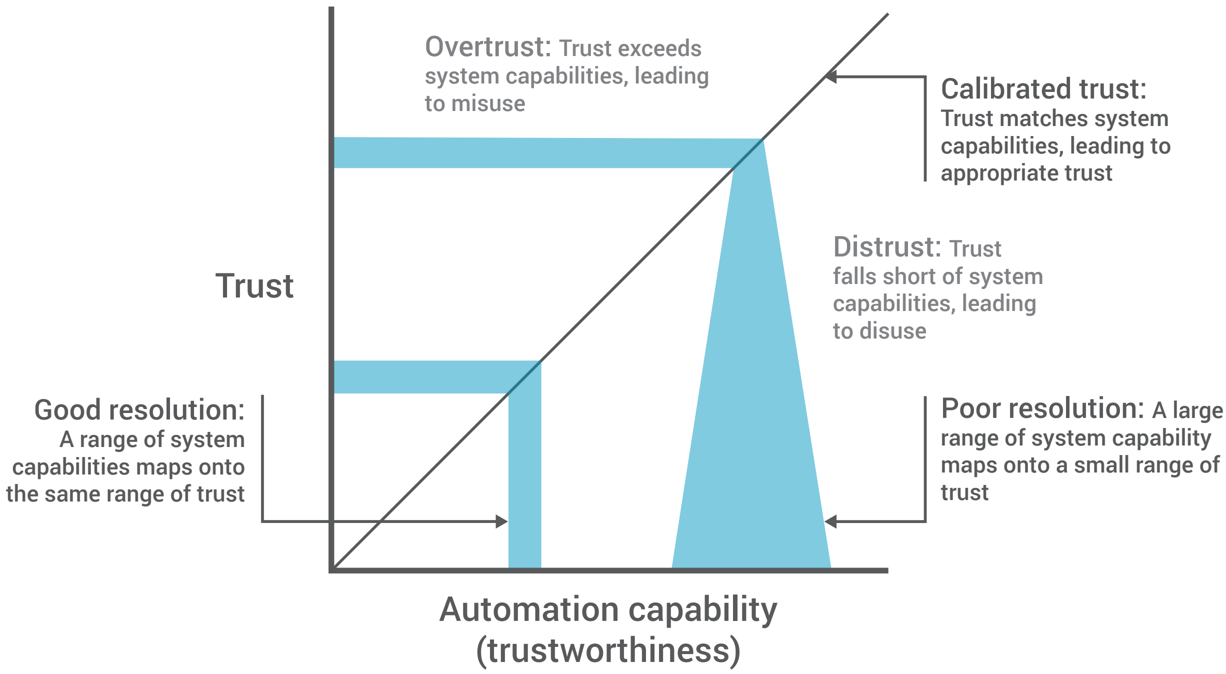

Figure 2.11: The relationship between calibration, resolution, and automation capability (Lee and See, 2004).

where the trust exceeds actual system capabilities, and distrust is when the user's trust in the automation is lower than it should be in relation to its capabilities. Resolution shows how well the user's trust differentiates different levels of capability within the automation. As different parts of the automation may have different levels of capability, a poor resolution means that a user's small range of trust corresponds to a large range of automation capability. Closely related to the concept of resolution, Lee and See (2004) explain specificity as how well the trust is associated with a particular aspect or component of the automation. Here, functional and temporal specificity are distinguished as two different types. Functional specificity refers to the trust in relation to the functions and modes of the automation; high functional specificity means that the trust reflects the capabilities of specific functions and modes, whereas low functional specificity means that the trust reflects the capabilities of the system in its entirety. Temporal specificity refers to changes in trust over time or depending on the situation; high temporal specificity means that the trust reflects the constant changes in automation capability depending on time and context, whereas low temporal specificity means that the trust only reflects changes in capability over long-term changes.

Applying these concepts to the context of HAV, an example may be a vehicle with SAE level 3 capabilities with high performance on highways and limited performance in urban traffic. When in AD mode, if the user trusts the vehicle to resolve any situation without having to intervene, the user overtrusts the vehicle and so has poor calibration. Should the user instead avoid activating AD mode on the highway because they do not trust the vehicle to perform despite it being capable, the user is distrusting the vehicle, which is also an example of poor calibration. If the user assumes that the vehicle as a whole has a small range of capability, and trusts it accordingly, when in fact the range of capability of the vehicle as a whole varies greatly, the user's trust has poor resolution. To exemplify functional specificity, it is assumed that the vehicle has impeccable longitudinal control, but sometimes requires user input to the lateral control. Here, high functional specificity means that the user trusts the vehicle with longitudinal control more so than they trust it with lateral control, whereas low functional specificity means that the user trusts the combined longitudinal and lateral control as one entity. High temporal specificity would be if the user's level of trust for the vehicle automation differs between highways and urban traffic, whereas low temporal specificity would mean that the user trusts the vehicle equally regardless of the context. This may be linked to high or low external variability, respectively, within situational trust.

2.5.4 Trust as a Variable

In summary, trust can be defined as a major variable affecting acceptance in HAV. Therefore, trust is defined as the primary dependent variable in this thesis.

2.6 Embodiment & Anthropomorphism

One strategy to affect the level of trust between human and vehicle is to use different types of embodiment in the design of an HMI. The term embodiment can be defined as "...the fact that a particular agent is realised as a physical robot or as a simulated agent" (Pfeifer and Scheier, 1999, p. 649). This definition implies that an agent not necessarily needs a physical body to be embodied, but may also be virtual. Fong, Nourbakhsh and Dautenhahn (2003, p. 149) build on this idea and add a potential measurement of embodiment, stating that "...the more a robot can perturb an environment, and be perturbed by it, the more it is embodied". This means that one might quantify embodiment in terms of complexity between agent and environment over all possible interactions. Despite this attempt to measure embodiment, it is difficult to find one single design approach on how to build an HMI which results in an appropriate level of trust. Instead, it is more useful to explore the different design approaches that have been applied to date, especially in the design of social robots within HRI.

Broadly speaking, there are four different categories of embodiment for social robots; functional, zoomorphic, caricatured, and anthropomorphic (Fong, Nourbakhsh and Dautenhahn, 2003). Researchers promoting the functional approach argue that a robot's embodiment should primarily reflect its task, and this approach has often been applied to agents in services such as health care. The zoomorphic approach, which builds on the imitation of living creatures such as pets, is often applied to toys in order to create a human-creature relationship. It has been argued that it is an effective approach in terms of building a human-machine relationship since it can be viewed as a simplified version of human-human relationships. The caricatured approach is based on the empirical evidence that a character not necessarily needs to be realistic to be convincing. Caricatures can be used as focal points as well as distractions to draw attention to, alternatively attention away, from certain robot features. The anthropomorphic approach is based on having a naturalistic embodiment, drawing on the argument that if a robot is to interact with humans effectively, it should also be structurally and functionally similar to humans. As the concept of anthropomorphism lies within the scope of this thesis, the following section looks further into its definition, origin, HMI application, and effects.

2.6.1 Anthropomorphism Definition

Anthropomorphism, which comes from the Greek words "anthropos" for man, and "morphe" for form/ structure, has been defined by Duffy (2003, p. 180) as:

> ...the tendency to attribute human characteristics to inanimate objects, animals and others with a view to helping us rationalise their actions. It is attributing cognitive or emotional states to something based on observation in order to rationalise an entity's behaviour in a given social environment.

Hence, anthropomorphism does not only involve humanlike appearance, but also humanlike behaviour and social interaction. This definition is supported by Zhang et al. (2008, p. 675) who, from an HRI perspective, state that qualities of anthropomorphism include "...physical characteristics, like human shape and size, as well as perceivable behaviours and mannerisms." Waytz, Heafner and Epley (2014) describe the act of anthropomorphising a nonhuman as not simply being the act of attributing superficial characteristics such as a face to an agent, but rather attributing essential human characteristics such as a humanlike mind to it. It is by identifying these characteristics that one can, without producing a replica of a human being, design an interface that is perceived as humanlike.

There are several different explanations to the origin of anthropomorphism. In their review on the topic, Złotowski et al. (2014) state that within the fields of psychology and anthropology, the reason for the human tendency to anthropomorphise can be found in the development of an adaptive evolutionary trait. By interpreting ambiguous shapes as either bodies or faces, early humans increased their genetic fitness - for instance by avoiding predators.

2.6.2 Factors Affecting Anthropomorphism

So why do humans perceive nonhuman agents as humanlike? The answer to that question is still debated. Złotowski et al. (2014) name a few explanations and hypotheses, including confirmation bias, neural correlates, and specific psychological traits, which may underlie the phenomenon. One theory that has received particular attention, especially in the field of HRI, is the three-factor theory of anthropomorphism proposed by Epley, Waytz and Cacioppo (2007). The model includes three psychological factors that determine when humans anthropomorphise:

1. **Elicited agent knowledge** - people tend to use anthropomorphism to explain non-human agents before they have gained enough knowledge to create a proper mental model of it.

2. **Effectance motivation** - if people are motivated to explain the agent's behaviour, the tendency to anthropomorphise increases.

3. **Sociality motivation** - people with limited social capabilities or possibilities tend to anthropomorphise non-human agents to a higher degree to compensate for their lack of connection to other humans.

Proof of this model's applicability can be found in many studies on human tendencies to anthropomorphise. In terms of sociality motivation, a study performed by Epley, Waytz and Cacioppo (2007) predicted that elderly people were more likely to anthropomorphise a service robot. This also indicates that there are age differences when it comes to anthropomorphising artefacts. In fact, a study conducted by Bumby and Dautenhahn (1999) which aimed to identify people's perception and reactions to robots, it was shown that children have stronger tendencies to anthropomorphise than older participants. Interestingly enough, there also seems to be a distinguishable gender difference when it comes to anthropomorphising artefacts when the target is animals, with females being more likely to make anthropomorphic attributions than males. However, when it comes to anthropomorphising machines, such as cars, no such gender difference can be distinguished (Złotowski et al., 2014).

2.6.3 Classifications

A controversial topic within mainly HRI the previous decade is the classification of different degrees of anthropomorphism. Which different degrees are there? Is it a uni-dimensional or multi-dimensional phenomenon? And what do people generally mean when they refer to an agent as "humanlike"? These are some of the questions that have been posed and which are crucial to shed light on in this thesis, due to its focus on the effects of anthropomorphism on trust, subsequently affecting acceptance of HAV.

One suggestion to a classification of anthropomorphism in terms of physical appearance of robots is the illustrative "map" provided by Duffy (2003). In his triangle diagram, each corner represents three primary categorisations for robots that use anthropomorphic features to some extent (see figure 2.12). The "Human" extremity represents the design that aims to, as much as possible, resemble the human physical appearance. The "Iconic" corner is, on the other hand, characterised by trying to achieve the minimum number of human features to express humanness. Lastly, the "Abstract" category refers to functional mechanistic design that is far from humanlike in terms of appearance. Although the model might be highly useful as an aid when designing physical appearance of an HMI, it only addresses the physical embodiment of the agent. These categorisations closely resemble those of Fong, Nourbakhsh and Dautenhahn (2003), where "Anthropomorphic" would correspond to "Human", "Caricatured" to "Iconic", and "Functional" to "Abstract".

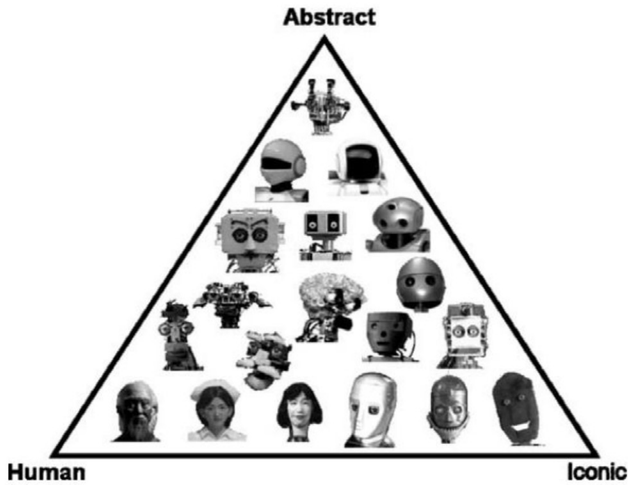

Figure 2.12: Duffy's (2003) triangle diagram of the design space of robot heads.

According to Złotowski et al. (2014), one needs to be aware of what is perceived as humanlike in order to define levels of anthropomorphism. They question the uni-dimensional approach that has been used to describe levels of the phenomenon and instead suggest that the level of anthropomorphism is decided based on many different variables on a multi-dimensional scale. According to them, previous studies have successfully identified factors affecting humanlikeness of robots, such as embodiment, verbal communication, emotions, and gestures - but failed in creating a unifying theory to explain which attributes affects the level of anthropomorphism. Złotowski also claims that the three-factor theory of Epley et al. (2007) is not enough to describe the impact of the previously mentioned factors on perceived level of anthropomorphism. Instead, inspired by the work of Waytz, Epley and Cacioppo (2010), Złotowski uses the opposite process to anthropomorphisation, namely dehumanisation. The concept of dehumanisation is defined by Waytz, Epley and Cacioppo (2010, p. 60) as "...representing human agents as nonhuman objects or animals and hence denying them human-essential capacities". The idea is that if one denies characteristics from an agent that is presumably human, and observes the effects on perceived humanlikeness, one can identify the characteristics that are essential to humanness. Haslam (2006) developed the concept of dehumanisation further by proposing a model including two distinct senses of humanness; Uniquely Human (UH) and Human Nature (HN). Depriving humans of UH characteristics, such as intelligence, leads to the perception of them as animal-like, whilst depriving them of HN characteristics, such as emotionality, leads to the perception of them as automata. Gray, Gray and Wegner (2007) support these findings in their research on perception of the mind and refer to these distinct senses as Agency and Experience, corresponding to UH and HN respectively. Based on this two-dimensional model of anthropomorphism, Złotowski et al. (2014) found in their study that primarily emotionality, and not intelligence, increases the perception of a robot as more humanlike - concluding that there is some evidence that anthropomorphism is a multi-dimensional phenomenon.

2.6.4 Anthropomorphism as a Construct

There is no complete model that can describe which different degrees there are of anthropomorphism and how to achieve these degrees by design. As a starting point for classifying anthropomorphism in this thesis, the four levels observed for service robots by (Zhang et al., 2008, p. 675) are used. These levels describe agents which are embodied both physically and virtually, and cannot be directly translated into being used for agents who are only virtually embodied. However, in the context of HAV, the vehicle itself is the robot and the embodied agent will be virtual, leading to a need for adapting these levels. In order to describe virtually embodied agents in terms of degree of anthropomorphism, the authors propose following basic classification:

1. Non-anthropomorphic agents.

2. Agents designed with certain anthropomorphic features as well as intentional deviations from the human "prototype".

3. Agents highly resembling the human "prototype".

These three degrees are proposed for the purpose of evaluating the appropriateness of anthropomorphism in HAV. The four levels described by Zhang et al. (2008) are reduced to three, because an agent needs to be morphologically similar to a human in order to be considered humanoid. The authors of this thesis hence argue that an agent that is not physically embodied can never be highly humanoid. The three degrees can furthermore be compared to the classifications proposed by Duffy (2003) and Fong, Nourbakhsh and Dautenhahn (2003), whose classifications act as suggestions on how to design the agents. They were therefore used as reference points in the concept development phase.

The three suggested degrees do not contain any specific information as to which features or characteristics may be used in order to design a virtual agent, but act as a general classification for developed concepts. However, in table 2.2, a summary of attributes aimed to increase the degree of anthropomorphism is presented. Each attribute is presented along with references that support it with empirical evidence.

2.6.5 HMI Application

Anthropomorphism is used in HMI as a means of facilitating the interaction between humans and machines. Fong, Nourbakhsh and Dautenhahn (2003) claim that the common assumption is that humans prefer to interact with technology in similar ways to how they interact with other humans. This assumption is supported by Reeves and Nass (1996), who state that humans often interact with technology as they interact with other humans. By using anthropomorphism in HMI design, one takes these tendencies and preferences into account in order to facilitate the interaction. Anthropomorphism can also be used as a means of creating acceptance for technology that the user cannot fully understand, as it can help the user understand and explain the behaviour of the technology by attributing it with a humanlike mind (Duffy, 2003; Epley, Waytz, and Cacioppo, 2007). DiSalvo and Gemperle (2003) identified four purposes for using anthropomorphism in product design that align with the aforementioned research. These reasons are as follows:

1. **Keeping things the same** - for products that traditionally use anthropomorphic form.

2. **Explaining the unknown** - to be able to understand and explain new technologies and functionality.

3. **Reflecting product attributes** - to structure the interaction according to how the product operates.

4. **Projecting human values** - to express personal, social, or cultural values.

Table 2.2: List of attributes to increase degree of anthropomorphism in virtually embodied agents.

Attributes to Increase Degree of Anthropomorphism		
Embodiment attributes		**References**
Head		Duffy (2003)
Chin		Hoff and Bashir (2015)
Eyes		Duffy (2003); Hoff and Bashir (2015)
Mouth		Duffy (2003)
Humanlike voice		Waytz, Heafner and Epley (2014)
Cognitive attributes		
Human Nature	Primary emotions	Haslam (2006)
	Sociability	
	Warmth	
Uniquely Human	Intelligence	Haslam (2006)
	Intentionality	
	Secondary emotions	
	Morality	
Identity	Name	Waytz, Heafner and Epley (2014)
	Gender	

In relation to vehicles, there are a few examples of anthropomorphism being used in the HMI design. As vehicle automation progresses towards higher levels of autonomy, the interaction between driver and vehicle needs to be reimagined. Since the driver will no longer always have the control and responsibility of the vehicle's actions, it becomes more important that the vehicle communicates its intentions and actions. This is in order to keep the driver informed about its capabilities and limitations, as well as keeping the driver in-the-loop. To showcase different approaches to HMI design in relation to anthropomorphism among vehicle manufacturers, two concepts for future autonomous vehicles (SAE level 3 or 4) are presented: The Nissan IDS Concept (see figure 2.13) (Nissan Online Newsroom, 2015) and the BMW Vision

Figure 2.13: Nissan IDS Concept embodying an agent with blinking eyes and eyebrows (Nissan Online Newsroom, 2015).

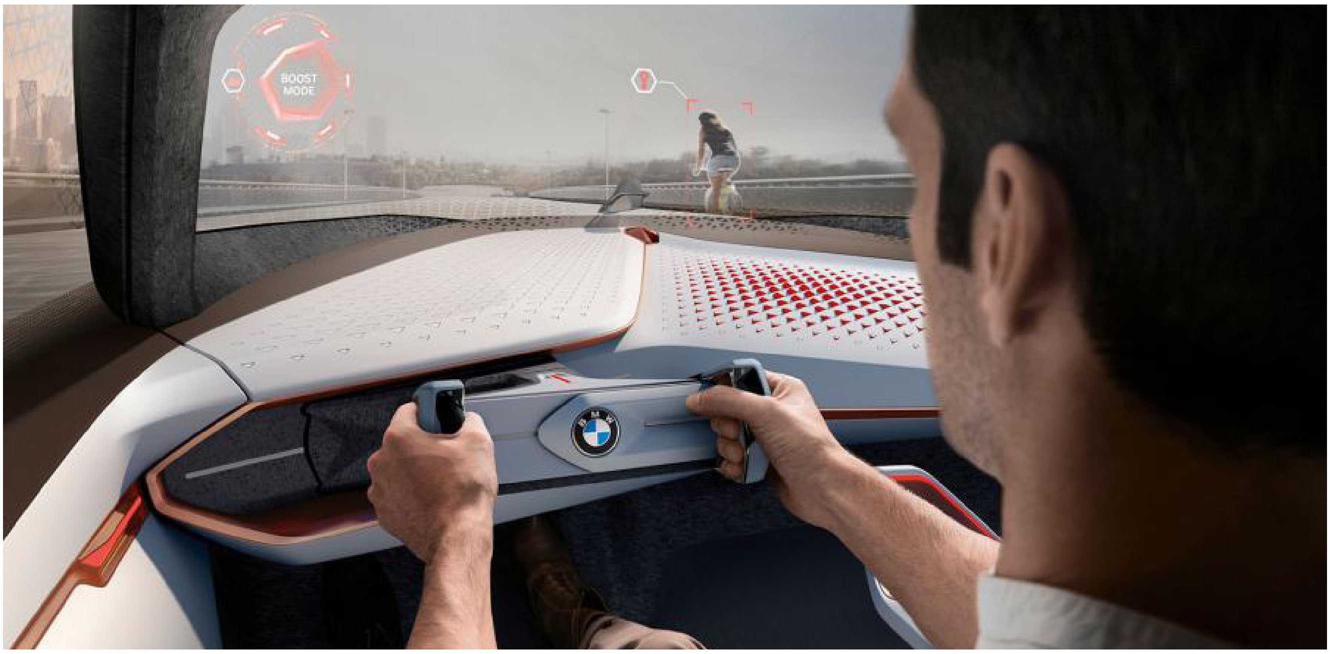

Figure 2.14: BMW Vision Next 100 with a sculpture in the centre of the tessellating dashboard (Next100.bmw, 2016).

Next 100 (see figure 2.14) (Next100.bmw, 2016). The BMW uses no humanlike form or communication, but a small sculpture at the centre of the dashboard representing the intelligence of its systems, called "The Companion". This sculpture is the centre of the vehicle's communication with the driver, which is done continuously through a tessellating dashboard. The Nissan instead utilises a pair of caricatured eyes with eyebrows to show attention and text prompts to keep the driver informed. It also utilises a large visual touch screen for communication regarding routes and schedules etc. Where the BMW visualises its intelligent systems as some form of omnipresent intelligence, the Nissan uses a metaphor in caricatured human form to convey its intelligence and attentive state.

2.6.6 Effects of Anthropomorphism

Introducing anthropomorphic features in an HMI design may be an efficient way to communicate competency, but the design strategy might also result in other effects. In this section, general implications as well as implications for HAV are described to further explore the effects of anthropomorphism.

General Implications

Using anthropomorphism in HMI design can facilitate the interaction, but it can also create expectations that exceed the capability of the technology (DiSalvo and Gemperle, 2003). Duffy (2003) states that the form of a robot should only contain those human characteristics that facilitate social interaction, without trying to emulate other human characteristics. When using anthropomorphism in the design, it is important that the robot still reflects some "robot-ness" to avoid creating false expectations of its capabilities. Within the field of human-computer interaction (HCI), Foner (1993) said that strong anthropomorphic features in the design may inflate user expectations of system performance, and stated that a restrained degree of anthropomorphism may therefore be optimal for robots that integrate work and social interaction.

Research suggests that the anthropomorphism of an interface can be a significant variable affecting trust in automation (de Visser et al., 2012; Gong, 2008; Green, 2010; Pak et al., 2012). As an example, the study performed by de Visser et al. (2012) showed that system errors affect user trust in the system less negatively with increasing interface anthropomorphism. According to Hoff and Bashir (2015), these findings suggest that anthropomorphism can help prevent inappropriate disuse of automation in certain applications. Important to note is that individual user characteristics such as age, gender, and culture can affect the trust formation process, making it crucial for designers to take potential users into account when anthropomorphising an interface (Pak et al., 2012).

The concept of the "Uncanny Valley" was first observed by Mori (1981), and describes a region of the design space for anthropomorphic robots where the robot becomes too humanlike and therefore is perceived as weird or eerie by humans (see figure 2.15). If a robot e.g. has facial features that strongly resemble those of a human, it is expected that it can also display facial expressions like a human would, and not being able to do so may create strange and negative feelings for the human interacting with it. However, Mori suggests using anthropomorphism to make the robot interesting and appealing while still keeping it visibly artificial.

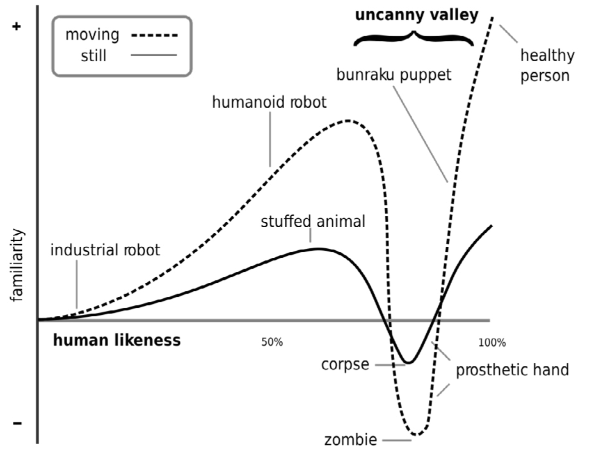

Figure 2.15: The uncanny valley illustrated with examples (Wikimedia, 2017).

Aforementioned research points towards a shared understanding that a robot must be designed in a way so that it is clearly not perceived to be human, while still making use of human characteristics that can facilitate the interaction. Most of the research on anthropomorphism has been done within HRI and HCI, and there are not many examples of studies where this knowledge has been applied to HAV and the acceptance of such systems.

Implications for HAV

Research on anthropomorphism in relation to HAV includes a planned study by Lee, Gu and Shin (2015), investigating how levels of anthropomorphism and levels of automation affect users' perceived safety and trust in an autonomous vehicle. Results from this study are yet to be published, and this thesis instead aims to further investigate some of the findings of Waytz, Heafner and Epley (2014), who showed that some degree of anthropomorphism positively affected users' trust in autonomous vehicles. The study also showed that users attributed more humanlike mental capabilities to the anthropomorphic concept, and that they blamed it less than they blamed the concept without anthropomorphic features for an accident caused by another driver. These results further support theoretical connections between perceived mental capabilities in others and assessment of competence, trust, and responsibility. Epley, Caruso, & Bazerman (2006) as well as Pierce et al. (2013) found that the more users attribute humanlike mental capabilities to technology, the more they should trust it to perform its function, regardless of the valence of this function. The relationship between competence and responsibility has been observed by Beckman (1970) and Wetzel (1982), who showed that when two people are potentially responsible for an outcome, the agent seen as more competent tends to be credited for success. Similarly, the agent seen as less competent tends to be blamed for failure.

It is important to note that "...design of automated systems is really the design of a new human–machine cooperative system" (Woods, 1996, p. 3), and that anthropomorphism is only one tool that can be used to facilitate the communication between human and machine in this cooperative system.

2.6.9 Anthropomorphism as a Variable

Anthropomorphism is considered as the independent variable in this thesis. The variable is used as defined in section 2.6.4.

2.7 Recommendations for HMI Design

This section summarises recommendations for HMI design, and includes usability heuristics (Nielsen, 1995), implications for creating trustable automation (Lee and See, 2004), and design recommendations for trustworthy automation (Hoff and Bashir, 2015).

2.7.1 Usability Heuristics for User Interface Design

Jakob Nielsen defines the following ten general interaction design principles, known as "heuristics", to counteract or prevent use errors (Nielsen, 1995):

1. **Visibility of system status** - The user should at all times, through appropriate feedback and in time, be kept informed about the system status.

2. **Match between system and the real world** - The system should provide the user with information according to real-world conventions, in a logical order and in the user's own language.

3. **User control and freedom** - If a function is accessed by mistake, the system should provide a simple possibility to exit from the unwanted state.

4. **Consistency and standards** - The system should be consistent in its use of words, actions and situations to avoid any confusion.

5. **Error prevention** - The system should eliminate the possibility to make errors or at least present error messages when needed.

6. **Recognition rather than recall** - Easily understood objects, actions, and options should be visible and easy for the user to retrieve at all times to prevent memory overload.

7. **Flexibility and efficiency of use** - The system should allow the user to customise the actions to promote expert user interaction efficiency.

8. **Aesthetic and minimalistic design** - The system should only display relevant information and avoid the use of rarely needed information that might overload the user's attentional resources.

9. **Help users recognise, diagnose, and recover from errors** - When presented, error messages, should contain a clear description of the problem, as well as a suggested solution to the problem.

10. **Help and documentation** - If needed, the system should enable the user to search for task-related help that include concrete steps to solve potential issues.

Even though these heuristics do not act as specific usability guidelines for the design of HMI in HAV, they may act as part of a framework for the development of such a system. Due to the high mental workload associated with a complex system such as the driver-vehicle system of an HAV, the requirements regarding usability are particularly crucial to fulfil. If the usability aspect is neglected in the development of HMI, the driver might not understand how to use it and potentially use the vehicle in a dangerous manner.

2.7.2 Creating Trustable Automation

Lee and See (2004) suggest a number of implications for creating trustable automation, where the designer needs to consider how the automation capabilities are conveyed to the user, how it is related to context, and how humans interact with each other in teams and on cultural and organisational levels. When creating automation, there is a trade-off between making it trustworthy and making it trustable. Trustworthy automation performs efficiently and reliably, which may require complex algorithms that are hard to understand. To create trustable automation requires a transparency that allows the user to understand its capabilities and limitations. Therefore, it may be beneficial to make the automation simpler but less capable, provided that this can make the automation more trustable.

Making Automation Trustable

In order to make automation trustable, a designer must try to convey the capabilities of the automation to the user in a clear way (Lee and See, 2004). This can be achieved by making the algorithms simpler or by showing more clearly how they operate, the latter relating to transparency. They suggest design, evaluation, and training considerations which are presented below:

- Design for appropriate trust rather than greater trust.
- Show how the automation has performed in the past.
- Simplify the automation's algorithms and operation in order to make it easier to understand.
- Present the process through revealing intermediate results in a comprehensible way.
- Show the automation's purpose and application range in a way that relates to the goals of the user.
- Train operators to understand what governs the behaviour of the automation, how reliable it is expected to be and how it is intended to use.
- Carefully evaluate any anthropomorphising of the automation in order to make sure that it facilitates appropriate trust.

Relating Context to Automation Capability

The user must understand how the context of use influences the capability of the automation in order to trust it appropriately (Lee and See, 2004). When automation operates in a dynamic environment that affects its capability, it is important that the user can understand how it is affected. The authors suggest design, evaluation, and training considerations which are presented below:

- Show the context and facilitate the user's assessment of situations that affect the capability of the automation.
- Show how different situations have affected past performance of the automation.
- Review how the relevance of trust is affected by the context.
- Evaluate trust appropriateness in relation to calibration, resolution and specificity. When automation performance is highly context dependent, specificity is most critical.

- When training operators for creating appropriate trust, show how different situations affect automation capability through revealing how they interact with specific automation characteristics.

From their review of existing research, Hoff and Bashir (2015) identified five design features that need to be taken into special consideration when designing a trustable automated system; appearance, ease of use, communication style, transparency/feedback, and level of control. For each of these features, they include empirically supported design recommendations for creating trustable automation. The features and associated recommendations are summarised below.

Appearance
In order to promote greater trust, one should aim to increase the anthropomorphism of the system. However, one should make sure to consider the potential differences in responses to anthropomorphic features associated with dispositional trust.

Ease of Use
Interfaces should be simple to use in order for trust to grow. To further increase trust from a usability point of view, one may consider increasing the saliency of the system's feedback.

Communication Style
The embodiment of agents should be carefully considered in terms of gender, eye movement, chin shape, and politeness in order for it to communicate trustworthiness.

Transparency/Feedback
Users should be provided with continuous and accurate feedback regarding the reliability of the automation to ensure appropriate trust levels and maximum task performance. Tendencies of how the user interprets that feedback should also be evaluated. One should also consider providing the user with additional error information if the errors occur early in the interaction or are perceived as "easy".

Level of Control
To increase trust in the system, one should consider increasing the transparency of automation on a high level. Furthermore, from a psychological perspective, one should make sure to investigate user's preferred level of control.

2.8 Implications from Theory
As seen in this chapter, user acceptance in relation to HAV is affected by numerous variables, such as perceived usefulness, perceived ease of use, and compatibility. However, one can argue that the main determinant for the relationship between user acceptance and anthropomorphism is trust. Therefore, trust is used as the dependent variable in the user test, linking anthropomorphism as the independent variable to user acceptance (see figure 2.16).

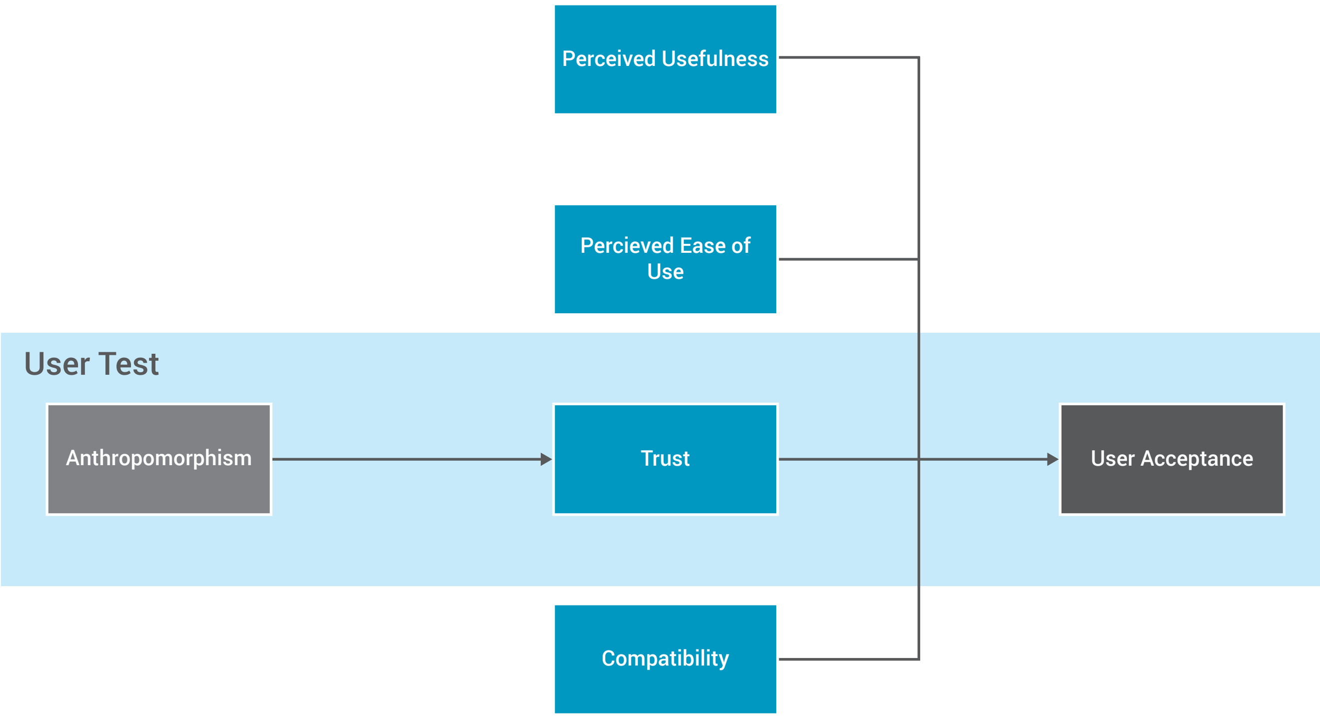

Figure 2.16: Anthropomorphism used as the independent variable, linked to acceptance through the dependent variable trust.

3

METHODOLOGY

This chapter presents the methods that have been used throughout the project. It is only intended to be used as an encyclopaedia for the reader when they need an explanation of a method while reading the report.

3.1 Data Collection

In this section, methods for data collection that were used in the project are presented.

3.1.1 Literature Review

A literature review is conducted in order to collect and analyse background information relevant to a project. A literature review can be conducted using a five-stage process: define, search, select, analyse, and present (Wolfswinkel, Furtmueller and Wilderom, 2013). First, a relevant area is defined along with the search words necessary to find information about that area. Second, a search for literature is conducted in relevant databases. The articles found are sorted and the most relevant ones are selected for analysis. The analysis can be done using an affinity diagram, before the processed information is presented.

3.1.2 Interviews

Interviews are conducted with users and experts in order to collect data on their experiences, opinions, and attitudes (Wikberg Nilsson, Ericson and Törlind, 2015). Interviews can be structured, where the interviewer keeps to a pre-defined set of questions and avoids probing and follow-up questions. Semi-structured interviews make use of pre-defined questions or topics, but the interviewer can deviate from these in order to explore other possible areas of interest. An unstructured interview is more like a conversation where the interviewer and interviewee discuss the subject at hand.

3.1.3 Observations

Observations are conducted in order to investigate situations where the observer has a need to experience the context first hand and to identify user needs (Wikberg Nilsson, Ericson and Törlind, 2015). Observations can be naturalistic, where the observer does not interfere with the users in order to study their behaviour in a natural setting. They can also be participatory, where the observer participates in the activities and asks questions to get a deeper insight into the context and use.

3.1.4 Benchmarking

Benchmarking is conducted in order to analyse competitors and similar offerings in a market or market segment, or to gather information about technology used in alternative applications (Bohgard et al. 2009). The objectives of a benchmarking can be to find inspiration for product development or to find an unexploited market niche.

3.1.5 Within-Subjects Test

In a user test, a within-subjects design means that all subjects are exposed to all conditions. There are two main advantages with a within-subjects design compared to a between-subjects design, where each subject is only exposed to one of the conditions (Psychology World, 1998). The first one is that it allows for a larger number of observations, since the same subjects test all concepts. The second advantage is that it reduces the error variance associated with individual differences. The fundamental disadvantage with within-subjects designs is that one subject's participation in one condition may affect their performance in another condition. Two possible factors are practice and fatigue, which may affect the result in a test following another positively and negatively respectively.

3.1.6 Wizard-of-Oz

Wizard-of-Oz is a method to quickly evaluate subject's responses to unimplemented technology. The "wizard" is a person who sits in a back room, simulates the system responses in real-time, and observes the user's reactions. The technique can give valuable insights regarding the interaction with a device and identify potential use errors or problems (Usabilitynet.org, 2017).

3.1.7 Questionnaire

Questionnaires are survey instruments aimed to elicit information regarding people's characteristics, attitudes, perceptions, or behaviours and are used alongside observations and interviews as data collection method. Typically, questionnaires are constructed with either open-ended questions, closed-ended questions, or rankings. Rankings are commonly designed so that the respondent needs select a response on a scale (Martin and Hanington, 2012). A highly recommended scale to use is a Likert scale (Likert, 1932), which consists of several symmetric agree-disagree items, to which the respondents state their level of agreement. This ensures that questions remain neutral while it gives an indication about the strength of the responses.

3.2 Data Analysis

Here, methods for data analysis that were used in the thesis project are presented.

3.2.1 Wilcoxon Signed-Rank

The Wilcoxon signed-rank test is a non-parametric statistical test that can be used to compare two samples or repeated measurements on a single sample (Lowry, 1998). The objective is to assess whether the population mean ranks differ between the samples. The test can be used as an alternative to the parametric Student's t-test when no assumption of normal distribution of the population can be assumed.

3.2.2 Affinity Diagram

An affinity diagram can be used to categorise and present large amounts of verbal data in an efficient way (Tague, 2005). Affinity diagrams are especially helpful when the data is diverse and complex, because it helps creating an overview of the themes that can be found in the data. To create an affinity diagram, each item of information should be represented on its own, so that the person or group conducting the sorting can move each item to come together with similar items. After the sorting has taken place, the categories can be defined and combined if applicable.

3.3 Ideation

Here, methods for ideation that were used in the thesis project are presented.

3.3.1 Design Sprint

Design sprints are a framework for solving and testing design problems in 2-5 days (Direkova, 2015), and originates from the Agile framework. Design sprints can be conducted by teams of any size, but the optimal team size is 5-8 people. The person who leads the team is the sprint master, who starts by defining the key challenge for the sprint. The sprint consists of six consecutive steps that allow for iteration: understand; define; diverge; decide; prototype; and validate.

3.3.2 Workshop

A workshop is a creative meeting where a group of people gather to explore an area of interest or solve a task (Wikberg Nilsson, Ericson and Törlind, 2015). The group of participants may contain users, experts, or people without connection to the project. Before the workshop, the aim is defined in order to create a schedule that can facilitate achieving the aim. The workshop starts by a short introduction and a warm-up exercise, before exploring the area of interest with the help of creative methods.

3.3.3 Brainstorming

Brainstorming is a method aimed at generating a large number of ideas (Osborn, 1967). Before the brainstorming session, a theme is defined and participants recruited. During the session, ideas are written down or sketched on sticky notes or paper. After a first ideation session, ideas are collected to form a brainpool for the participants to review, before a new session on the same theme or a related one starts (Wikberg Nilsson, Ericson and Törlind, 2015). The method can be varied greatly, but the basic rules are as follows: Criticism of ideas during the session is forbidden, crazy ideas are promoted, ideas can be combined and improved, and quantity beats quality.

3.3.4 Brainwriting 6-3-5

Brainwriting 6-3-5 is closely related to brainstorming. Here, six participants create three ideas each during five minutes, before the ideas are passed on to the next participant for further development (Wikberg Nilsson, Ericson and Törlind, 2015). This process is repeated several times in order to create a large and diverse set of ideas, before they are reviewed by the participants. The same basic rules apply here as they do to brainstorming.

3.3.5 Speed Dating

Speed dating is a research method aimed to evaluate, or "speed date" design opportunities rapidly. The method makes use of various methods, including storyboards, scenarios, potential users, and simulated environments, to illustrate needs and problems associated with a product. First, contextual field research is conducted to understand the users to whom the product is designed for. Next, storyboards are created, describing scenarios in which the needs of the users are addressed with potential designs. When the storyboards are finished, they are "speed dated" and evaluated based on how well the needs are satisfied. In the last step, user enactment (further described in section 3.4.3) is used to identify context related issues (Martin and Hanington, 2012).

3.4 Evaluation

Here, methods for evaluation that were used in the thesis project are presented.

3.4.1 Heuristic Evaluation

Heuristic evaluation (Nielsen, 1994) is a method created to evaluate user interfaces with regards to established usability heuristics. The aim is to find usability problems during the course of a design process so that they can be attended to. The evaluation is conducted by a small number of evaluators, preferrably experts.

3.4.2 Scenario

A scenario tells a story about the use of a product or service by a user in a specific situation (Wikberg Nilsson, Ericson and Törlind, 2015). It can be used to describe current user interactions as well as envisioned future interactions. Scenarios can be used to generate ideas about the interaction, to communicate a solution, or evaluate different ideas. A scenario is created by defining its purpose, and which stakeholders should be involved. The full scenario can then be created and defined by using e.g. brainstorming methods. Scenarios can be visualised using storyboards, writing, or a mixture of components.

3.4.3 User Enactment

User enactment is a method that allow designers to imagine the use of a product in a simulated product context. Enactments are usually built on a pre-defined scenarios and are used to reveal potential problems in context and how they might play out in real life (Martin and Hanington, 2012).

3.4.4 Guerrilla Testing

Guerrilla testing is a low cost usability testing method that enables direct user feedback. The technique only requires low fidelity prototypes, e.g. paper models, a brief description the use situation, and voluntary participants. The participants are first asked to interact with the prototype and by the end of the session, allowed to give feedback regarding its function and design (The Interaction Design Foundation, 2017).

3.4.5 Kano Model

The Kano model (Kano, 1995) aims to develop attributes that benefit users. It can be used to evaluate existing designs and as a basis for developing new concepts (Wikberg Nilsson, Ericson and Törlind, 2015). The basic idea of the model is that user needs can be divided into must-be needs, performance needs, and excitement needs. The must-be needs cover attributes that satisfy the most basic user needs, that users take for granted and often do not mention. These needs do not contribute to a higher user satisfaction, but will disappoint them if they are not met. Performance needs contribute to a higher satisfaction if met, and most of them are known and can be vocalised by the users. Excitement needs refer to attributes that are not vocalised by the users and create a positive surprise and significantly heightened value when fulfilled.

3.5 Visualisation

Here, methods for visualisation that were used in the thesis project are presented.

3.5.1 Sketching

Sketching is a powerful design tool to illustrate ideas and concepts. It may include fast sketching with pen and paper, as well as digital sketches created with 2D vectors in illustration software programs such as Adobe Illustrator (Österlin, 2003).

3.5.2 Storyboards

A storyboard is a graphic representation of a sequence, commonly described by the help of illustrations. It is used as an aid to communicate ideas and is effective in order to present interactions. A storyboard is created by first drawing a series of squares on an empty piece of paper, add a script beneath each square, and finally fill the squares with explanatory illustrations (GoAnimate Resources, 2017).

3.5.3 User Experience Prototype

A user experience prototype is a tangible representation of a product can be used to evaluate its design. The prototype should be designed so that it captures both function and appearance of the real product, enough to use it as an evaluation tool in user research (Boagworld - User Experience Advice, 2017).

4

PROCESS

This chapter aims to give the reader an understanding of the process for the thesis project. It begins by giving an overview of the main phases and continues by describing each phase in detail. Here, the reader can find information about how the results were produced.

4.1 Process Overview

The project process (see figure 4.1) was based partly on a research process, and partly on a product development process. It started with a theory phase to create a theoretical framework for the user test. The findings from the theory and user test were then summarised in HMI design guidelines, which were used as a framework for the HMI concept development phase.

relation to user acceptance of HAV, and to contribute towards the definition of a set of HMI design guidelines.

The literature review was carried out by defining relevant keywords, e.g. *autonomous driving/vehicles, trust, automated driving/vehicle, anthropomorphism, human-like, acceptance, HMI, HRI, HAI, embodiment,* and combinations of these that were used to search for articles in a number of different databases. The selection of databases consisted of ones that specialise in topics related to the project,

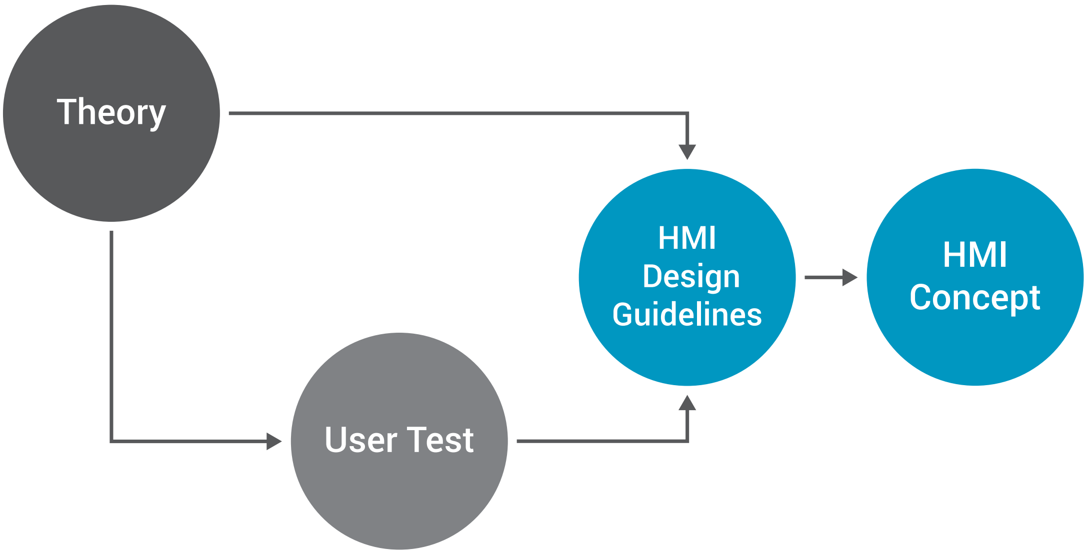

Figure 4.1: Illustration of project process.

4.2 Introduction

The project's aim, objectives, delimitations, and timeframe were outlined in a project plan in order to ensure that its goals would be fulfilled at the end of the project. A Gantt chart (see appendix I) was used to plan the different phases of the project, divide them into smaller work packages, and assign these with work resources. The project plan later came to form the introductory chapter of this thesis (see chapter 1).

4.3 Theory

A literature review was carried out in order to gain an understanding of how different theoretical constructs relevant to the project relate to each other and to the context of autonomous vehicles. The aim of this review was to answer the first research question of this thesis, namely:

> *Which variables affect user acceptance for HAV?*

The goals of the literature review were to define which theoretical constructs are most relevant to examine in

such as transportation (TRID and Transguide), as well as general databases for academic literature (Google Scholar, SCOPUS, CPL; and Web of Science). The search generated approximately 70 articles with relevant titles, which after reading their abstracts were reduced to approximately 35 that were chosen for thorough review. Those articles were read and summarised, before the content was analysed using an affinity diagram in order to find and organise interrelated themes. The themes found in the affinity diagram forms the structure for the theory chapter of this report (see chapter 2), which is the theoretical basis on which this thesis stands. The theoretical findings then formed the basis for the HMI design guidelines.

4.4 User Test

The aim of the user test was to find an answer to the second research question of the thesis in relation to the findings from theory, namely:

> *How is trust influenced by HMIs based on different degrees of anthropomorphism?*

To be able to answer this question, a hypothesis was formed based on the theory about the close relationship between anthropomorphism, trust, and user acceptance:

H_1: An increased degree of anthropomorphism will lead to an increased level of trust in the system.

With its corresponding null hypothesis:

H_0: The level of trust in the system will not be affected by an increased degree of anthropomorphism.

Several steps of preparation and implementation were necessary in order to be able to test the hypotheses in a user test. Below, the considerations that were made are described along with the steps that were taken in order to plan, carry out, and analyse the collected data.

When the constructs to be subject to investigation had been chosen, it was necessary to define a scenario containing events likely to occur while driving an autonomous vehicle. The scenario was defined with a starting point in the framework for creating appropriate trust in autonomous vehicles by Ekman and Johansson (2015). The thesis focuses on SAE level 4 autonomous vehicles. Little research addresses the interaction during AD mode, but previous research in the field of HMI has rather focused on other areas, such as control transitions. Through discussions with the project owner and supervisor, the decision was hence made to focus on AD mode. Also, this focus would ensure that the result of the project would be compatible with higher levels of automation.

4.4.1 Heuristic Scenario

Initially, a heuristic scenario was constructed by the authors as a mediating object, aimed to facilitate the creation of a more developed scenario. The scenario was built by first ideating around the following two questions: "What planned actions may a vehicle perform when in AD mode?" and "What actions may the vehicle have to take as a result of events in the environment around the vehicle?" Having generated the events on sticky notes using brainwriting and brainstorming techniques, they were inserted into a table, which aimed to classify the events as either causes to an action or effects of an action. When necessary, the causes were grouped into categories labelled with names that better described each type of cause. Next, the notes containing causes and effects were mapped onto a timeline to make the scenario as tangible as possible. Lastly, each category was ranked in terms of trust importance. The ranking was based on the answer to the question "How much would inaccurate or lack of feedback from the system in this specific event negatively impact your level of trust to the vehicle?" and could assume three levels: low, medium, or high. Having ranked all events, they were categorised into a table according to their relative trust importance, with the ones ranked as high in the top and the ones ranked low in the bottom of the table.

Since at the time of this thesis project there were no users of SAE level 4 autonomous vehicles except for technical experts and test participants, the project could not rely on actual users. Instead, to define possible events necessary for the construction of a plausible scenario, interviews with experts, driving of a vehicle with SAE level 2 autonomy, and an ideation workshop with students were carried out.

4.4.2 Interviews

In total, five semi-structured interviews were conducted with experts in the fields of HMI development, autonomous vehicles and HRI, using pre-defined interview guides (see appendix II). The interviewees were presented with a draft of the scenario created by the authors, and were then allowed to freely reflect upon its design. However, the primary aim of the interviews was not to give direct input to the scenario development. Rather, they were used to verify the scenario's validity and to develop a broader understanding of HMI development and research, autonomous vehicles and their market, and closely related technical fields. Hence, they provided input not only to the scenario, but also to the latter project phases.

4.4.3 Driving

In order for the authors to gain a better understanding of events that may occur when driving an SAE level 4 autonomous vehicle, it was deemed necessary to experience it first-hand. Due to the fact that SAE level 4 autonomous vehicles were not available, a 2016 Volvo XC90, equipped with SAE level 2 autonomy in the form of Pilot Assist, was used to experience automated functions, including their use, limitations and reliability. Even though the car corresponds to an SAE level 2 autonomous vehicle, it was deemed to provide a driving situation that could result in useful insights for level 4 autonomy. An expert in HMI and autonomous vehicles drove the vehicle and showed the authors its automated functions, before the authors tested the functions. During the drive, a video recorded interview with the aforementioned expert was held in order to gain as much knowledge of the automated functions as possible.

4.4.4 Workshop

As a means to receive further external input to refine and validate the defined scenario, and to mitigate the negative effects of not having access to users of SAE level 4 autonomous vehicles, a workshop was conducted (see figure 4.2). The workshop included seven students, five males and two females, between the ages of 23 and 29, all studying Industrial Design Engineering at Chalmers University of Technology. The workshop was structured identically to the heuristic scenario creation, meaning that the participants generated events, categorised, and finally ranked them according to a predefined workshop procedure (see appendix III). There were however two differences between the two ideation sessions. Firstly, the workshop included additional explanatory steps, including a presentation of the workshop goal, a warm-up exercise, and information regarding trust and reliance. Secondly, the mapping of events onto the time diagram was removed in the workshop procedure as a result of time limitations and since it was deemed less important than the step generating events.

Figure 4.2: Workshop for creating scenario.

As a result of the heuristic scenario, interviews, driving and workshop, a HAV scenario was finalised. It aims to illustrate all types of events that can take place in AD mode and was put together by including one event from every category of the extensive list. The categories listed from most critical to least critical were:

1. Direct and dangerous situations to driver

2. Indirect or potentially dangerous situations to driver

3. Minor continuous situations involving a low level of safety risk

The full scenario and all events can be found in appendix IV.

4.4.5 Event Selection

To be able to measure trust in the user test, a few specific events found in the scenario needed to be included. It was important that these events were deemed critical in affecting a driver's trust formation, as well as being implementable in a test setting. This led to the selection of two events from the most critical category "Direct and dangerous situations to driver" to be selected:

Avoiding collision with...

1. ...a moving obstacle in the form of a pedestrian crossing the road unexpectedly and;

2. ...a static obstacle in the form of a traffic cone in the way of the vehicle's projected path.

Due to the potential difficulty of distinguishing a driver's spontaneous reaction to an event, both of the selected events involve a short time-to-effect and a perceived vulnerability from the driver's point of view, possibly increasing the chance of observing such a spontaneous reaction (see appendix IV).

4.4.6 Subject Recruitment

Test subjects were recruited using lists of persons whom have previously participated in one or more user tests for the division of Design & Human Factors at Chalmers, and have indicated an interest in participating in further user tests. The aim of the recruitment process was to find subjects with characteristics that largely corresponded to a probable future user group in terms of age and gender. However, to avoid a nuisance factor in terms of communication problems resulting from the use of a second language, it was decided that the test should be carried out in Swedish, and that all subjects needed to be fluent speakers of the language.

A large number of potential recruits were contacted and asked to mark their interest and availability for the user test, and a group of 14 subjects were put together by considering availability as well as subject age and gender. Due to loss and technical issues, the number of subjects who completed the test was eleven, out of which ten answered all questions needed for the quantitative analysis. Of the eleven subjects, six were male and five were female, all between 25-68 years old (mean age 47, median 43), residing in, or close to, the Gothenburg area. The subjects can be found in table 4.1. In addition to creating a sample with a probability of corresponding to a future population of drivers of SAE level 4 autonomous vehicles, one consideration when selecting subjects was to reveal potential differences in tendency to anthropomorphise, as well as differences in general attitudes towards automation as depending on age and gender.

Table 4.1: Subjects recruited for the user test.

Subject	P	1	2	3	4	5	6	7	8	9	10
Age (Y)	28	25	68	66	58	43	56	38	28	63	25
Gender	M	F	M	F	M	M	F	F	M	F	M
Driving experience (Y)	3-10	3-10	>20	>20	>20	0-2	>20	11-20	3-10	>20	3-10

4.4.7 Test Materials

The user test was carried out on a test course (see figure 4.3) built inside of a fenced area at Lindholmspiren to which no other traffic could access. This ensured that no unforeseen interferences from other vehicles would occur during the test. In total, the test course measured approximately 400 metres, consisted of four turns, one static obstacle (traffic cone) location, and three different locations for the moving obstacle (a pedestrian).

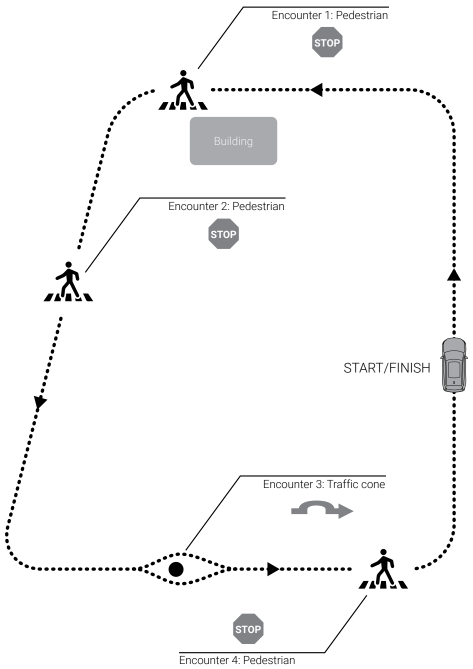

Figure 4.3: Test course overview, including all four encounters and vehicle actions.

A right-hand driven Volvo V40 provided by Volvo was used to represent an SAE level 4 autonomous vehicle. Inside the vehicle, three action cameras (GoPro Hero 4 Silver Edition) were used to video record the test. To display the interface, a 9.7 inch tablet (Apple iPad 2) was mounted on the dashboard on the passenger's side. Auditory displays were achieved by placing a speaker (Roxcore Crossbeat) between the driver and the passenger. To create an illusion of the vehicle in fact being autonomous, a blind was mounted between the driver and the passenger, separating the two sides visually. Hence, the subjects could never visually confirm that a person was driving the vehicle. The interfaces, which represented the three conditions, were created using Adobe Illustrator CS6 and the interface animations were created in Adobe Flash CS6. A laptop (Apple MacBook Pro Retina, 13 inch, 2013), operated by a test leader overlooking the test in the backseat, was used to control the interface animations and initiate the auditory displays (see figure 4.4). A green button mounted next to the tablet, connected to an LED light mounted next to the driver was used to allow the subjects believe that they were the ones who started the tests.

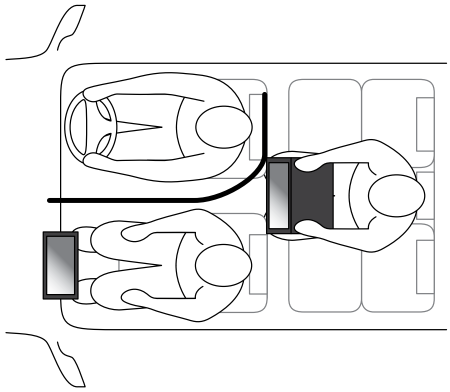

Figure 4.4: Test setup with the test leader in the back seat. Driver and subject are separated by a blind.

4.4.8 Conditions

Three versions of an interface representing three different degrees of anthropomorphism, whilst communicating the same information, were created to form the test conditions.

The first step in creating the conditions was to define the characteristics of the three desired points on the scale from machine-like to human-like. The three points were described as:

1. Non-anthropomorphic agents

2. Agents designed with certain anthropomorphic features as well as intentional deviations from the human "prototype"

3. Agents highly resembling the human "prototype"

Based on a comprehensive list of humanlike characteristics that have shown to increase the degree of anthropomorphism (see section 2.6.4), the characteristics of the three points on the scale could be defined. The conditions were then created by taking inspiration from previous user tests regarding anthropomorphism and with the help of brainstorming sessions. To ensure that the content of the information communicated would stay coherent between conditions, their exact communications were visualised using storyboards to represent the procedure of the user test.

In order to be able to observe the hypothesised correlation between the independent variable (degree of anthropomorphism) and the dependent variable (level of trust), it was crucial to counteract any effect that perceived ease of use might have had on the level of trust. As stated in AAM (see section 2.4.2), perceived ease of use is one of the main factors affecting trust-induced behaviour. The main challenges for the user test therefore included the handling of two identified nuisance factors: usability aspects and modalities. If any of the conditions would lack in terms of usability, the results may have been contaminated. For example, if the test subjects did not notice an HMI feature in one condition, but notice it in another, they might have put more trust in the latter condition than in the former. This means that the interface content had to be kept similar across conditions.

4.4.9 Procedure

In the following section, the test procedure is described in detail.

Test Design

The test was conducted with a within-subjects design. Due to the size of the project, it was deemed necessary to use within-subjects design in order to get as many observations as possible from a relatively small number of subjects, while minimising the effect of individual differences among the subjects. However, a small number of subjects also meant that the impact of a few instances of contaminated data was higher. To mitigate the consequences of this, the subjects were exposed to the conditions in a randomised order (see table 4.2).

Before Test

Before the test, the subjects were asked to answer a questionnaire online in order to gather data on their current experience of driving, experience and attitudes towards automated driving functionality, and their individual tendencies to anthropomorphise. This data was collected in order to control whether individual personality traits may have affected the test results. For the full pre-test questionnaire, see appendix V.

During Test

A test script was followed by the test leader during the test to ensure consistency between the tests (see appendix VI). At the beginning of the test, the subjects were asked to read through and sign a consent form (see appendix VII) and informed about the purpose and the procedure of the test. They were also told that the blind was used so that the person sitting on the other side of the blind, who was observing the test and making sure that it was safe, would not disturb them during the test. Next, the subjects were introduced to the interface structure and told that they could abort the test at any time by pressing the green button next to the tablet in front of them. Having completed the introduction, the subjects were taken on an initial warm-up lap, in which no condition was applied. This in order to make the subjects accustomed to the interface structure and the vehicle's driving style. When the warm-up lap was completed, the subjects were informed that the test would begin.

Figure 4.5: Traffic cone in the way of the vehicle's path at encounter location 3.

Table 4.2: The order in which the test subjects were exposed to the three conditions.

Condition/Subject	P	1	2	3	4	5	6	7	8	9	10
C1 - Baseline	1	2	1	2	3	1	2	1	2	3	1
C2 - Caricature	2	3	2	3	1	3	1	2	3	1	3
C3 - Human	3	1	3	1	2	2	3	3	1	2	2

During the test, the vehicle was driven three laps with one condition active during each lap. Every lap consisted of two encounter locations. One in which the vehicle needed to avoid a traffic cone (see figure 4.5) and one in which it had to stop for a pedestrian crossing the road (see figure 4.6). In order to minimise the effects of the subjects predicting the vehicle's action between the laps, the vehicle avoided the traffic cone on different sides depending on the active condition. Also, the pedestrian shifted encounter location between each lap. Between the laps, the test subjects were asked to answer a set of questions regarding each condition. The questionnaire consisted of five Likert scales, where each scale consisted of three to five items. The first part measured their immediate emotional response after the drive using the Self-Assessment Manikin (SAM) (Bradley and Lang, 1994), in order to compare this to their responses to interview questions. The second part measured usability or understanding of the condition, in order to see if there was a difference in how well the conditions were understood. This scale was applied since usability differences between conditions may affect the subjects' level of trust in the system. The third, fourth, and fifth scales measured anthropomorphism, perceived competency, and trust in the system respectively. Anthropomorphism was measured as a manipulation check to assure that the independent variable was successfully manipulated. The test subjects also answered brief interview questions regarding positive and negative opinions of each condition, as well as their view of the condition in relation to the car (i.e. if the condition was an independent agent controlling the car or if they saw the conditions as a representation of the car as a whole). For the full test questionnaire and interview questions, see appendix VIII.

During the test, three action cameras were recording. One focused on the road ahead and was mounted in front of the driver on the dashboard, one focused on the test subject and was mounted on the windscreen, and one focused on the test subject, screen, and button, and was mounted on the headrest of the driver's seat. This setup was used in order to record the test subjects' physical reactions to events on the road ahead as well as their answers to the interview questions.

After completion of the test, a short semi-structured interview was conducted with each of the test subjects. During the interview, the test subjects were to rank the conditions according to their preferences and their level of trust with the help of pictures of each condition as mediating objects. The interview also aimed to provide qualitative data on the test subjects' opinions of different condition features, and to check the validity of the results by asking how autonomous the test subject thought that the car was. For the full interview guide, see appendix IX. At the end of the test, the subjects were asked not to reveal any information regarding the test that could compromise it and were finally rewarded with a cinema ticket for their contribution.

4.4.10 Data Analysis

The data analysis was divided into two parts: analysis of quantitative data for the responses recorded on the questionnaires, and analysis of qualitative data for the answers recorded to the interview questions, as well as the video material recorded during the test.

Figure 4.6: Pedestrian walking out in front of vehicle at encounter location 1.

Quantitative Data

The quantitative data was summarised and presented graphically as different plots and diagrams, in order to find trends visually to choose for further investigation. The main investigation related to the hypotheses and whether a positive correlation could be found between the degree of anthropomorphism and the level of trust in the system. This was tested using a non-parametric statistical test in the form of a Wilcoxon Signed-Rank Test.

Qualitative Data

The qualitative data collected in the form of video recordings of the participants during the test laps was analysed by reviewing the recordings to see if there were any observable reactions that could imply that the subjects were startled or unsure whether they wanted to abort the test.

The audio recordings of the interviews were transcribed and a thematic analysis was conducted using an affinity diagram. From this, an implication analysis was done, and the findings were organised according to the themes found in the affinity diagram (see appendix X). The findings were then classified according to how crucial they were to consider when developing HMI for HAV. This was done with the help of three criteria:

1. How applicable the consideration is to HMI design and to this thesis;

2. How severe the consequences may be if one overlooks the consideration, and;

3. How many times and by how many different subjects it was mentioned.

By answering these questions, the authors classified the findings into three groups:

1. Findings that are required to consider;

2. Findings that are desired to consider, and;

3. Cosmetic or non-applicable findings.

The ranked findings from the user test served as the empirical contribution to the formation of HMI design guidelines.

4.5 HMI Design Guidelines

The HMI design guidelines were initially created with the findings from theory as a base, and later revised with empirical contributions from the user test.

An affinity diagram was used in the process of transferring findings from the theory into HMI design guidelines. Each theoretical framework related to HMI design guidelines was reviewed and each guideline organised according to a category. When all guidelines had been grouped into different categories, each category was described with new guidelines that summarised the essence of it. By the end of the session, the HMI design guidelines consisted of eight categories and a total of 32 guidelines.

To incorporate the empirical findings from the user tests, they were all mapped onto the HMI design guidelines table and sorted into the eight different categories. A part of the findings were already covered by the pre-existing guidelines, while some findings required an addition of new ones. Finally, a letter was assigned to each guideline, stating its source. The different sources included theory (T), user test (U), or both (T and U). In order to prioritise the guidelines based on their relative importance from a user need perspective, a Kano model was used to sort the categories.

The HMI design guidelines were used as a framework for the development of the HMI concept and as an evaluation tool to ensure the quality of the latter.

4.6 HMI Concept

The HMI concept was created in order to achieve the objective of the thesis, namely:

> *Make the findings from the two research questions tangible in the form of an HMI concept.*

The objective was created in order to evaluate the usefulness of the findings, as well as to synthesize these findings into something that can be applied to HMI design for HAV.

The process of developing an HMI concept was divided into two parts. Firstly, a model describing the modalities and characteristics of V2D communication during autonomous driving was developed. It was named *AVID Model*, for Autonomous Vehicles'

Interaction with Drivers. The model served as a basis for the development of the second part of the concept, alongside the HMI design guidelines. The second part was the development of a vision for the HMI of SAE level 4 autonomous vehicles, named *Vision AVID*. This part of the concept serves an exemplification of how the AVID Model can be used together with the HMI design guidelines, and how HMI for HAV may be developed from a holistic viewpoint.

4.6.1 AVID Model

The AVID Model was created using a Design Sprint process (see section 3.3.1). The challenge statement as defined by the authors was as follows:

> Design a model for how the vehicle-driver communication of an SAE level 4 autonomous vehicle should vary depending on vehicle-external and vehicle-internal states.

The deliverable for the sprint was a model describing the input and processing logic of the vehicle as well as its output through the HMI, and how this relates to the need for driver intervention. This model was to be described using a graphical representation together with explanatory text.

Since the content and characteristics of the interface communication was to be dependent on vehicle-external and vehicle-internal states in relation to the driver's need to intervene, the first step was to classify these states. The vehicle-external states were taken from the scenario and re-classified depending on whether or not the driver needs to intervene, may want to intervene, or will not want to intervene. The states which required driver intervention were also classified depending on the urgency. The vehicle-internal states were defined by using brainwriting and mapped visually on a two-dimensional scale, capturing both the human and environmental aspects. One axis on this scale was "noise level", which included auditory, visual, and haptic noise. The other axis was "driver attention level", meaning how attentive the driver is to the external driving environment. By mapping the states on this scale, they could be divided into four quadrants each representing one type of vehicle-internal situation.

By having defined and classified both vehicle-external and vehicle-internal states, the vehicle's input was described. To describe the processing logic, all possible combinations of external and internal states were reviewed using the findings from the user test along with theory on the use of modalities in different types of collision warnings. By creating this logic, the output in each of the combinations of external and internal states could be defined and exemplified.

4.6.2 Vision AVID

Vision AVID was created by using a Design Sprint method (see section 3.3.1). The challenge statement as defined by the authors was as follows:

> Create a holistic HMI concept that illustrates how the AVID Model can be used in concept development.

The development of Vision AVID was divided into two consecutive parts. Firstly, in order to be able to create a holistic HMI and achieve consistency and simplicity in the interaction, a metaphor for the interaction between the vehicle and the driver was created. Secondly, in order to exemplify how the AVID Model can be used, the interface was defined with the help of scenarios. The deliverables included a description of the interaction metaphor that would permeate the concept, a sketch of the vehicle interior that describes the vital parts, and storyboards visualising scenarios in order to exemplify how the concept would work.

Metaphor for Interaction

The metaphor for interaction was created based on a workshop with the same name, originally based on the research method "Speed dating", which specifically aims to help designers create and define metaphors for interaction between autonomous vehicles and human users. To start, a few pre-defined metaphors were described using a set of parameters relating to the relationship between the vehicle and driver. Ideas formed in this process led to the creation and definition of new metaphors, which were turned into quick and dirty concepts in order to be able to evaluate them. Four metaphors (see figure 4.7) were chosen for further development and were further defined by using user enactment in a pre-defined scenario that was altered to incorporate components necessary to illustrate the AVID Model. An example of a metaphor used is the H-metaphor, likening the operation of an autonomous vehicle to riding a horse. To choose a final metaphor, they were evaluated against how well they could perform consistently during all events in the scenario to facilitate a satisfactory interaction with the driver (see appendix XI). The criteria for the evaluation were adaptability, customisability, and personality intrusiveness. The metaphor "Personal assistant", created by the authors was selected since it, according to the authors, best manages to reflect the essence of the role of an HAV, namely to be adaptable, customisable, and non-intrusive.

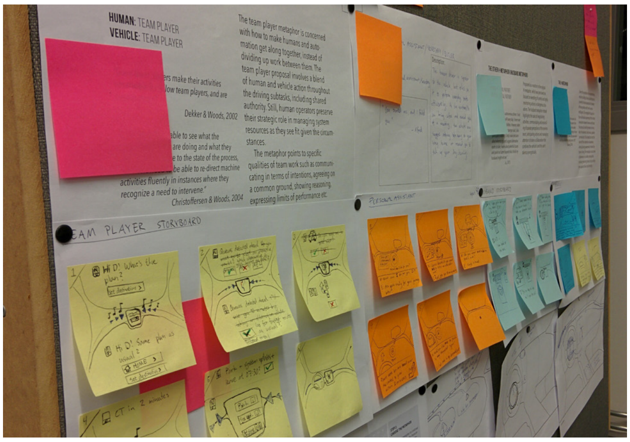

Figure 4.7: The four chosen metaphors illustrated in a scenario using storyboards.

Embodiment
After a metaphor had been chosen, the next step was creating an appropriate embodiment representing it. To do so, a workshop was conducted where inspiration was taken from concepts for embodiment within the automotive industry, as well as from fiction. The participants of this workshop were four students including the authors. The first part of the workshop consisted of a brainpool that aimed to provide ideas for the question "how can an intelligent system be embodied?" With the results of the brainpool at hand, a brainwriting 6-3-5 session aimed to answer the question "how can it be embodied in a driver environment?" This generated a large number of ideas and quick sketches and served as inspiration for the final selection and definition of embodiment.

Interface
In order to create an interface using the chosen interaction metaphor and embodiment, three scenarios were created to include several combinations of vehicle-external and cabin states, as well as different levels of experience of users and different tasks. This was done by using the AVID Model to ensure that Vision AVID would exemplify how the model can be used in the development of vehicle-internal interfaces. With the scenarios as a means of providing the context for specific interactions, the interface was created by rapid sketching on templates representing the driver environment of a vehicle cabin. Ideas were evaluated by creating and altering quick and dirty mock-ups and using guerrilla testing on three Industrial Design Engineering students at Chalmers. By defining and visualising the interactions in all events for each scenario, a description of the concept as a whole could be created.

4.6.3 Heuristic Evaluation
In order to evaluate the AVID Model and Vision AVID, they were evaluated heuristically by the authors against the HMI design guidelines. This was done in order to see if they take into account important HMI design considerations.

5

USER TEST

This chapter describes the results of the user test. The events selected from the scenario are presented along with the conditions, followed by a presentation of the analysis and results along with the resulting HMI design and project implications.

5.1 Events & Conditions

Two events were selected for the user test:

1. Avoiding collision with a moving obstacle in the form of a pedestrian crossing the road unexpectedly

2. Avoiding collision with a static obstacle in the form of a traffic cone in the way of the vehicle's projected path.

In figure 5.1, the three conditions, represented by prototypes, with three different degrees of anthropomorphism are presented - Baseline, Caricature, and Human. These correspond to the three different degrees of anthropomorphism according to the proposed classification (see section 2.6.4), respectively. The conditions all consist of two parts: one part visually displaying the surrounding environment and the vehicle's intentions (equal between concepts), and one part conveying information with three different degrees of anthropomorphism. Both parts, including all conditions, are described below.

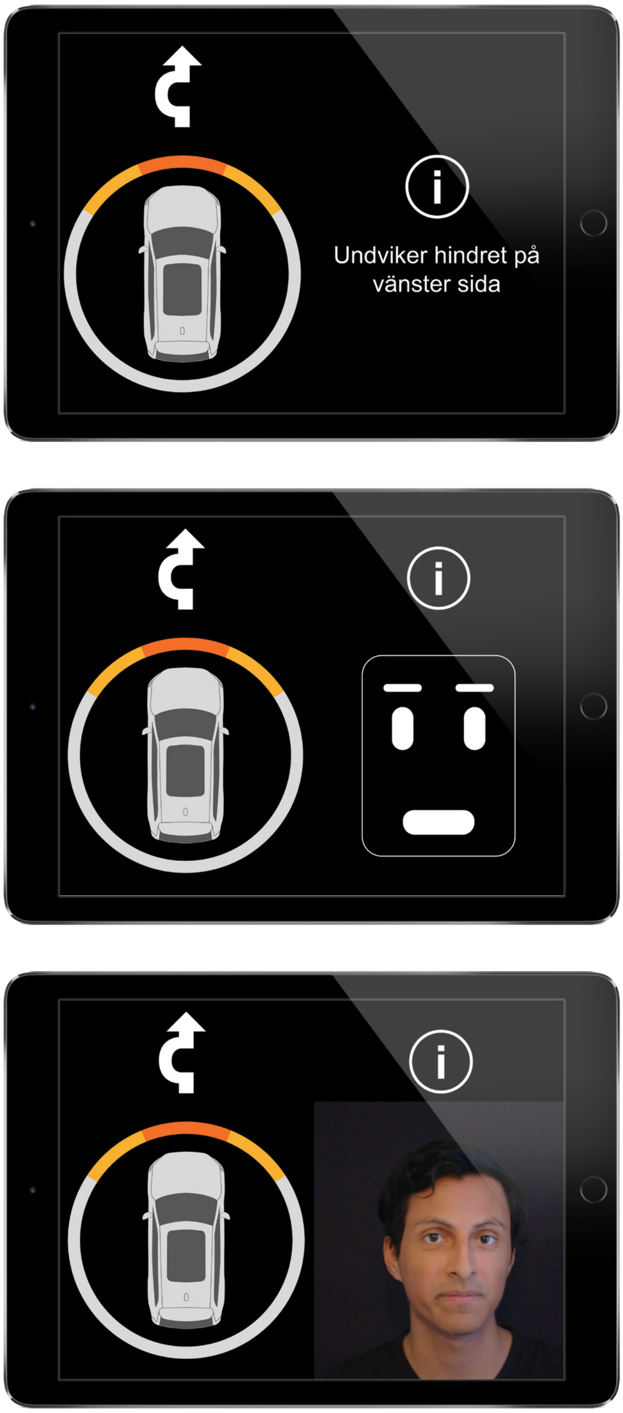

Figure 5.1: The three conditions used in the user test. The Ring Concept is shown to the left and the conditions are shown to the right.

5.1.1 Ring Concept

The Ring Concept (Ekman and Johansson, 2015) is a representation of the vehicle that indicates surrounding objects' relative distances and direction to the vehicle. When an object is in the vehicle's vicinity, parts of the grey ring change colour to yellow or red depending on the vehicle's distance to the object. In addition to this, the area on top of the Ring Concept is dedicated to icons representing the vehicle's intentions, such as turning, avoiding, and stopping. The Ring Concept and the intention icon together form the part of the interface that is used in all conditions to ensure that the driver is sufficiently aware of what the system senses, and helps to minimise the effects of the nuisance factor usability.

5.1.2 Baseline

The Baseline condition aims to represent a non-anthropomorphic agent so that a potential difference in trust between the conditions can be compared to a baseline. It consists of visual displays (alphanumeric and icons), and an auditory display (two-tone earcon). Every time a message is displayed, it is preceded by the earcon.

5.1.3 Caricature

The Caricature condition aims to represent an agent designed with certain anthropomorphic features as well as intentional deviations from the human "prototype". It consists of visual displays (icons), including an animated caricatured representation of a human face named "Kim", and auditory displays (two-tone earcon and speech), including a computer-generated voice. Anthropomorphic embodiment attributes hence include head; eyes; mouth; and humanlike voice, and anthropomorphic cognitive attributes include the agent's identity, i.e. her name and gender. Similar to the Baseline condition, the message provided by the voice of the caricatured face, is preceded by the earcon.

5.1.4 Human

The Human condition aims to represent an agent highly resembling the human "prototype". It consists of visual displays (Icons and video), including a recording of a human named "Isak" speaking, and auditory displays (two-tone earcon and speech), including the human's voice. Anthropomorphic embodiment attributes hence include head; chin; eyes; mouth; and humanlike voice, and anthropomorphic cognitive attributes include the agent's identity, i.e. his name and gender. Similarly to the Baseline condition, the message provided by the voice of the human, is preceded by the earcon.

Common for all conditions is that they make use of both visual and auditory displays. This is because the Human and Caricature conditions both need a visual representation to achieve a higher degree of anthropomorphism. Anthropomorphism is not all about appearance, but is rather a result of a combination of humanlike attributes. A face helps to increase the perception of the virtual agent having an identity. Furthermore, by using both modalities in all conditions, the usability nuisance factor is minimised between the conditions.

5.2 Analysis & Results

The results from the statistical analysis of the quantitative data as well as the key findings from the affinity diagram used to analyse the qualitative data are presented in this section.

5.2.1 Quantitative Analysis

This section begins by presenting the results of the statistical analysis of trust between the concepts, and follows with key findings relating to other quantitative variables.

Trust

The results of the Likert scale composed of five items regarding trust are presented in figure 5.2. On a 7-point Likert scale, the results show that Baseline condition (5.12) scored highest, followed by Human condition (5.06), and Caricature condition (4.66). As can be seen in the figure, the concepts did not differ notably in terms of trust, which also is indicated by the standard deviations of each concept ($\sigma_{Baseline}$ = 1.51, $\sigma_{Caricature}$ = 1.39, σ_{Human} = 1.19).

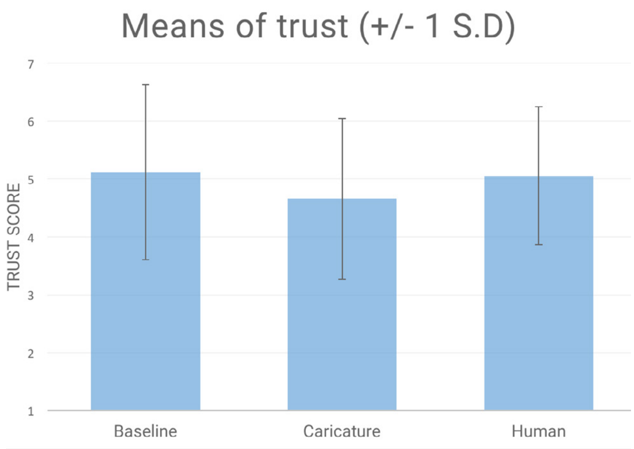

Figure 5.2: Mean scores of the five trust related items from the Test questionnaire. The scores are based on a 7-point Likert-scale the figure displays a comparison between the three conditions Baseline, Caricature, and Human.

Furthermore, the results from the non-parametric Wilcoxon signed-rank tests with an applied continuity correction, which was performed pairwise on all concepts showed that for α = .05, no significant differences between any of the conditions could be found.

In figure 5.3, a comparison between the rankings of liking and trust is displayed. As can be seen in the graphs, there seems to be a strong correlation between the two rankings, implying that a higher liking ranking will generate a higher trust ranking, and vice versa. Furthermore, it can be seen that the Caricature condition was the one that scored the lowest rankings, both in liking and in trust, indicating that it was the least preferred condition by the subjects. This might partly be explained by the fact that the subjects were annoyed by its voice, and partly by the fact that the subjects did not fully understand what value it would add to the user experience.

Other Variables

In figure 5.4, the mean scores of the other variables, apart for trust, that were measured during the test are displayed. Overall, the scores did not differ much between the conditions. The mean scores on the Likert scale for anthropomorphism were: Baseline (B), 0.41; Caricature (C), 0.32; Human (H), 0.73. That Human scored higher than the Caricature condition (0.32) shows that the two conditions successfully represented different degrees of anthropomorphism with the intended relation. Baseline scored higher than the Caricature condition,

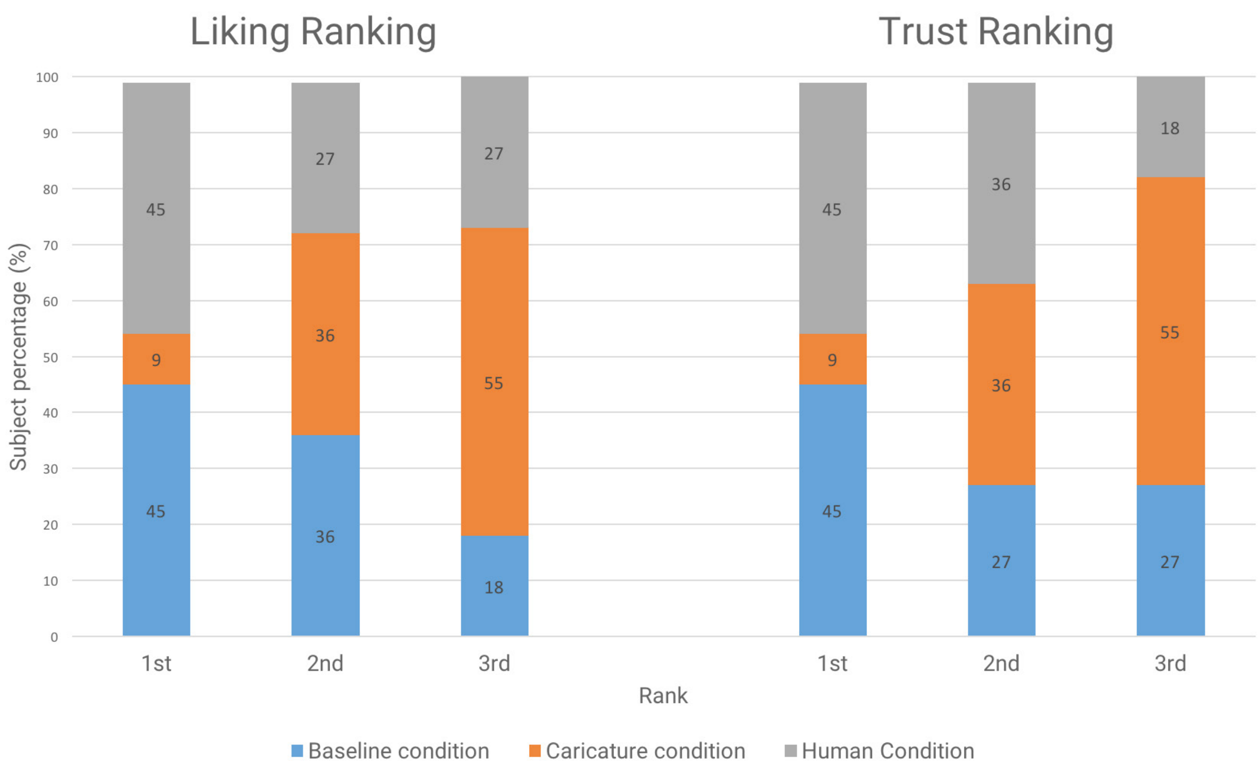

Figure 5.3: Comparison between liking and trust rankings for all three conditions.

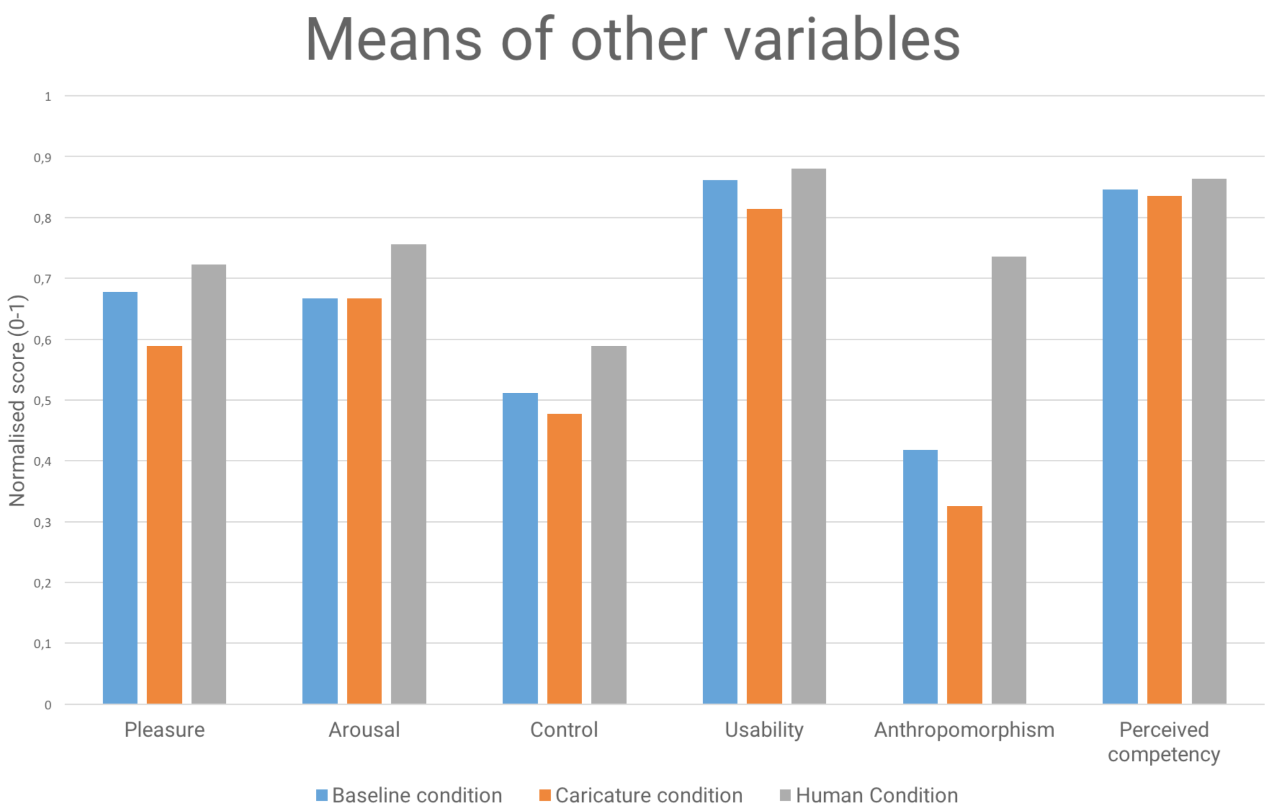

Figure 5.4: Mean scores of the items related to other variables. The scores are based on Likert-scales, but normalised for the sake of comparison. The figure displays a comparison between the scores for the three conditions Baseline, Caricature, and Human.

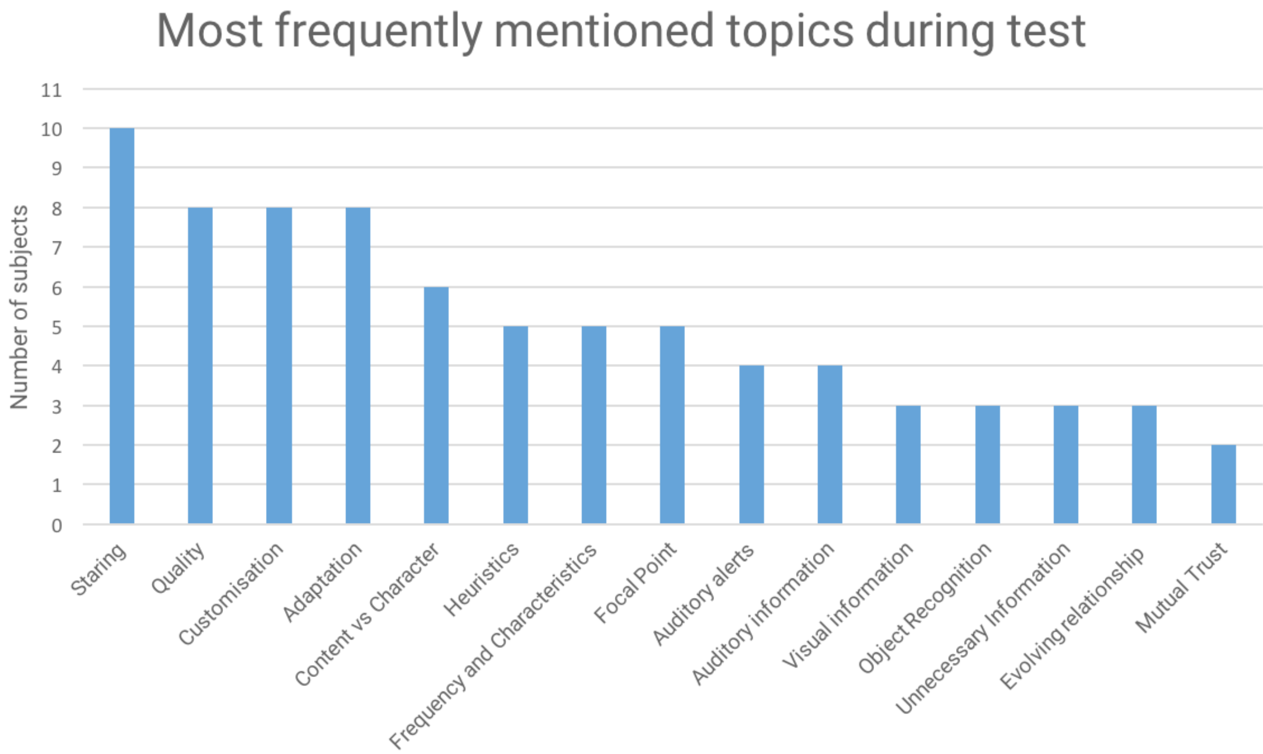

Figure 5.5: The graph displays the topics most frequently mentioned by the subjects during the test.

but this result is not interesting considering the fact that Baseline contained no anthropomorphic features. Interview data suggested that since Caricature did have anthropomorphic attributes that were far from the human "prototype", the subjects reacted accordingly when responding to the Likert items.

All three conditions scored high on usability: B, 0.86; C, 0.81; H, 0.88, and interview data further confirms that the subjects had no problems understanding either of the conditions. Perceived competency was very similar between the conditions: B, 0.84; C, 0.83; H, 0.86. Interview data suggests that the Likert scale for perceived competency was answered in relation to the vehicle, which stayed the same throughout the test, rather than the interface. Regarding SAM, Caricature scored slightly lower on "pleasure" than the other two conditions: B, 0.67; C, 0.58; H, 0.72. This corresponds to the subjects' ranking of the conditions for liking, where only nine percent (one of eleven subjects) ranked Caricature as their favourite. This compared to the other two condition, who scored equally on both trust and liking (B, 45 percent and H, 45 percent).

5.2.2 Qualitative Analysis

The interview data for all eleven subjects was used in the affinity diagram, and the findings are presented below. In figure 5.5, the most frequently mentioned topics are displayed. In table 5.1, the topics are further elaborated.

Table 5.1: Elaborated description of the findings from the qualitative analysis, including each topic's description, analysis and related quotes.

Topic	Description	Analysis	Quote/Example
Trust and Perceived Competency			
Quality	Eight subjects felt that Caricature could be associated with old technology and low quality, resulting in a feeling that the vehicle may also be of lower quality.	Embodiment in the form of visual appearance of an agent and verbal communication affects the perceived competency of the system.	
Mutual trust	Two subjects felt that they may only trust the vehicle appropriately if the vehicle "trusts" that they do not need to be alerted about situations that the vehicle can handle.	The system must allow for creation of a relationship based on "mutual trust" - if the car over- or under-informs the driver, an appropriate level of trust may not grow.	

Topic	Description	Analysis	Quote/Example
Object recognition	Three subjects commented on the fact that the Ring Concept did not present any specificity in object recognition, and that it made them feel unsure about how well the vehicle could distinguish objects in the environment.	The vehicle needs to present a high level of specificity in object recognition to ensure the driver that it is aware of the surrounding environment. The interface content may therefore be more important than the communication style.	"I might want to see more detail regarding what the car sees." (Subject 10)
Usability			
Heuristics	Topics relating to many of Nielsen's usability heuristics were brought up in the interviews, and five subjects specifically discussed topics relating to the importance of visibility of system status, minimalist design, recognition rather than recall, and flexibility and efficiency of use.	The shortcomings of the conditions in relation to usability made it clear that it is important to consider all usability heuristics when designing HMI for HAV.	Subjects stated that they want interface content such as vehicle speed, acceleration, destination, ETA, and surrounding environment.
Frequency and charac-teristics	Five subjects discussed how information was presented to them by the conditions in relation to the vehicle's actions. Many felt that it was unnecessary to receive auditory alerts and information about passing an obstacle and stopping for a pedestrian. However, they did like having access to visual information.	The frequency and character of information prompts are important to consider, as drivers want efficient access to relevant information at all times, but also react negatively to being force fed with information that they do not want.	
Unnecessary information	Three subjects said that the human face, and to some part the simplified version of the Caricature, could be distracting and attract unwanted attention. This was due to the fact that facial expressions provide information in themselves that the subjects subconsciously had to interpret.	The use of a visual embodiment of a highly anthropomorphic agent, e.g. a human face or an advanced animation representing a human leads to unnecessary information being presented to, and having to be interpreted by the driver. This goes against Nielsen's heuristic for aesthetic and minimalist design.	
Modalities			
Auditory alerts	Four subjects commented that the auditory alerts (earcons) could be annoying when they appear frequently and that it is hard to know what they mean	Since earcons do not contain any actual information about their meaning, they require interpretation and should not be used to deliver information but rather to capture attention. It is important to not overuse auditory alerts in order to avoid annoyance.	
Auditory information	Four subjects commented that speech messages were annoying when used frequently, but may be good for keeping the driver's attention for delivering important information.	Speech messages are highly intrusive and forces the user to take in the information presented, which makes it good for low-frequency high-importance messages.	

Topic	Descriptioon	Analysis	Quote/Example
Visual information	Three subjects felt that it was good to have the visual information readily available at all times, but that it is not enough for capturing their attention.	Visual displays are less intrusive than auditory displays and are especially good for communicating continuous information that that the driver can access when wanted.	
Adaptation and customisation			
Customisa-tion	Eight subjects saw both advantages and disadvantages with visual and auditory communication, related to personal preferences.	The vehicle's communication style should be customisable to fit personal preferences.	"I would have wanted to choose if I want text or a human voice, and in that case maybe have a choice between three different voices." (Subject 7)
Adaptation	In relation to the test situation, several subjects discussed how the concepts might work in various environments rather than a controlled one. Eight subjects mentioned that they would like vehicle's communication to adapt to the cabin state and external state.	The vehicle's communication should be able to adapt to both the cabin state and the external state.	"What I like here is that the information is available, but it is not forced upon me. If I consider the car to be in control, I do not need it to constantly tell me what it is doing." (Subject 1)
Evolving relationship	Three subjects mentioned that they may want more information presented to them during the initial use, but that they would want the car to adapt to their decreased need for information with time.	The content and characteristics of the interface may have to change over time as it adapts to the driver's experience and personal preferences, to allow for expert use of the car.	
Embodiment			
Focal point	Five subjects felt that having a visual representation of an agent drew their attention to this agent, and that the speech messages delivered by the agent helped them focus on the message.	A highly anthropomorphic agent represented visually and auditorily creates an intense focal point and may thus be effective both in capturing the driver's attention and delivering information.	
Staring	Ten subjects found that the embodied agents, especially the Human condition, created a feeling of being stared at. This was deemed unpleasant by the subjects.	During driving, using a highly anthropomorphic visual representation of an agent may be unwanted, since it may create a notion of being stared at and draw unwanted attention.	
Content vs character	Six subjects commented that their assessment of trust in the vehicle mostly depended on the vehicle itself and the content delivered through the interface rather than the characteristics of it.	The vehicle may not need to be embodied as an agent in order for trust to grow, as trust formation may instead depend mostly on the underlying functions and the content of the interface.	

5.3 HMI Design Implications

The quantitative analysis provided no indication for anthropomorphism affecting trust. Hence, no further conclusions can be drawn from the statistical analysis, apart from that no particular choice of anthropomorphism degree in an HMI can be decided based on the quantitative results. Instead the following HMI concept development is primarily based on the conclusions from the qualitative analysis. The qualitative analysis provides insights useful to the HMI concept, and is used to complement the theoretical guidelines to form a set of HMI design guidelines (see chapter 6). Below is a summary of the key implications from the qualitative analysis, synthesised both from the affinity diagram as well as from test observations.

Trust and Perceived Competency

- No significant correlation between level of trust and degree of anthropomorphism could be found. However, it was found that anthropomorphism, as part of the interface characteristics, indirectly through perceived and perceived usefulness affects user acceptance. Hence, the interface characteristics need to be adapted to the need for driver intervention and to all AD mode events. This is imperative to create an efficient vehicle-driver interaction.

- Mutual trust and respect between the driver and the vehicle is important for trust to grow. The interface characteristics and content must hence be designed to avoid any unnecessary information or unwanted distractions by considering the state of the cabin.

Usability

- The interface needs to communicate consistently as an entity, and leverage the benefits of using a focal point for communicating information and directing attention.

- The interface should provide the driver with enough information regarding system status, intentions and processes to satisfy the need for sufficient driver SA.

Modalities

- The interface characteristics should be built around the need for driver intervention and leverage the benefits of each modality when possible.

- Information regarding the system processes, for instance the actions of the vehicle, should be shown by using multimodal displays to avoid overloading the driver's attentional resources.

Adaptation and Customisation

- To incorporate differences in drivers' personal preferences and to allow for expert use, the interface needs to allow customisation of its characteristics, for instance its use of modalities.

- The interface characteristics should be adaptable to cabin states as well as external states.

Embodiment

- Anthropomorphism should, as an HMI design tool, be utilised cautiously. Visual embodiment attributes necessary for higher degrees of anthropomorphism, such as head, chin, eyes, mouth, may lead to mental overload if used in situations characterised by need for high driver SA.

- The embodiment attributes humanlike voice, in combination with the cognitive attribute identity may be a suitable way to use anthropomorphism. It relies less on the visual modality, and is perceived as competent as it leverages the human tendency to interact socially with technology. Also, it enables the driver to connect emotionally to the vehicle, as the agent is assigned with a personality.

5.4 Project Implications

To conclude, the user test had a major impact on the direction of the project (see figure 5.6), since no significance between degree of anthropomorphism and level of trust could be found. Therefore, it was decided that the following HMI concept development would be focused on how user acceptance can be increased by an improved perceived usefulness and perceived ease of use.

It was also concluded that anthropomorphism mainly is a design tool which can be used to improve the perceived usefulness and perceived ease of use and hence it was used as such in the following HMI concept development.

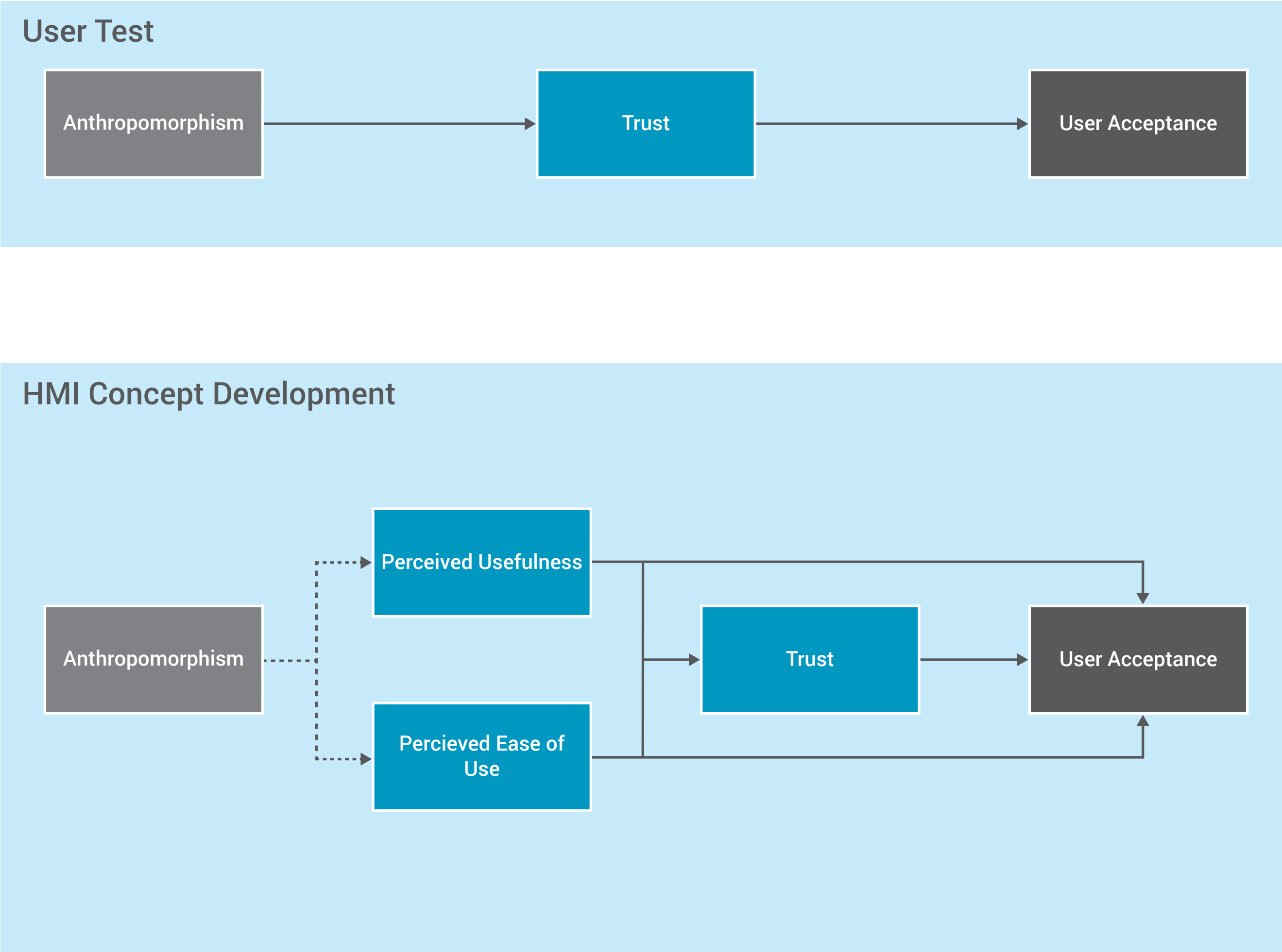

Figure 5.6: Graphical representation of the new project direction, focusing on perceived usefulness and perceived ease of use as variables affecting user acceptance, instead of trust. Anthropomorphism is viewed as a HMI design tool, facilitating the improvement of perceived usefulness and perceived ease of use.

6

HMI DESIGN GUIDELINES

This chapter presents the main synthesis of theory and user test, visualised in the form of a table of HMI design guidelines. The guidelines are organised in eight categories, and their relative importance is visualised in a Kano model. The guidelines form the basis for the HMI concept development.

6.1 Kano Model

In total, 32 guidelines were identified and organised into eight categories, namely: (1) General Design Strategies; (2) Usability; (3) Content; Transparency and Feedback; (4) Communicating System Capabilities and Responsibilities; (5) Modalities; (6) Adaptation and Customisation; (7) Embodiment and; (8) Training.

6.2 Guidelines

In table 6.1, the key findings from the theory and the user test are presented. These guidelines are not to be used as requirements, but rather as a framework for the development of HMI concepts for HAV. An elaborate description of each guideline category is presented below.

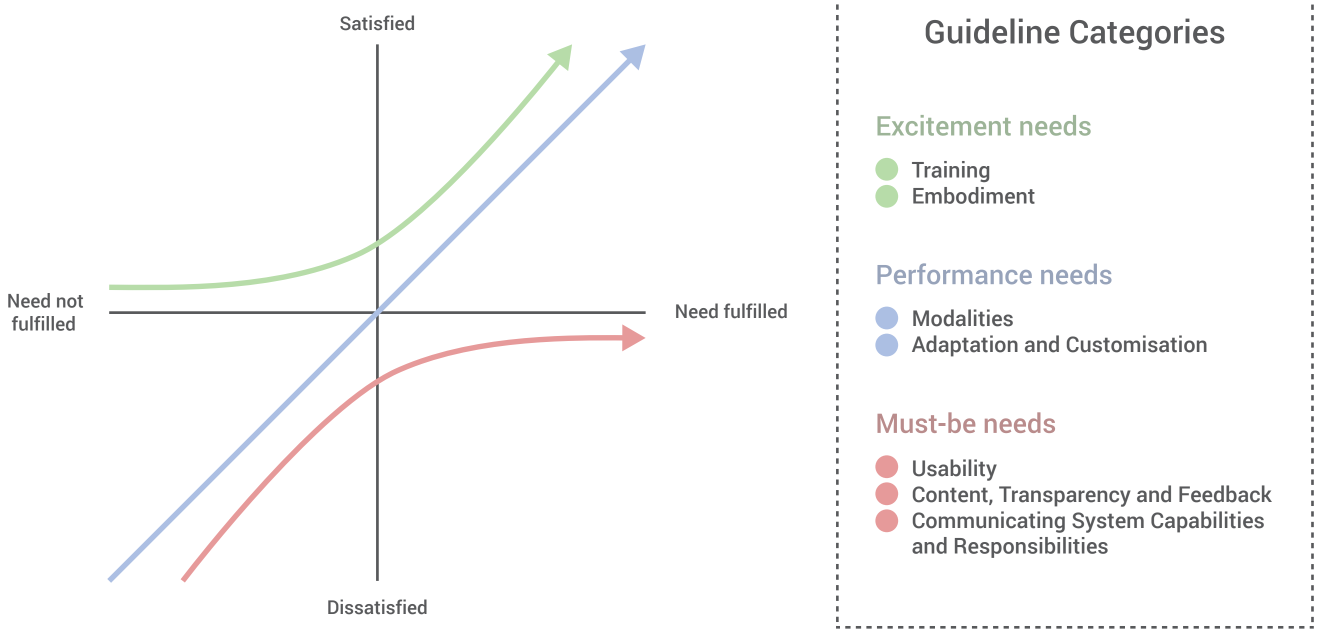

Figure 6.1: The diagram shows the HMI Design Guideline categories mapped onto a Kano Model, which represents "Excitement needs" (Green), "Performance needs" (Blue), and "Must-be needs" (Red).

In figure 6.1, the eight categories are visualised in a Kano model, sorting the categories into either "Must-be needs", "Performance needs", or "Excitement needs". The model describes the relative importance of each category. It shows that the interface must achieve a minimum, or "Must-be", level of usability, a sufficient level of transparency and communicate system capabilities and responsibilities in order for the driver to fully understand the system. For instance, a driver may expect a vehicle HMI to be reasonably intuitive to interact with. The model further shows that "Performance needs" related to modalities, adaptation and customisation should be considered when designing the interface to increase the performance of the DVS. For instance, a driver who uses a vehicle may expect that some elements of a vehicle HMI may be customisable, but not all. Lastly, the "Excitement needs", including the training and embodiment categories, shows that the overall user experience of the interface can be improved by adding elements that not necessarily are expected by a driver. For instance, drivers may not expect that the vehicle interface will help improve their driving skills or that it will interact socially with them.

6.2.1 General Design Strategies

The general design strategies aim to describe the overall strategies that should be applied to design for a trustable HMI in HAV and originates in the work of Lee and See (2004). These guidelines aim to permeate the entire HMI concept development in order to ensure that the main goal of designing a communication structure for a DVS is achieved in the final concept.

6.2.2 Usability

Guidelines included in the usability category stem both from the theory and the user test, and aim to ensure that the HMI concept fulfils the fundamental requirements for usable interface design. These include Nielsen's ten usability heuristics, as well as sufficient driver SA by communicating through the proper modalities.

6.2.3 Content, Transparency, and Feedback

In this category, further guidelines regarding the usability of the system are specified. This category focuses on autonomous vehicle functions and is unlike the usability category more specific for HMI design in HAV. The guidelines are mainly based on the theory of Hoff and Bashir (2015) and Lee and See (2004), but were also supported by findings from the user test.

6.2.4 Communicating System Capabilities and Responsibilities

This category summarises the findings regarding the importance of effectively conveying the HAV capabilities and the distribution of responsibility between the driver and the vehicle. The guidelines, which are based on those from Lee and See (2004) and partially supported by the findings from the user test, highlight the importance of supporting the driver's mental model of the system to increase safety.

6.2.5 Modalities

All guidelines regarding the use of modalities are gathered in this category, summarising the guidelines presented by Campbell et al. (2007), which all are supported by the user test. When designing communication in a DVS, modalities are an important aspect to consider since they determine how information is provided to drivers and how their attention is captured. In this sense, the modalities form the communication channels between the vehicle and the driver.

6.2.6 Adaptation and Customisation

In this category, guidelines related to personalisation of the interface and adaptation to cabin state and external state are summarised. From the analysis of the user test, it was found that the ability to customise interface characteristics, e.g. modalities, is of high importance to incorporate the needs of different user groups. This finding aligns with Nielsen's heuristic "Flexibility and efficiency of use" stating that the system should allow the user to customise the actions to promote expert usage.

6.2.7 Embodiment

Both the theory and user test found embodiment to be a salient factor affecting the success of interface designs. Although there are few specifications defining how an interface should be embodied to facilitate the formation of an appropriate level of trust, the guidelines in this category act as a summary of findings from Duffy (2003) regarding the use of anthropomorphism, as well as the analysis from the user test.

6.2.8 Training

The training category encompasses guidelines that have to do with the driver's understanding of the system and his or her mental model of it. These guidelines are primarily based on the theory regarding trustable automation presented by Lee and See (2004) and highlights the importance training has on the formation of trust.

Table 6.1: The table "HMI Design Guidelines" summarises the main findings from the theory chapter as well as from the user test. Each guideline is labelled based on its origin, and references are found at the bottom of the table.

#	Guideline	Theory	User Test
1	**General Design Strategies** The designer should...		
1.1	...first and foremost design a structure for communication and collaboration in a driver-vehicle system	6	
1.2	...design for appropriate trust rather than greater trust.	2	
1.3	...consider how the context affects the relevance of trust.	2	
1.4	...consider compatibility between task, technology, and driver.	7	
1.5	...evaluate the appropriateness of trust after having designed an HMI.	2, 3	
2	**Usability** The interface should...		
2.1	...be designed with Nielsen's ten usability heuristics for user interface design in consideration.	1	2:3, 5:2
2.2	...help the driver to maintain an appropriate level of SA.	8, 10	
2.3	...communicate through modalities in which attentional resources are available.	4, 5, 9	
3	**Content, Transparency, and Feedback** The interface should...		
3.1	...communicate its intentions, processes, and actions to keep the driver in-the-loop.	10	2:3
3.2	...continuously present results of performed actions.	2, 3	
3.3	...display past and present automation performance as well as present status.	2, 3	
3.4	...display how it has previously performed and is expected to perform depending on context.	2	
3.5	...present accurate information in a timely manner.	1, 2	
3.6	...communicate specificity in object recognition.		1:1
4	**Communicating System Capabilities and Responsibilities** The interface should...		
4.1	...clearly communicate the division of responsibilities between driver and vehicle.	2	5:1
4.2	...clearly communicate the capabilities and limitations of the automated functions.	2, 3	
4.3	...provide the driver with information on contexts that may affect the capability of the automation.	2	

#	Guideline	Theory	User Test
5	**Modalities** The interface should...		
5.1	...strive to not overload the attentional resources associated with an already loaded modality.	4, 5	2:12
5.2	...make use of visual information in situations where less intrusive information is desired.	4, 5	2:6, 4:5
5.3	...avoid the use of visual information in situations characterised by high mental workload.	4, 5	4:4
5.4	...make use of auditory information in situations where the driver needs to be alerted.	4, 5	4:1, 4:2, 4:8
5.5	...avoid the use of auditory information in situations where less intrusive information is desired.	4, 5	4:6, 4:7
5.6	...make use of haptics in situations where the driver needs to be alerted.	4, 5	
5.7	...make use of the benefits of multimodal interaction.	4, 5	2:1, 2:2, 2:8, 2:12
6	**Adaptation and Customisation** The interface should...		
6.1	...adapt the frequency, intensity, and modalities of communication based on the state of the vehicle's internal (the cabin) and external environment (e.g. the road).		1:5, 2:10
6.2	...allow for customisation of communication style and be able to select different combinations of information transmitting modalities and frequency of prompts.	1	1:3, 3:1-3:6
6.3	...enable customisations for expert usage and adapt its communication based on information about the driver.	1	2.4, 3:9
7	**Embodiment** The interface should...		
7.1	...leverage the human tendency to interact socially with technology.	11, 12	1:6, 1:16, 6:6
7.2	...only make use of those human characteristics that can facilitate the interaction with the user.	11, 12	1:4, 1:11, 1:17, 2:7, 2:9, 5:3, 5:4, 6:4
7.3	...use anthropomorphism in a way that facilitates the formation of an appropriate level of trust.	2, 11, 12	1:5, 1:7
8	**Training** The driver should be...		
8.1	...provided with training on how to use and interact with the system.	2	1:5, 2:5
8.2	...given information about expected automation reliability, and how it depends on context.	2	1:14

References from Theory

1. Nielsen (1995); 2. Lee and See (2004); 3. Hoff and Bashir (2015); 4. Campbell et al. (2007); 5. Haas and van Erp (2014); 6. Woods (1996); 7. Ghazizadeh, Lee and Boyle (2011); 8. Parasuraman, Sheridan and Wickens (2008); 9. Bazilinskyy and de Winter (2015); 10. Cunningham and Regan (2015); 11. Duffy (2003); 12. Foner (1993)

References from User Test

See appendix X - Affinity Diagram

7

HMI CONCEPT

This chapter presents the results of the HMI concept development, which focused on how user acceptance can be increased by an improved perceived usefulness and perceived ease of use. It further presents how anthropomorphism can be used as an HMI design tool to improve the perceived usefulness and perceived ease of use.

The chapter consists of four parts: First, the AVID Model is described. It is a model describing how vehicle-driver communication in AD mode should vary depending on vehicle-external and cabin states. The classifications of these states are described along with examples, and how they affect the communication in terms of different modalities and their characteristics. Second, Vision AVID is described. It is a holistic vision for the interaction between drivers and level 4 autonomous vehicles, aimed at illustrating the potential of the AVID Model as a framework to develop HMI for HAV. Third, the concept is heuristically evaluated against the previously presented HMI design guidelines. Lastly, a summary of the chapter is presented, highlighting its most important parts.

7.1 AVID Model

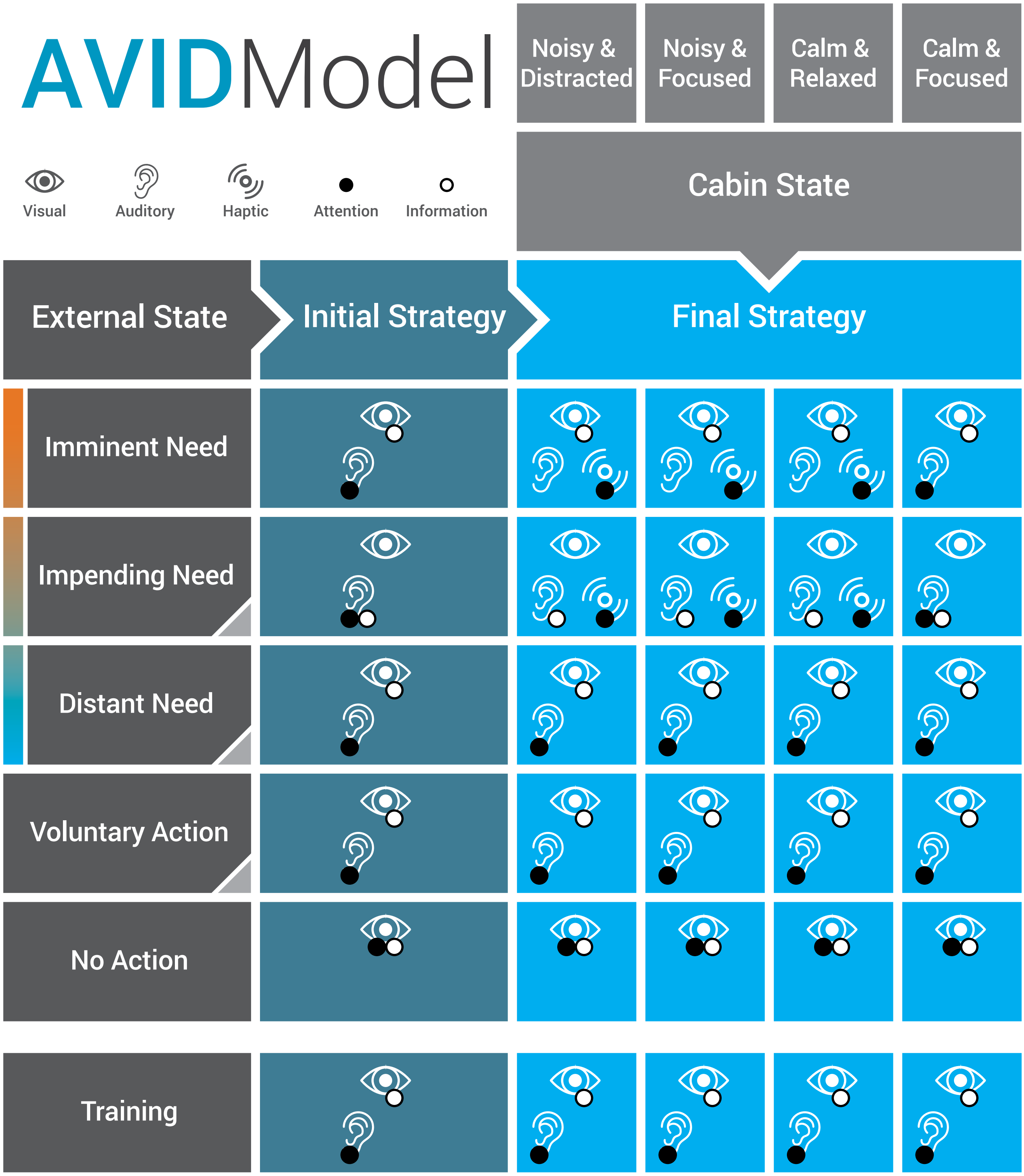

Figure 7.1: The AVID Model describes how external and cabin states affect the vehicle's communication strategy, when the vehicle is in control of the driving situation in AD mode.

7.1.1 Overview

Figure 7.2: The main components of the AVID Model.

Description

The AVID Model is a result of the HMI design guideline 1.1: "The designer should first and foremost design a structure for communication and collaboration in a driver-vehicle system", and describes the formation of a V2D communication strategy in a level 4 autonomous vehicle. The full model can be seen in figure 7.1 and its main components are illustrated in figure 7.2. The model only describes situations that occur during autonomous driving, where the vehicle has full responsibility for the driving performance.

The vehicle collects different types of sensory data, e.g. GPS, radar, LIDAR, cameras, from the external driving environment as well as its driving related systems. This data is processed and interpreted as an external state, which is classified according to its characteristics. The classification of the external state forms an initial V2D communication strategy. This strategy consists of the use of different modalities for capturing the driver's attention and delivering information, which is based on Campbell et al. (2007) research regarding collision warning systems as well as findings from the user test.

The vehicle also collects sensory data from the cabin, e.g. cameras used for eye tracking, face detection and head position, as well as noise level measurement. This data is processed and interpreted as an internal state, which is classified according to its characteristics. The classified cabin state may then affect the initial strategy by adding a modality for capturing the driver's attention when needed.

Delimitations

The model only applies to level 4 autonomous vehicles driving in AD mode. Furthermore, it only considers diagnosable situations where the vehicle is fully operational and can communicate its status to the driver. Hence, non-diagnosable situations, such as unknown system failures, are not considered in the model.

The extended version of AVID Model, which includes descriptions of the strategies inside the model, can be found in appendix XII.

7.1.2 External States

The external states (see figure 7.3) are based on the scenario events created for the user test and classified according to whether or not the driver needs to take action, may want to take action, or will not want to take any action based on the information delivered by the interface. A special case is training, which may take place during autonomous driving, but also when the vehicle is standing still. For the states where the driver needs to take action at some point, three classifications of urgency have been defined on a continuous time scale represented by the gradient. All states that fall into these categories will move upward and eventually become imminent needs if the driver does not take action. Although the time scale is continuous, discrete time intervals are defined to give the reader a better understanding of the relationships between the categories.

Figure 7.3: External states.

Imminent Need
Here, driver action is required within one minute of the interface communication. Examples of this include that the driver needs to resume manual control because the autonomous stretch of road is ending, or that the driver needs to turn off at the next exit to charge the car in order to avoid running out of power.

Impending Need
Here, driver action is required within one to ten minutes of the interface communication. Examples include that the driver needs to wake up and regain SA before the autonomous stretch of road ends, or that the driver needs to reroute to a petrol station in order to fill up on antifreeze within 10 minutes.

Distant Need
Here, the driver has at least ten minutes until any action is required in order for the vehicle to function. Examples include needing to perform a scheduled service within 500 km or running low on petrol and needing to refuel within 100 km.

Voluntary Action
Here, driver action is not required for the vehicle to function. However, the driver may want to take action in relation to the information presented by the interface. Examples include a suggested change in route to save time because of building queues or a suggestion for visiting a world heritage site just off the scheduled route on a leisure trip.

No Action
Here, the driver does not need nor want to take action in relation to the information presented by the interface. Examples include stopping at the side of the road to let an emergency vehicle pass or that the vehicle is accelerating because it has just passed a sign raising the speed limit with 20 km/h.

Training
Here, training is required or wanted in order for the driver to be able to utilise the vehicle to its full potential. Examples include a tutorial on how to perform a control transition before the driver is authorised to use AD mode or an informational video on how to customise personal preferences.

7.1.3 Initial Strategies
The modalities (visual, auditory, and haptic) are represented by icons placed inside the coloured rectangles. In each rectangle, the white dot represents the primary information delivering modality, and the black dot represents the primary captor of attention (see figure 7.4). Below is a description of the initial strategies based on the external states.

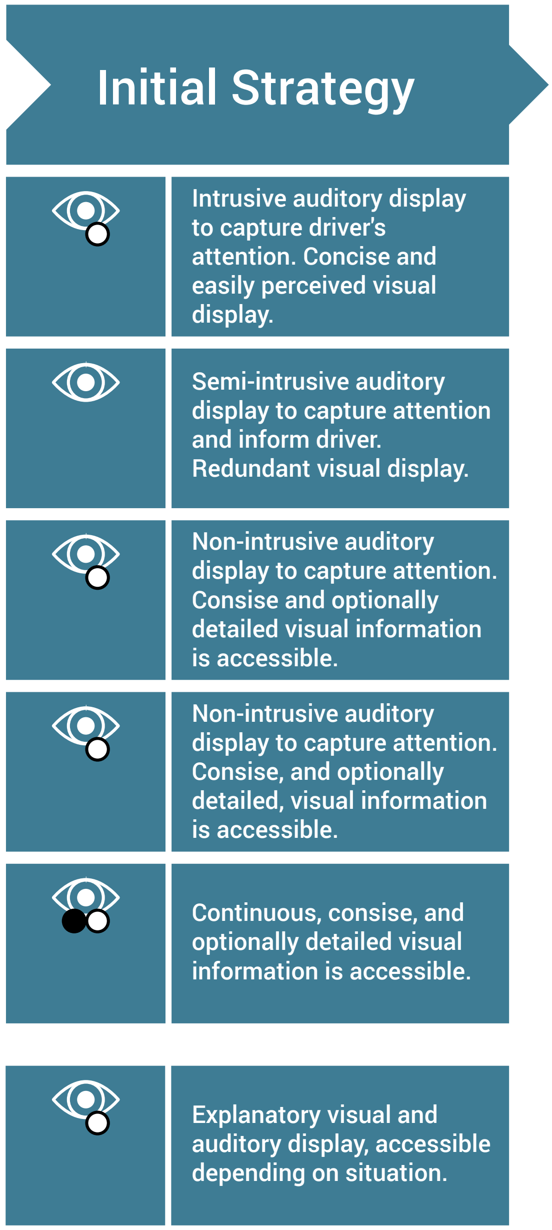

Figure 7.4: Initial strategies depend on external states.

Imminent Need
Make use of a concise and intrusive auditory display to capture the driver's attention as well as a concise and easily perceived visual display to deliver information.

Impending Need
Make use of a semi-intrusive auditory display to capture the driver's attention and deliver the information. A visual display conveying the same information is used for redundancy.

Distant Need
Make use of a non-intrusive auditory display to capture the driver's attention. Concise visual information should be accessible with the option of receiving detailed information.

Voluntary Action

Make use of a non-intrusive auditory display to capture the driver's attention. Concise visual information should be accessible with the option of receiving detailed information.

No Action

Continuous and concise visual information should be accessible with the option of receiving detailed information.

Training

Make use of an explanatory visual and auditory display, which should be accessible depending on situation.

7.1.4 Cabin States

The cabin state depends on two variables: the cabin noise level, including auditory, visual, and haptic noise, and the driver's attention level in relation to the external driving environment (see figure 7.5). Both variables can assume either of the values: low, medium, or high. In this way, driver and passenger activities can be divided into four quadrants, each describing a certain type of cabin state.

The four quadrants representing different types of cabin states are labelled: noisy & distracted, noisy & focused, calm & relaxed, and calm & focused (see figure 7.6).

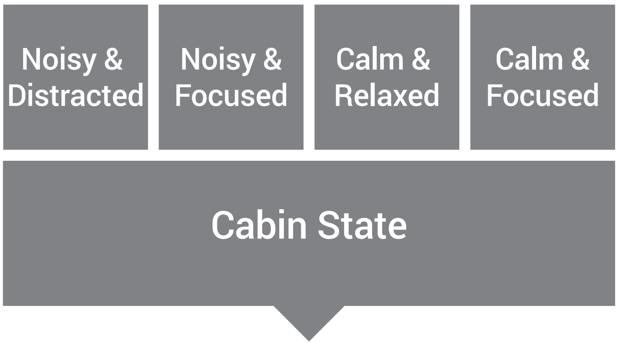

Figure 7.6: The four cabin states.

Noisy & Distracted

In this state, there are high levels of auditory, visual, and/or haptic noise in the cabin, and the driver is inattentive to the external driving environment. Examples include the driver being engaged in conversation with passengers or on the phone, trying to intervene when their children are fighting in the backseat, and working on a nomadic device.

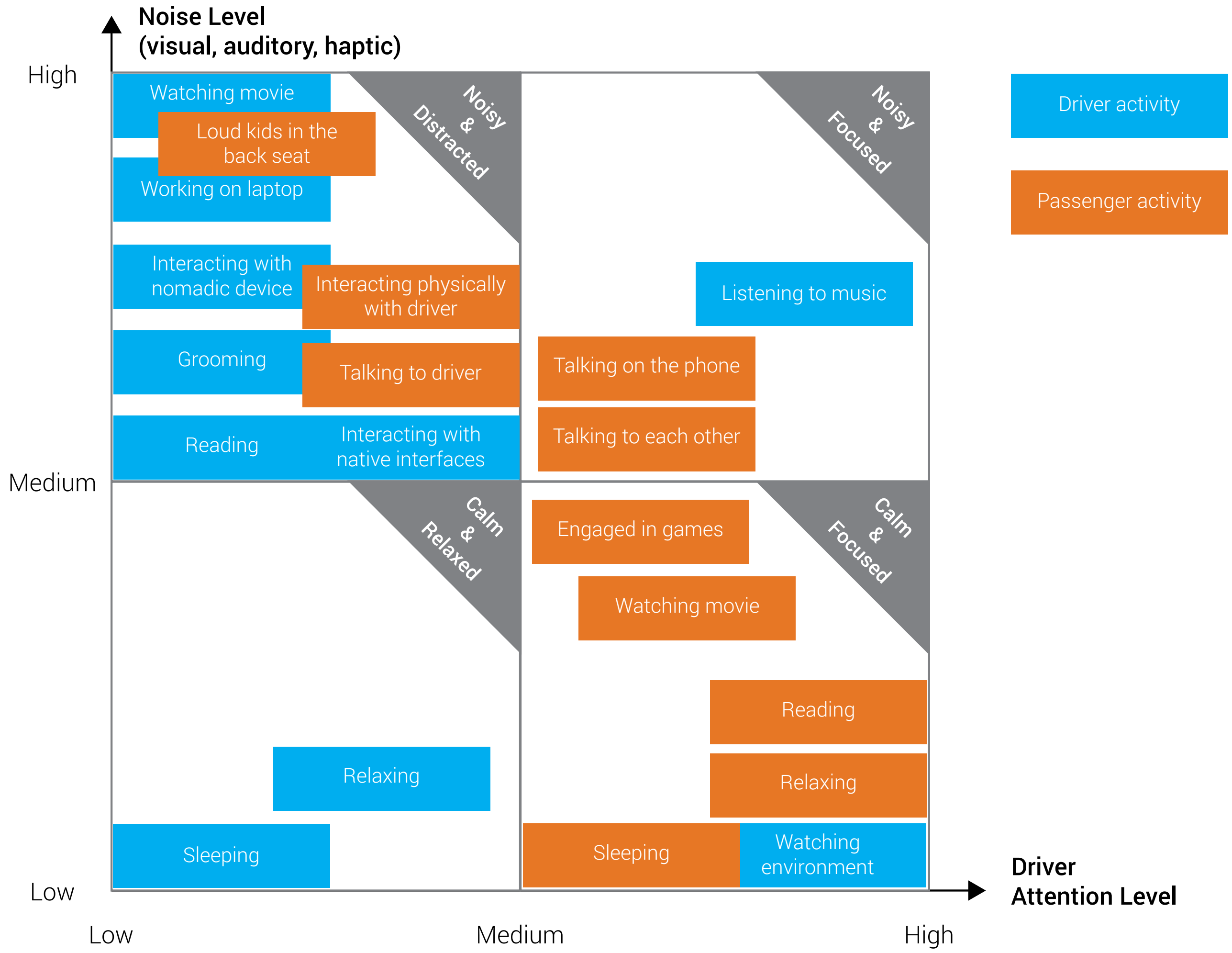

Figure 7.5: Figure showing the four quadrants, each describing a certain type of cabin state. In each quadrant, examples of driver and passenger activities relating to each cabin state are displayed.

Noisy & Focused
In this state, there are high levels of auditory, visual, and/or haptic noise in the cabin, but the driver is attentive to the external driving environment. Examples include listening to loud music while staying alert to the external environment or having passengers that are engaged in a loud conversation with each other.

Calm & Relaxed
In this state, there are no higher levels of auditory, visual, or haptic noise in the cabin, but the driver is inattentive to the driving situation. Examples include the driver relaxing or sleeping.

Calm & Focused
In this state, there are no higher levels of auditory, visual, or haptic noise in the cabin, and the driver is attentive to the driving situation. Examples include passengers being engaged in activities that do not directly affect the driver, such as watching a film or playing video games in the backseat with the volume turned down.

7.1.5 Final Strategies

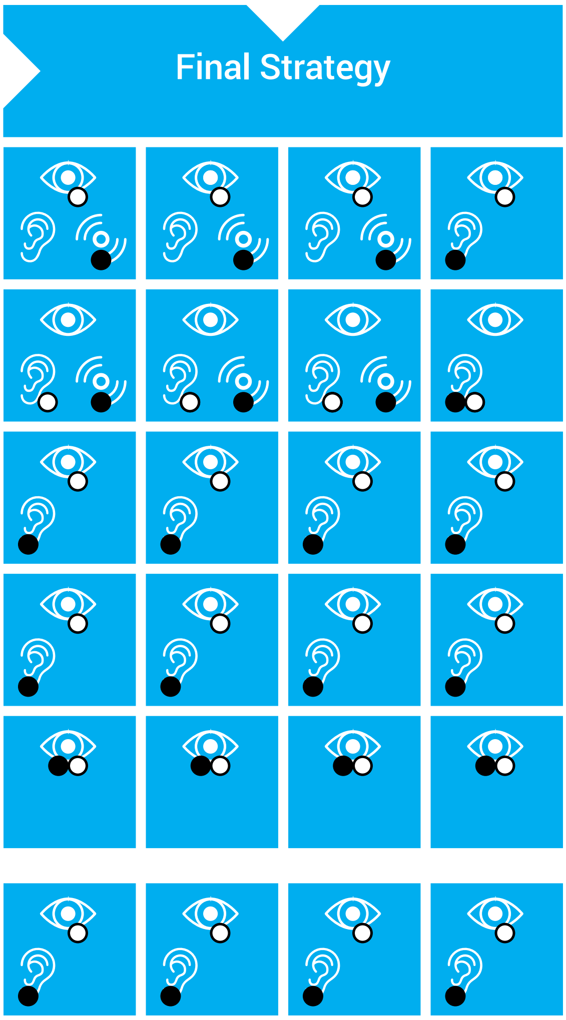

Figure 7.7: Final strategies.

The initial strategy for communication may be altered depending on cabin states before becoming the final communication strategy (see figure 7.7). For instance, the haptic modality replaces the auditory modality as the primary captor of attention during the cabin states “noisy & distracted” and “noisy & focused” combined with the external states “imminent need” and “impending need”. This is since the auditory modality interferes with auditory cabin noise and will be unlikely to capture the driver’s attention in these types of cabin states and since the communication through the haptic modality will enable cross-modal time-sharing (Wickens, 2002).

The model displays the strategies as they exist in the standard design, but it allows for user customisation which affects these strategies, such as a “silent mode” or a “do not disturb mode” (see figure 7.8). These customisations may for instance affect the strategies associated with impending need, distant need, and voluntary action (see the grey triangles in AVID Model), so that an auditory display is exchanged for a haptic display in order to capture the driver’s attention. However, in the case of imminent needs, such customisations would not override the standard communication strategy.

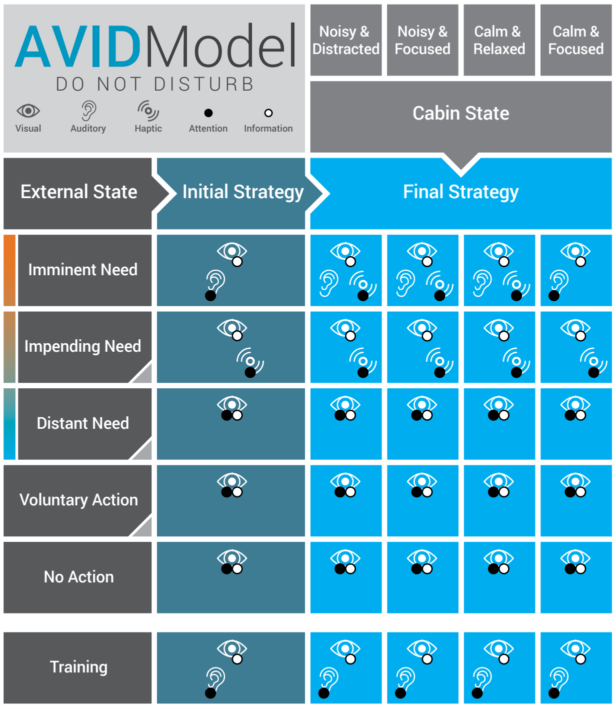

Figure 7.8: AVID Model in “do not disturb” mode. The model changes slightly to rely less on auditory displays and instead relies more on visual and haptic displays.

7.1.6 Interface Design Parameters
With the final V2D communication strategy as a starting point, the detailed HMI concept design can be decided. As a starting point for deciding this detailed

design, table 2.1 in section 2.3.4 can be consulted. The parameters presented there are based on examples from Campbell et al. (2007), and with the help of the table, the design space can be defined and categorised according to modality. The table presented is not exhaustive in its listing of variables, but it provides designers with the possibility to create numerous concepts based on the AVID Model. In this thesis, only one of all possible concepts is visualised and presented. By using the AVID Model and the modality design parameters, designers may achieve a variety of HMI solutions that can be tested and evaluated.

7.2 Vision AVID

Vision AVID is an example concept, illustrating how AVID Model may be used as a framework to create a holistic HMI concept. As of this, the concept should be seen as an aid to communicate the full potential of using the AVID Model in the HMI development process, rather than as a fully implementable HMI concept. Further testing of the concept is needed in order to validate its design.

In the following sections, Vision AVID and its parts are described in an overview, followed by a description of how the concept proposes solutions to each of the HMI design guidelines categories. Since the usability category refers to multiple parts of the concept, it is presented after the other categories. Lastly, the use of the concept is exemplified in three different scenarios, reconnecting it to the AVID Model.

7.2.1 Concept Overview

In figure 7.9, an overview of Vision AVID is presented along with markers of all its parts. Full descriptions of the parts are presented in table 7.1. The interfaces were inspired by the common structure of existing HMI designs as well as concepts for future autonomous vehicles, created by HMI developers.

7.2.2 General Design Strategies

As Vision AVID is an example concept of the AVID Model, it is structured around the AVID Model logic and is hence defined by the model's V2D communication strategies. From the user test, it was concluded that driver's trust in the vehicle is highly dependent on the vehicle's ability to communicate effectively, independent of situation. Therefore, the general design strategy of

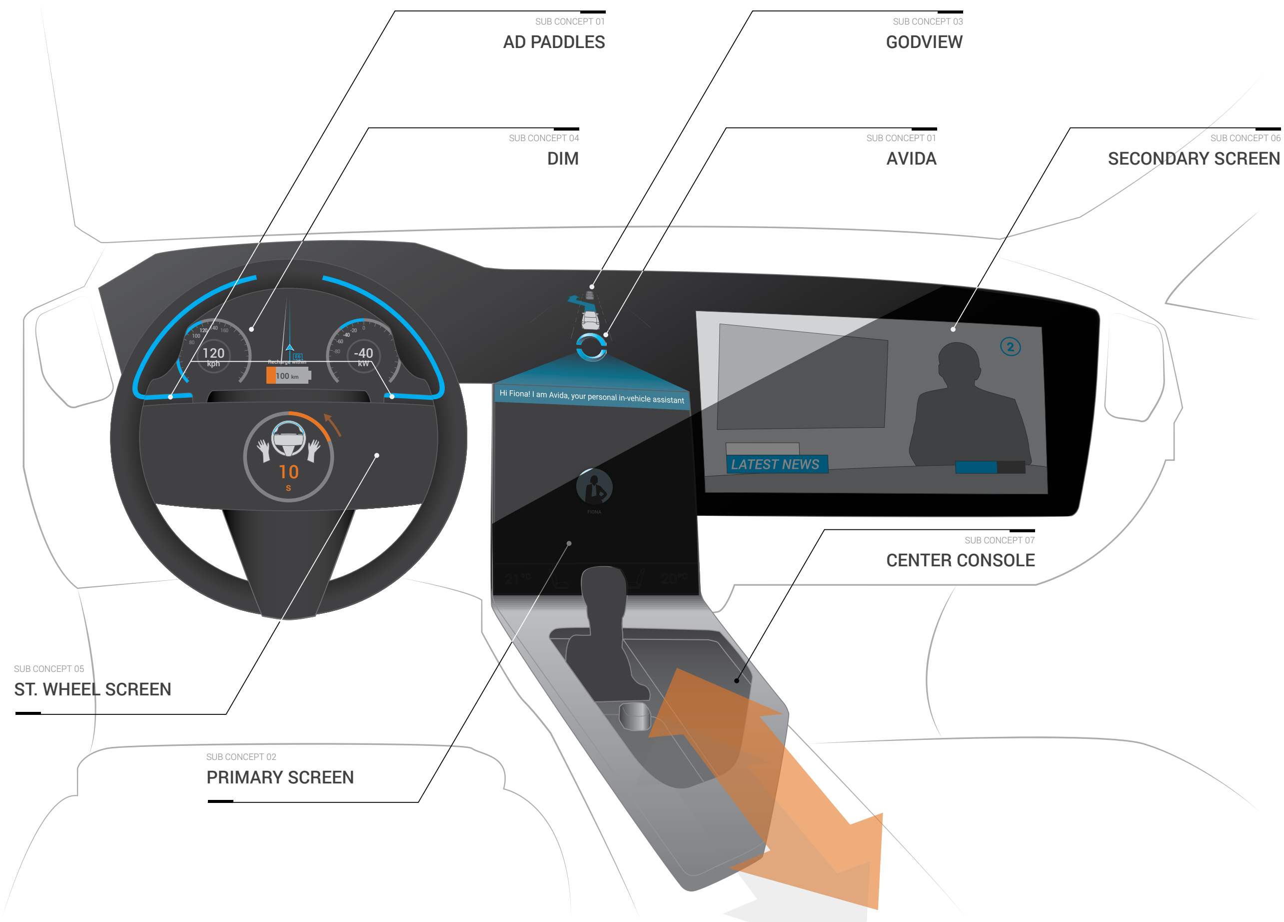

Figure 7.9: An overview of Vision AVID, including markers of all its parts.

Table 7.1: List of all parts included in Vision AVID. Each part is labelled with a number, part name, and a description. The description includes the part's potential subparts and functions.

No.	Part	Description
1	**Primary screen (CSD)**	Main touch display for the driver to interact with. Settings, navigation, entertainment, AC, temperature is handled here.
2	**Secondary screen**	Works as external display to the primary screen and allows the driver to have multiple screens open at the same time. Is a touch screen so that a passenger has the possibility to interact with it directly.
3	**AVIDA / Godview screen**	Area designated to the driver's personal assistant AVIDA, who helps the driver to direct attention to important information, teaches the driver about the AD functions, adapts to the driver's preferences, and makes suggestions. AVIDA shifts from grey to blue and rotates 180 degrees when the driver enters AD mode. The vehicle awareness representation is called Godview. It is only available in AD mode.
4	**Biometric key**	Physical key which has a built-in fingerprint sensor. It recognises who the current driver of the car is and loads that specific person's personal preferences and settings. It also works as a security precaution as it does not allow unauthorised drivers.
5	**DIM**	Contains speedometer, odometer, tachometer, navigation, and warning icons.
6	**Steering wheel screen**	In manual mode, the driver can swipe through menus found in the primary screen. When in AD mode, an AD icon and a timer showing estimated time until end of AD appears in the centre of the screen.
7	**AD lights**	When transitioning between manual and AD mode, light beams along the steering wheel rim will visualise the time remaining until control is transferred.
8	**AD paddles**	Paddles on the back of the steering wheel, containing lights that pulsate when AD mode is available. The driver needs to hold them down for five seconds to transfer the control of the vehicle.
9	**Centre console**	Contains the primary screen, the biometric key, and the gearshift. Whenever the driver adjusts the seat position, the centre console will follow smoothly in order for the driver to be able to reach the controls. In its innermost position, the primary screen attaches seamlessly to the dashboard, creating a notion of one unified dashboard screen.
10	**Interior sensors**	Eye and head tracking sensors and microphones that capture the cabin state in terms of noise levels. This allows the vehicle adjust its communication strategies to fit all kinds of situations.

Vision AVID is to design the interaction around the driver so that the V2D communication effectively may adapt to the external and the cabin states, and to avoid any superfluous information to the driver.

Because the vehicle will only allow the driver to transition control to it in contexts where it can handle the driving situation, trust is primarily relevant in the sense that the driver needs to trust the vehicle enough to use its automated functions. The interface is designed in transparent manner that aims to reduce the risk for overtrust or distrust, which might lead to misuse or disuse. It is however unlikely that overtrust could lead to an accident, as the vehicle will always bring itself to a safe stop, should the driver not intervene when prompted to do so. Despite this, a concept at a higher refinement level needs to be evaluated using prototypes to decide the appropriateness of trust.

7.2.3 Content, Transparency, and Feedback

Godview enables instant on demand visual information regarding the vehicle's placement on the road and in relation to other vehicles, as well as its intentions and action in this environment (see figure 7.10). Simplified representations of other vehicles, pedestrians and structures are used to facilitate the driver's interpretation of the situation and to ensure that the driver knows that the vehicle is aware of its environment in real-time.

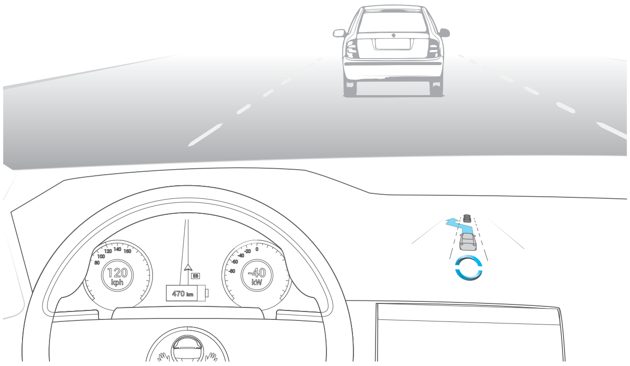

Figure 7.10: Godview displaying intention.

When the driver is requested to take action in any way, his or her attention is directed to the area of interest by a blue indicator connected to AVIDA, whose light flows in the direction of the screen. This reinforces the vehicle's intention and clarifies to the driver that he or she needs to intervene.

The results of actions that are not directly related to the immediate driving environment are displayed appropriately in relation to the nature of the action. For instance, a selection of a setting made by the driver will be displayed in the primary screen.

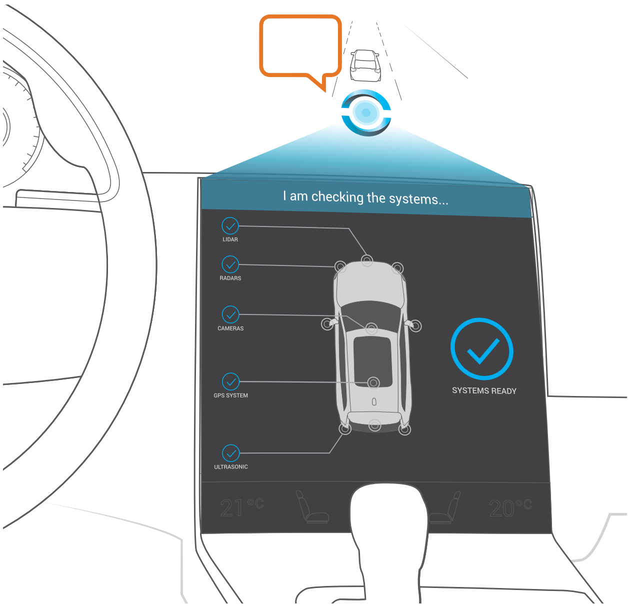

Figure 7.11: System check.

When a driver starts the vehicle, a check of all systems is performed and displayed on the primary screen to ensure the user that AD mode is available and fully functional (see figure 7.11). This is in order to transparently display automation performance to make the driver aware of its present status. Performance history is available through menus found in the primary screen so that the driver may check past automation performance at any time.

7.2.4 Communicating System Capabilities and Responsibilities

During control transitions, two light beams located on the steering wheel rim are connected after the driver has held the paddles long enough (see figure 7.12). The steering wheel here acts as a symbol for who is in control of the vehicle; so that the driver knows that the vehicle is in control when the blue lights are on. To further emphasize that the vehicle is in control, the colour of AVIDA changes from grey to blue when activating AD mode. When entering manual mode again, the reverse happens.

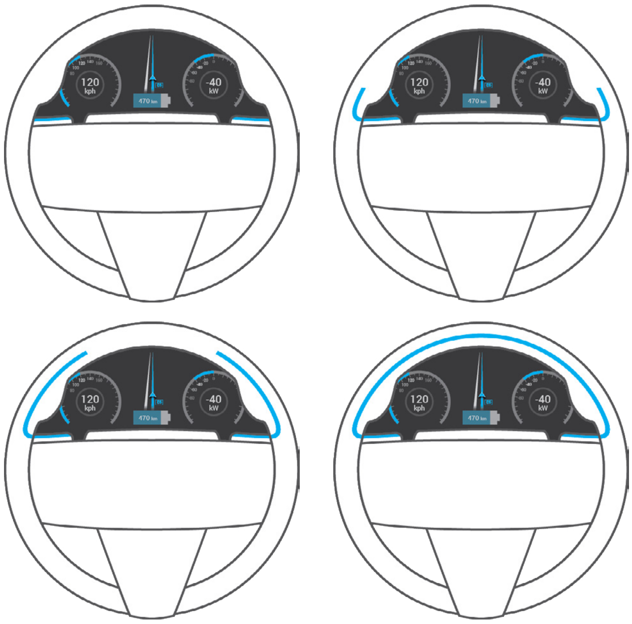

Figure 7.12: The steering wheel rim light beams, during a control transition.

The capabilities and limitations of the self-driving functions are communicated through training before the first use of AD mode. This is done in order to ensure that the user is aware of when they may expect AD mode to be available, and when they may be expected to resume manual control. During driving, the vehicle also indicates on the AD paddles and steering wheel screen when AD mode is available and similarly, when it will no longer be available within a near future.

7.2.5 Modalities

The use of modalities is decided by the logic from AVID Model, which decision of modalities depends on the external need for driver action and the state of the cabin. In general, the more urgent the need for driver action or attention is, the higher frequency and intensity the resulting display will have.

7.2.6 Adaptation and Customisation

By using a Bluetooth enabled digital key, similar to the solution being used for Volvo In-car delivery (Volvo In-Car Delivery, 2017), the driver can unlock the car (see figure 7.13). To start the car, the driver needs to twist the Biometric key (see figure 7.14). The fingerprint reveals the person's identity, which must have been registered in the mobile application prior to the drive. The mobile application profile is also linked to that specific individual's user in-vehicle profile. In this way, user specific content can be loaded from the driver's profile and personal preferences can be loaded in all vehicles connected to the application.

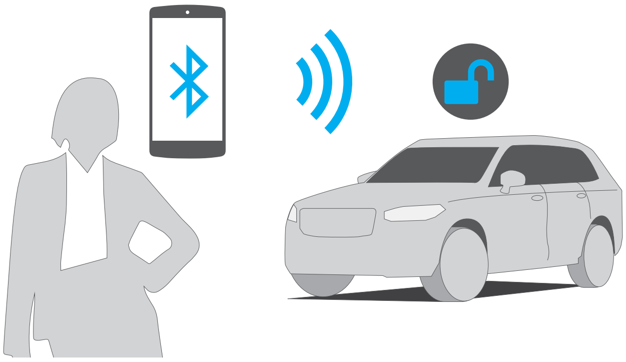

Figure 7.13: A Bluetooth enabled digital key found in a mobile application is used by the driver to unlock the vehicle.

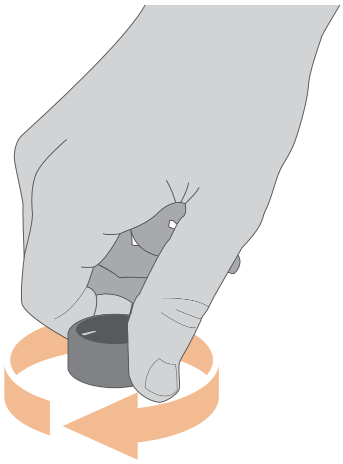

Figure 7.14: Twisting of Biometric key to start the vehicle.

The driver has the ability to customise the vehicle's communication style, either by changing the settings in the primary screen or in the vehicle's associated mobile application (see figure 7.15). However, the driver's own preferences will not override the displays related to the external states impending and imminent, since this would risk compromising the traffic safety. The available settings include "Normal mode", in which the displays are according to AVID Model, "Silent mode", in which the auditory displays are replaced with haptic displays, and "Do not disturb mode", in which the number of displays are set to a minimum. Further settings include "Smart suggestions", in which suggestions, such as points of interest, food deliveries and other services are presented to the driver. Reroute suggestions, in which the destination is unchanged, can however never be turned off. "Verbal" is an optional setting that enables verbal communication from AVIDA.

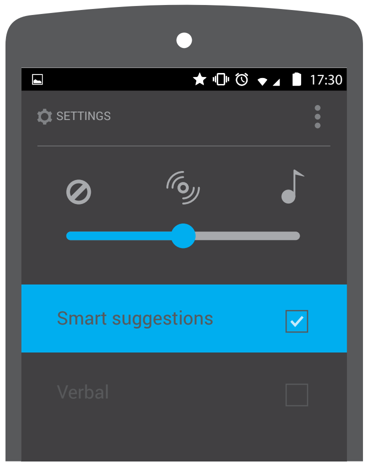

Figure 7.15: Mobile application displaying the settings menu where the driver can select different communication modes depending on personal preferences.

7.2.7 Embodiment

Figure 7.16: The personal in-vehicle assistant AVIDA, with ripples indicating verbal communication.

AVIDA is an abstract Volvo-inspired circular agent that transmits ripples when communicating verbally (see figure 7.16). He does not have any visual human characteristics, but makes instead use of the human embodiment attributes, i.e. identity, humanlike voice, that are essential to the facilitation of communication between vehicle and driver. Furthermore, by using humanlike attributes such as an identity and a humanlike voice, the embodiment of AVIDA reflects a level of robotness, not having visual human attributes, in order to not create false expectations of its capabilities. AVIDA's round shape and serious appearance are inspired by the preferences of humans when it comes to robots, facilitating the formation of trust.

As a means to leverage the human tendency to interact socially, AVIDA is based on the metaphor of a personal assistant. He is constantly available to the driver, both in the vehicle and in the mobile application, to support his or her decisions. Much like a real personal assistant, AVIDA respects your wishes and your privacy and do not interfere more than necessary to capture the driver's attention when needed.

7.2.8 Training

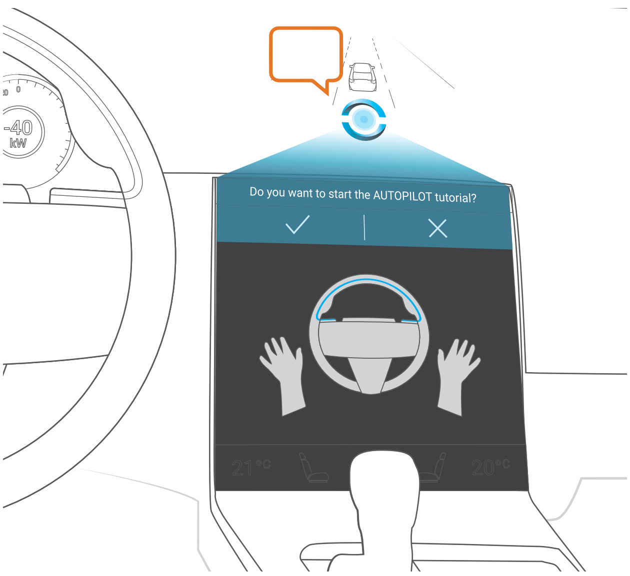

Figure 7.17: The tutorial in first use states that the vehicle is not entirely capable of driving itself in all kinds of situations and that the driver will need to resume manual control when prompted to do so.

After the driver's first biometric scan, the car recognises that it is a completely new driver. The driver is first offered to create a user profile and then offered to go through a tutorial on how to engage and disengage AD mode (see figure 7.17). Not until the driver has finished the tutorial, AD mode will be unlocked. The car also instructs the driver that it will notify the driver whenever AD mode is available.

In the primary screen, the driver can find all tutorials regarding handling of the car, the interface, and the AD mode. For instance, the tutorial includes how to open the trunk with a kick, how to watch a movie when in AD mode, how to change personal settings using the mobile application, and how to enter AD mode or resume manual control.

7.2.9 Usability

In this section, Vision AVID is described from a usability perspective, covering the key heuristics described in the theory chapter (see section 2.7.1).

There are several ways that Vision AVID provides a good visibility of system status. Upon starting the vehicle, a checklist is displayed ensuring that all systems are operational. Should a problem with a system occur during the drive, it is clearly displayed so that the user can take appropriate action. The transition of control between driver and vehicle is clearly illustrated visually with the use of moving lights in the steering wheel. The status of the vehicle's operation in the external environment, and its intentions, are always displayed in the godview area so that the driver knows that the vehicle can sense and classify its surroundings, as well as plan for and carry out safe manoeuvres in relation to it. This also demonstrates recognition rather than recall in that the user recognises how the interface represents the surroundings as simplified images of reality.

The interaction required for the user to perform a control transition is an example of how the concept is designed for *error prevention*. By making the users hold down paddles using both hands for a number of seconds before they give control to or take back control from the vehicle, it is extremely difficult to perform this action by mistake. If a mistake is made when navigating the menus on the primary screen, the user may easily recover from that mistake as the interface uses conventions found in touchscreen devices such as mobile phones and tablets, which is a demonstration of *user control and freedom*, *consistency and standards*, and the concept's ability to *help users recognise, diagnose, and recover from errors*.

Since AVIDA functions as a personal assistant who communicates using words, phrases, and concepts that are familiar to the driver rather than using system-oriented terms, it demonstrates a *match between system and the real world*. The driver's option to customise how AVIDA communicates, both while in the vehicle and by using an external mobile application, allows for expert use and demonstrates the concept's *flexibility and efficiency of use*. The interface continuously communicates several units of information, which could make it hard for the driver to know which information should be in focus. AVIDA mitigates the negative effects of this by always serving as a focal point which directs the driver's attention to the important information. This along with the fact that functions are only visible when they are available, such as the secondary screen only being visible in AD mode, demonstrates *aesthetic and minimalist design*. Through the use of easily accessible tutorials, instructional videos, and documents, the concept provides the *help and documentation* needed for the user to utilise the vehicle to its full potential.

7.2.10 Exemplifying the AVID Model

To illustrate how the interface communicates based on the AVID Model, three examples were created. The first example shows what happens in a situation where the cabin state does not alter the initial strategy, the second example shows what happens in a situation where the cabin state does alter the initial strategy, and the third example shows what happens when a customisation alters the initial strategy.

Example I

A driver is in an electric vehicle driving in AD mode on the highway. The cabin is quiet as the driver is reading a book, when the vehicle detects that it is running low on charge and needs to be recharged within 100 km. In the AVID Model, this would correspond to a "distant need" as the time to a required action is over ten minutes. This means that the initial strategy would be to make use of a non-intrusive auditory display to capture the driver's attention, and concise visual display to deliver information, with the option of accessing more detailed information. The state of the cabin would correspond to being "calm & relaxed", which means that it will not alter the initial strategy. The result is that AVIDA uses a single tone auditory display to capture the driver's attention and visually direct it to the DIM, where a battery icon is displayed along with the text "recharge within 100 km" (see figure 7.18).

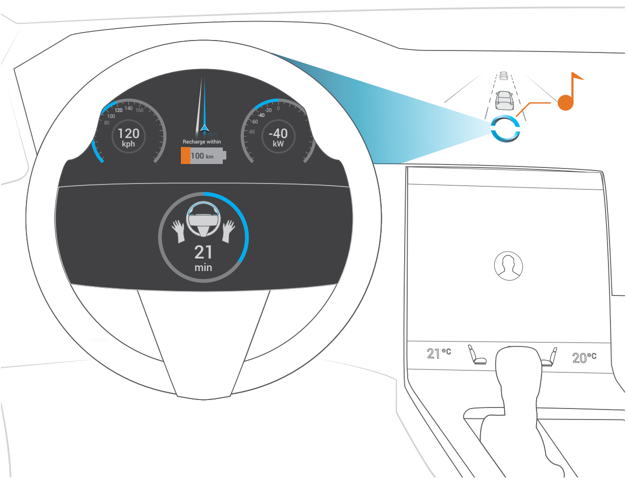

Figure 7.18: AVIDA captures the driver's attention with an auditory display and directs it to the DIM where the message "recharge within 100 km" is displayed.

Example II

A family with young children travels in an electric vehicle driving in AD mode on the highway. The cabin is noisy as the children are fighting in the backseat while the parents are looking back at them trying to intervene. This cabin state would correspond to being "noisy & distracted", as the children are being loud and the driver is inattentive to the external driving environment. While this happens, the vehicle detects that it needs to be recharged within 15 km in order to not run out of power. This would correspond to an "impending need", as the time to a required action is between one and ten minutes. The initial strategy would then be to make use of a semi-intrusive auditory display to capture the driver's attention and deliver the information, with a visual display conveying the same information for redundancy. However, in the case of an "impending need", a "noisy & distracted" cabin leads to an alteration of the initial strategy by adding a haptic display as a primary captor of attention. The result is that AVIDA simultaneously uses a dual tone auditory display and a seat vibration (see figure 7.19) to capture the driver's attention, before delivering the information, "recharge within 15 km" in speech as well as visually on the DIM.

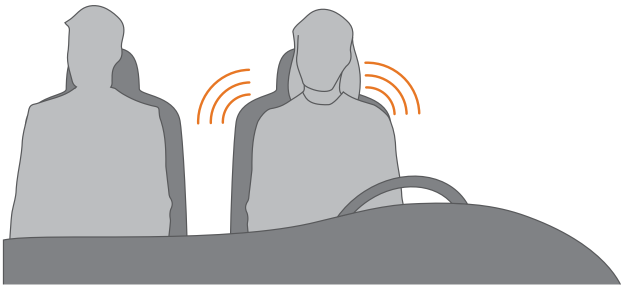

Figure 7.19: A seat vibration is added to capture the driver's attention in a noisy environment.

Example III

Figure 7.20: AVIDA suggests a route change to save time, without interrupting the news broadcast on the secondary screen.

A driver is in AD mode on the highway in the late afternoon, watching today's news on the secondary screen. This driver has set AVIDA to the "Do not disturb mode", meaning that auditory displays are kept to a minimum. As the car travels along the highway, it detects that queues are building further ahead on the planned route and calculates an alternative route that would save time. In the "Normal mode", this would have led AVIDA to use a single tone auditory display in order to capture the driver's attention and direct it to the primary screen where the driver would have the option to accept or decline the new route suggestion (see figure 7.20). However, since AVIDA is in the "Do not disturb mode", auditory displays are kept to a minimum, and since this is not a situation where the driver needs to take action, the information is just displayed visually on the primary screen, without using an auditory display to capture the driver's attention and without interrupting the news on the secondary screen.

Vision AVID in Action

FIRST TIME USER	COMMUTER	FAMILY HOLIDAY
goo.gl/xUI9g4	goo.gl/uwATFE	goo.gl/Zuv8wU

7.3 Heuristic Evaluation

In table 7.2, a heuristic evaluation of the AVID Model and Vision AVID is presented. The evaluation is based on the HMI design guidelines and concludes, along with a description of the concept solution, to what extent the HMI concept considers each guideline.

Table 7.2: Heuristic evaluation of the HMI concept based on the HMI design guidelines.

HMI Design Guideline	Considered	HMI Concept Solution
1. General Design Strategies The designer should…		
1.1: ...first and foremost design a structure for communication and collaboration in a DVS	Yes	The AVID Model provides a framework for deciding V2D communication strategies.
1.2: ...design for appropriate trust rather than greater trust.	Yes	Training tutorial and system checks give the driver a proper mental model of the system which enables the formation of appropriate trust.
1.3: ...consider how the context affects the relevance of trust.	Yes	Drivers only need to trust the system enough to use its automated functions, which can only be activated on AD authorised roads.
1.4: ...consider compatibility between task, technology, and driver.	Yes	The vehicle's primary task is to provide the driver with mobility. Its secondary task is to facilitate activities that the driver may want to engage in, when in AD mode.
1.5: ...evaluate the appropriateness of trust after having designed an HMI.	Partially	Further prototyping and evaluation is needed.
2. Usability The interface should...		
2.1: ...be designed with Nielsen's ten usability heuristics for user interface design in consideration.	Yes	All heuristics are considered in Vision AVID.
2.2: ...help the driver to maintain an appropriate level of SA.	Yes	Godview enables instant on demand visual information on the vehicle's placement on the road and in relation to other vehicles, as well as its intentions and action in this environment.
2.3: ...communicate through modalities in which attentional resources are available.	Yes	In AD mode, attentional resources are available depending on the cabin state, and so the car adapts its communications (modalities, intensity, frequency etc.) to deliver information to the driver so that they can perceive and process it.

HMI Design Guideline	Considered	HMI Concept Solution
3. Content, Transparency, and Feedback The interface should...		
3.1: ...communicate its intentions, processes, and actions to keep the driver in-the-loop.	Yes	Godview enables instant on demand visual information on the vehicle's placement on the road and in relation to other vehicles, as well as its intentions and action in this environment.
3.2: ...continuously present results of performed actions.	Yes	Results of actions are presented visually in the Godview display.
3.3: ...display past and present automation performance as well as present status.	Yes	System check is presented when starting the vehicle and performance history can be accessed via the primary screen.
3.4: ...display how it has previously performed and is expected to perform depending on context.	Yes	Performance history can be accessed via the primary screen.
3.5: ...present accurate information in a timely manner.	Yes	The AVID Model V2D communication strategies include timeliness of displays.
3.6: ...communicate specificity in object recognition.	Yes	Simplified representations of other vehicles, pedestrians and structures are used in Godview.
4. Communicating System Capabilities and Responsibilities The interface should...		
4.1: ...clearly communicate the division of responsibilities between driver and vehicle.	Yes	Training, the AD lights, the AD paddles, as well as the colour shift from grey to blue indicates the distribution of responsibility.
4.2: ...clearly communicate the capabilities and limitations of the automated functions.	Yes	Training tutorials, and the AD icon and timer on the steering wheel screen indicates when AD mode is available.
4.3: ...provide the driver with information on contexts that may affect the capability of the automation.	Partially	The tutorials include AD training, but further tutorials needs to be defined to describe the context dependence.
5. Modalities The interface should...		
5.1: ...strive to not overload the attentional resources associated with an already loaded modality.	Yes	AVID Model providing information in different modalities depending on the need for driver action and the state of the cabin.
5.2: ...make use of visual information in situations where less intrusive information is desired.	Yes	AVID Model.
5.3: ...avoid the use of visual information in situations characterised by high mental workload.	Yes	AVID Model.
5.4: ...make use of auditory information in situations where the driver needs to be alerted.	Yes	AVID Model.

HMI Design Guideline	Considered	HMI Concept Solution
5.5: ...avoid the use of auditory information in situations where less intrusive information is desired.	Yes	AVID Model.
5.6: ...make use of haptics in situations where the driver needs to be alerted.	Yes	AVID Model.
5.7: ...make use of the benefits of multimodal interaction.	Yes	AVID Model.
6. Adaptation and Customisation The interface should...		
6.1: ...adapt the frequency, intensity, and modalities of communication based on the state of the vehicle's internal (the cabin) and external environment (e.g. the road).	Yes	AVID Model.
6.2: ...allow for customisation of communication style and be able to select different combinations of information transmitting modalities and frequency of prompts.	Yes	The driver has the option to customise the vehicle's communication style in the vehicle as well as in the mobile application.
6.3: ...enable customisations for expert usage and adapt its communication based on information about the driver.	Partially	Customisability of the communication style enables expert usage, but further customisability may need to be included.
7. Embodiment The interface should...		
7.1: ...leverage the human tendency to interact socially with technology.	Partially	AVIDA is used as a focal point for the interaction, but input from the driver needs to be further defined.
7.2: ...only make use of those human characteristics that can facilitate the interaction with the user.	Yes	AVIDA only makes use of embodiment attributes such as a humanlike voice and an identity to facilitate the interaction with the user.
7.3: ...use anthropomorphism in a way that facilitates the formation of an appropriate level of trust.	Yes	By using few humanlike attributes and have a simple physical shape, the embodiment of AVIDA reflects a level of robotness, in order to avoid creating false expectations of the capabilities of the vehicle it represents.
8. Training The driver should be...		
8.1: ...provided with training on how to use and interact with the system.	Yes	A training tutorial regarding AD mode activation is included.
8.2: ...given information about expected automation reliability, and how it depends on context.	Partially	A training tutorial regarding AD reliability is included, but further concepts prompting the driver with context-dependent information needs to be defined.

7.4 Summary

This chapter started with a description of the two parts of the HMI concept, AVID Model and Vision AVID. AVID Model was then described as a framework to decide V2D communication strategies - first by considering external states to form initial strategies, and later also by considering cabin states to form final strategies. Furthermore, in order for AVID Model to act as an efficient tool for HMI designers, it was noted that interface design parameters could be used by HMI designers to create multiple HMI concepts.

Vision AVID, which was created based on AVID Model, was then described as an example concept, illustrating how AVID Model might be applied to HMI concept design. It was noted that Vision AVID is permeated by the metaphor for the relationship between the driver and the vehicle in the DVS, and makes use of the personal in-vehicle assistant AVIDA to attract and direct attention, as well as conveying information. Furthermore, Vision AVID showed that training can be used to communicate system capabilities and responsibilities, and that the driver can customise the V2D communication to fit his or her personal preferences. Three examples were thereafter presented to further illustrate how the communication would look in real situations. Lastly, a heuristic evaluation of the HMI concept was presented, stating that a majority of the guidelines had been considered.

Relating back to the new project direction mentioned in section 5.4, AVID Model aims to generate a positive user acceptance by focusing on the variables perceived usefulness and perceived ease of use, as can be seen in figure 7.21. The example concept Vision AVID further illustrates how these variables can be approached by making use of anthropomorphism.

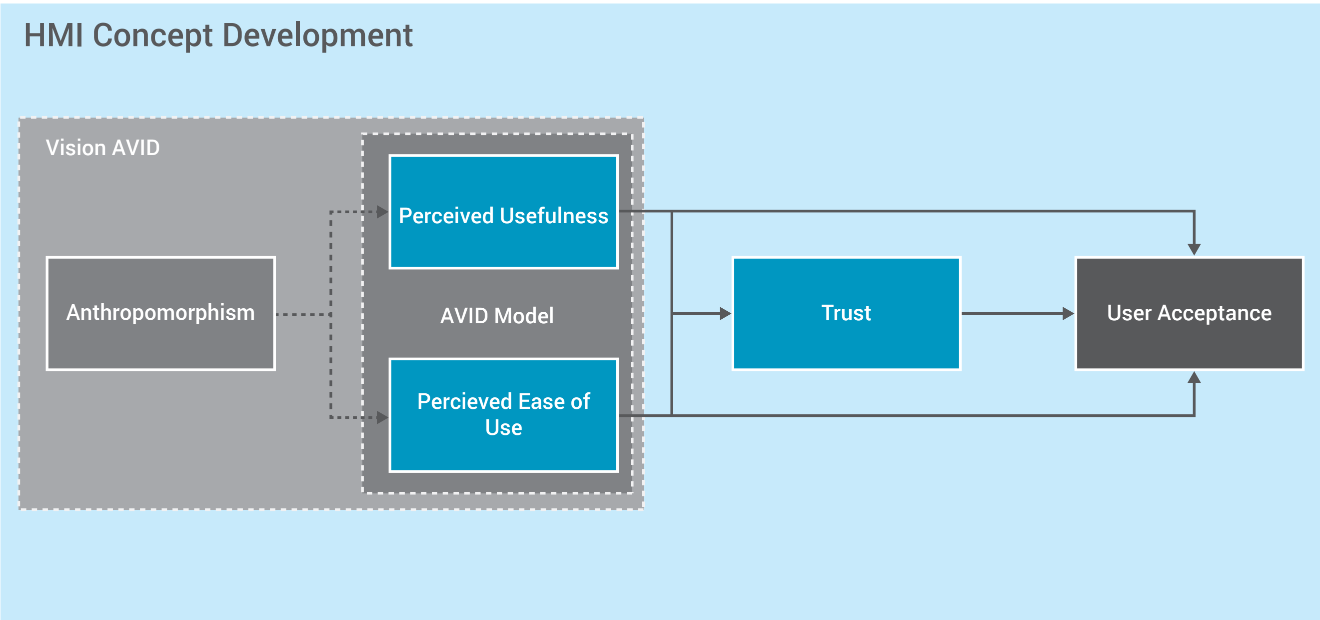

Figure 7.21: Graphical representation of which variables AVID Model and Vision AVID approach in order to affect user acceptance.

8

DISCUSSION

This chapter discusses the project and its outcomes. Here, the key findings are restated in order to discuss their meaning and importance. The findings are related to similar studies, and alternative explanations to the results are discussed in relation to the limitations of the project. The chapter ends with a recommendation for future work.

8.1 Aim & Objectives

The project aim has been achieved by addressing the two posed research questions stated in the introduction. The first research question aimed to investigate which variables are determinants for user acceptance in relation to HAV, and was addressed through the literature study which indicated a correlation between anthropomorphism, trust, and acceptance.

Research question two, which aimed to investigate how these variables were influenced by HMIs based on different degrees of anthropomorphism, was addressed through user test and could not show that anthropomorphism has a significant effect on trust. However, through the qualitative analysis it was found that anthropomorphism had an effect on other factors. The major conclusion was that anthropomorphism, as part of the interface characteristics, indirectly through perceived usefulness and perceived ease of use affects user acceptance.

Lastly, the objective, which was to make the findings from the two research questions tangible, was addressed through the development of an HMI concept. The concept includes the AVID Model, depicting how different situations results in different V2D communication strategies, and Vision AVID, which illustrates the potential of using the AVID Model as a framework for HMI development.

8.2 Contributions

The contributions of this project include a proposed model and a visionary concept for V2D communication aimed to help and inspire HMI designers and researchers in their development of HMI in HAV. The model can be used as a practical tool in HMI development and bring clarity in how to design holistically to achieve increased user acceptance in HAV. Since this is an area that has not been covered by previous HMI research, the authors believe that the model has the potential to contribute to a more structured HMI development process and to new innovative design ideas. This is because it provides HMI designers with a framework that classifies the vehicle-driver interaction from a holistic perspective, covering both cabin states as well as external states, and providing hands-on V2D communication strategies to handle those states. In addition to the AVID Model and Vision AVID, the HMI design guidelines highlight important aspects to consider in the development of HMI for HAV and hence create a foundation a holistic HMI development.

8.3 Results

This section discusses the results and the most important implications that these results bring. The key results from the user test and HMI concept are discussed before putting them into the larger perspective by considering sustainability aspects.

8.3.1 User Test

Research suggests that the anthropomorphism of an interface can be a significant variable affecting trust in automation (de Visser et al., 2012; Gong, 2008; Green, 2010; Pak et al., 2012). When applied specifically to autonomous vehicles, Waytz, Heafner and Epley (2014) showed that some degree of anthropomorphism positively affected users' trust. The study also showed that users attributed more humanlike mental capabilities to their anthropomorphic condition. However, the study presented in this thesis showed no significant relationship between anthropomorphism and trust, and no tendency amongst the test subjects to attribute more humanlike mental capabilities to the most anthropomorphic condition.

If this proves to be right, the interrelations between the constructs of trust and anthropomorphism according to Waytz, Heafner and Epley (2014) may be questioned. Even though anthropomorphism may have an impact on trust, the constructs may not be directly dependent on each other. Instead, the authors argue that an indirect dependence may be found in AAM (Ghazizadeh, Lee and Boyle 2011), where trust is a variable that affects user acceptance, along with perceived usefulness and perceived ease of use. According to AAM, trust has a unidirectional effect on both perceived usefulness and perceived ease of use, as well as direct effect of the behavioural intention to use. However, the authors argue that these relationships may be bidirectional in a dynamic process, in which the driver's trust in a system also depends on its perceived usefulness and/or perceived ease of use. This phenomenon could be seen in the test, as the Caricature condition's low trust ranking could not be seen as a direct result of its anthropomorphic attributes, but rather its perceived usefulness. In other words, the subjects did not assign low scores to the condition only based on its appearance or perceived mental capabilities, but also based on its utility and usability as a feature in an HAV interface. Anthropomorphism could hence be seen as a design tool, which indirectly, through perceived usefulness and perceived ease of use, may affect trust. Hence, by serving as a part of the interface characteristics, anthropomorphism would, according to the structure of AAM, have the ability to indirectly affect user acceptance through trust.

Although these proposed theoretical relationships reveal a possible change in how anthropomorphism is approached in HMI design for HAV, they should be further validated before they are applied. It should also be noted that the test designs differed considerable between this study and that of Waytz, Heafner and Epley (2014). They conducted a large scale simulator study using a between-subjects design, while this study consisted of a small scale test in a real vehicle using a within-subjects design. The limitations that this brought are discussed in section 8.4.2. Nevertheless, the qualitative results from the user test made it clear that user acceptance is affected by the suitability of the interface characteristics to the need for driver intervention. This finding is important to take into consideration when designing HMI for HAV as failing to do so may result in an HMI which is unsatisfactory to use, making it less likely that users will adopt the technology.

8.3.2 HMI Concept

Similar to need for guidelines regarding the use of CWS by Campbell et al. (2007), the authors argue that there is a need for guidelines for V2D communication in HAV. As with previously introduced automated systems such as ACC, the introduction of autonomous vehicles will lead to new user needs regarding system functionality, transparency and usability. The fulfilment of these needs will most likely rely heavily on the system's ability to communicate intentions, actions, and processes effectively and efficiently to the driver. As stated by Woods (1996, p. 3), "...design of automated systems is really the design of a new human–machine cooperative system". With this statement in mind, the AVID Model was created. The model has made it possible to categorise and highlight events during AD mode, and based on those decide a V2D communication strategy that establishes a basis for user acceptance. To the authors' knowledge, no such model of V2D communication for level 4 autonomous vehicles exists to this date. As stated by Cunningham and Regan (2015), user acceptance is crucial for the future of HAV technology. Without a holistic approach to the design of HMI in HAV, it is reasonable to assume that some factors affecting user acceptance may be neglected, and thus not satisfied. As several major manufacturers within the automotive industry are expected to reveal their first HAV models within the next five years, the issue of user acceptance is crucial for the long term success of HAV technology.

Vision AVID is not prescriptive in the sense that it provides a specification for HMI design for HAV, but rather descriptive in the sense that it illustrates the full potential of the AVID Model as a framework to develop HMI for HAV. The overall idea of the concept is that it should permeated by a clear strategy for V2D communication and utilise a metaphor to guide the design of interface characteristics. The choice to include a metaphor created by the authors, i.e. the "Personal assistant", proved to be crucial in guiding the development of a consistent interface in Vision AVID. Furthermore, the metaphor facilitates the understanding for the driver regarding the relation and the distribution of responsibility between the driver and the vehicle. It might be argued whether or not "Personal assistant" was in fact the most appropriate metaphor to describe the driver-vehicle relation in HAV. Other metaphors, such as the H-metaphor (Flemish, 2003) which makes use of the analogy of the relation between a rider and a horse, could equally have been used. However, what made the "Personal assistant" more appropriate than other metaphors in regards to this project was that the metaphor included the aspect of adaptability. A personal assistant caters to the driver's needs, and is at the same time highly sensitive to his or her mood as well as the situation. These aspects are all included in the essence of AVID Model, in which the communication adapts to external and cabin states.

Vision AVID was created with the full interaction, i.e. input and output, in mind. However, the focus has been on developing the V2D communication, i.e. the output. Hence, no conclusions can be drawn regarding the appropriateness of the choice of input modalities from the driver. One might argue that this in fact narrows the perspective and prohibits a holistic mind set in the HMI design. However, one may also argue that focusing on the output is a precondition that allows for a better understanding of how the input should be designed in relation to this. Furthermore, since the AVID Model only considers driving in AD mode, the driver input is reduced to secondary tasks which are not related to the driving and therefore not safety critical. Instead, the safety critical tasks are handled by the vehicle, and the V2D communication hence becomes the primary information channel regarding these tasks. This emphasises the importance of designing a V2D communication strategy.

8.3.3 Sustainability

From a sustainability point of view, an increased user acceptance in relation to vehicle automation may lead to a number of positive societal implications - mainly in terms of urban infrastructure, where the introduction of autonomous vehicles has the potential of reducing the need for parking space, increasing individual mobility, and reducing the number of vehicles (Pacific Standard, 2015). For a manufacturer of autonomous vehicles, being the first to market could prove hugely economically advantageous, possibly leading companies to introduce autonomous vehicles before they are completely ready for market introduction. This makes it paramount to ensure that sufficient research into safety-critical areas is conducted, and that the results and recommendations are clearly communicated and adhered to. In this project, HMI has been considered as one safety-critical factor that may be improved, and the authors are convinced that its outcome may aid the development of improvements necessary to increase HAV safety.

The transportation sector is one of the sectors with biggest environmental impact, making ecological sustainability a critical subject. Within the transport sector, road transport is the biggest contributor to global warming. Since autonomous vehicles can optimise energy efficiency and road use, and subsequently allow for more efficient infrastructures, the ecological implications of this technology are potentially enormous. To enable a shift towards autonomous traffic, it is crucial to create an acceptance for this technology so that policy makers create the conditions necessary for the technology to thrive, and so that the users adopt it. By focusing on creating preconditions for a satisfactory user experience, the authors believe that this project has managed to establish a basis for such adoption.

8.4 Process & Methodology

This section discusses how the chosen process, methodology, and limitations have influenced the project and intends to provide insights that can be useful for similar projects. It is divided according to the different chapters of the result in order to make the discussion more comprehensible.

8.4.1 Theory

Overall, the literature review provided the authors with sufficient theory regarding trust and anthropomorphism in order to support the user test. However, since the focus of the project changed as a result of the findings from the user test, showing no significance between level trust and degree of anthropomorphism, the theory needed to be complemented with additional theory regarding use of modalities in HMI. It might be argued that this literature review could have been more extensive, in order to rely less on fewer sources. On the other hand, the sources used for the development of the AVID Model, including Campbell et al. (2007) as well as Haas and van Erp (2014), were deemed as highly reliable as they provide an extensive review of existing human factors literature regarding the use of Collision Warning Systems (CWSs) and multimodal warnings. Even though the authors had to extrapolate the results of the studies onto autonomous driving, the guidelines regarding the use of modalities were deemed to be general enough to be applied the HMI of HAV.

8.4.2 User Test

The user test was successful in the sense that it provided useful insights to bring into the following HMI concept development phase. However, since the quantitative analysis did not show any significant differences in trust levels between the three conditions, no conclusions could be drawn about this relationship only based on the statistical data. Three possible error sources were found in the process.

Test Design

As the user test was conducted using a within-subject design with ten subjects and the same vehicle between the test laps, the results of the statistical analysis may have been skewed. By using a within-subject design, each subject was aware that the vehicle remained the same although the interface did not. This may have given the subjects a reason to assume that the vehicle would not act differently depending on interface. Hence, trust may not have depended on the degree of anthropomorphism, but rather on the actions of the vehicle. And since the vehicle remained the same during the entire user test, trust did not change considerably between the conditions.

Test Context

As the tests were performed in a closed off area with no traffic, with a slow moving vehicle, and long distances to the obstacles, the subjects felt that the situation did not pose any danger to them. The context in which the test was set, may therefore have led to a situation in which trust was never an issue for the subjects. For instance, the subjects were during two out of three laps able to spot the pedestrian long before the point of encounter. On the other hand, if the context would have been seen as dangerous to the subjects, it would assumedly also have been hazardous. Inevitably, this would never have been an option since the authors could not risk the safety of the subjects during the test.

Conditions
The conditions may also have had an effect on the result of the user test. Due to the inherent issue of creating agent designs representing different degrees of anthropomorphism, the subjects tended to put more focus on the quality of the design, rather on the degree of anthropomorphism it represented. In particular, this may especially have affected the Caricature condition as it relied on a computer-generated voice, which gave rise to many subject's disapproval. Furthermore, the trade-off between minimising the nuisance effects of modalities and achieving different degrees of anthropomorphism, lead to less usable designs.

These three sources of error might have had a negative impact on the test validity. As a result of this, the following HMI concept development was chosen not to rely on the quantitative analysis of the user study.

8.4.3 HMI Design Guidelines
The process of creating the HMI design guidelines was iterative by nature. By summarising the theoretical findings and identifying the overlaps in a wide range of theory, the authors managed to create a first draft which consisted of the key theoretical guidelines. By analysing the qualitative data resulting from the user test and synthesizing this into key findings, the draft could be revised by adding new empirically based guidelines but also adding empirical weight behind some of the original theoretical guidelines. This process gave the authors the possibility to create a finalised set of HMI design guidelines which both has theoretical and empirical weight. However, the empirical findings could only be based on one user study aiming to investigate one specific relationship between constructs, and therefore further empirical studies are needed to confirm its validity.

8.4.4 HMI Concept
Given that the allocated time for creating an HMI concept was three weeks, it was decided that design sprints would form the outline for the entire concept development process. This way of setting goals and deliverables for the end of each week helped the authors take the development process forward rapidly. However, by taking the design sprint approach, the authors were forced to continuously take the development process forward despite having some questions regarding each sub concept's feasibility left unanswered, which may have compromised the holistic approach. The ideal team size for a design sprint is 5-8 people with expertise in different areas (Direkova, 2015), which can provide the sprint with input from a number of different perspectives. The fact that the two authors conducted the sprints without external input for the majority of the process may have created a less exhaustive process and resulted in a narrower solution space. Despite this, the use of design sprints was successful in helping the authors create and iterate the ideas necessary to reach a final concept. Also, the design sprints were complemented with additional literature reviews when needed, for instance the one regarding the use of modalities, which was used to create AVID Model.

8.5 Lessons Learned

Throughout this thesis, many valuable lessons have been learned, both regarding the process and the subject. Overall, most of the practical lessons were learned during the user test, since this represented the phase with most uncertainty. In order to design a similar test and to avoid potential pitfalls, one should consider the following aspects.

8.5.1 Test context
Creating a test context in which trust becomes an issue for the subjects is a complex task, since it is difficult to control situations which are perceived as dangerous and impossible to guarantee the safety of the test subjects. A possible solution to this would be to conduct the test in a vehicle simulator. In a test rig, dangerous situations can be simulated without compromising the safety of the subjects and perhaps one may then achieve a distinguishable difference in trust levels.

8.5.2 Conditions
The conditions need to be designed in a way that minimises the effects of nuisance variables. If nuisance variables are not reduced, the results might be contaminated and it might be difficult to draw conclusions from the test. Furthermore, the constructs underlying the conditions should be properly tested before using them in a user test to ensure that are valid.

In addition to this, much was learnt about HMI development during the project. An important lesson was that there is a difference between development of physical products and HMI concepts. The main difference is that while physical products have relatively concrete interactions, HMI concepts require a more profound understanding of the use to decide the interactions. Therefore, it was imperative to create scenarios, visualise concepts in quick sketches, and enact and evaluate them to build a holistic concept.

8.6 Recommendations for Future Work

To conclude the discussion, the following recommendations for future work are provided:

- Conduct further research into the effects of anthropomorphism on user acceptance of HAV. If possible, create a between-subjects design that eliminates nuisance factors such as subjects learning the test context and experiencing the different conditions in the same vehicle. The context should also be designed so that the situation is perceived as safety-critical by the subjects. Whether or not this type of context can be created in a secured environment or a simulator study needs to be further investigated.

- Investigate AAM and question whether trust has a unidirectional relationship with perceived usefulness and perceived ease of use or if they affect one another in a dynamic relationship.

- Based on the HMI design guidelines, create a requirement specification for the implementation and detailed design of the HMI. This should be done by thoroughly reviewing research that has been conducted in each area and if possible, conducting tests in areas where more information is needed.

- Further develop the AVID Model to include driver input in order to consider the entire interaction between driver and vehicle in AD mode. Vision AVID could also be refined by building and evaluating prototypes in terms of technical feasibility, usability, and user experience.

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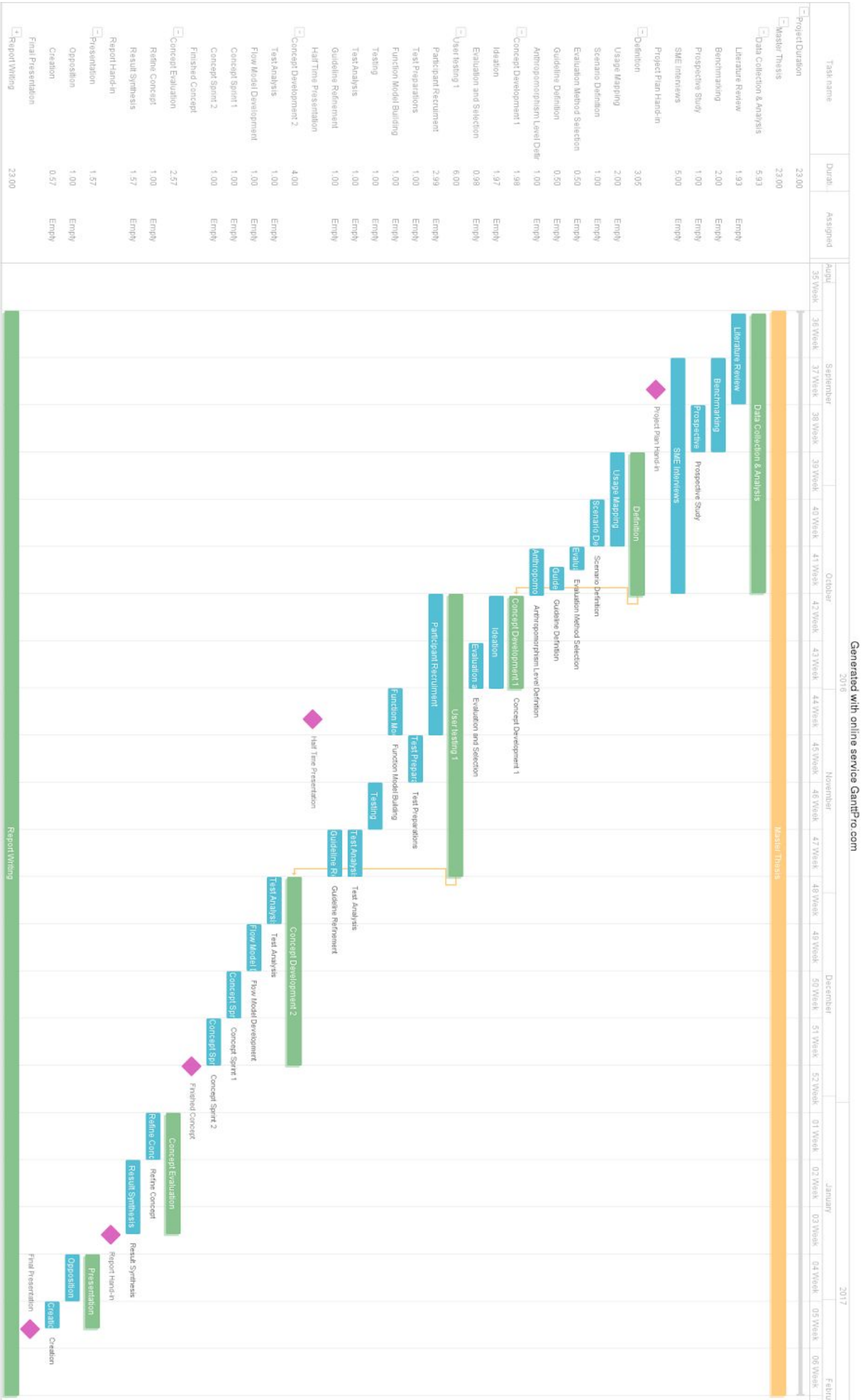
APPENDIX

Appendix I - Gantt Chart



Appendix II - SME Interview Guides

Example SME Interview Guide

Name:
Position:

Introduction
If possible: Suggest a short brainstorming (plus brain writing) to arrive at a likely scenario for user level 4 vehicles.

Issues
Which touchpoints / events are part of a supposed user scenario for running a level 4 autonomous vehicle?
What / Which touchpoints / events are most critical for a driver's confidence in the system?

If not: Discuss our scenarios validity.

Questions

1. What is position here at [Company]?
2. Which project have you been involved in?
3. What experience do you have of autonomous vehicles?

4. Is it important to create acceptance for semi-autonomous cars? Why?
5. Is it important to create trust in the system in a semi-autonomous car? Why?
6. How have you worked with the design of the HMI to provide an appropriate level of trust? For example, what information is presented and how it is presented?
7. Have you worked with handling tendencies of over-reliance and under-reliance of the system?
8. In the parts of the system have been used by anthropomorphism?
9. User tests: what have you tested, why have you tested it and what methods have you used?

10. Do you think anthropomorphism in any form can inform one / strengthen the interaction between driver and car?
11. How can anthropomorphism used in the interaction between driver and vehicle to enhance the driver's confidence in the system?
12. How can the supervisory role of a driver in a level 4 vehicles affect confidence? How to deal with a potential negative impact on trust?
13. Is that a likely scenario for SAE / NHTSA Level 4 vehicles? Is there any touchpoint / events that are missing or that need to be corrected?

Appendix III - Workshop Guide

Workshop - Scenario

2016-10-07

Total duration: 30 minutes
6 participants from Industrial Design Engineering
Participants will during the process be provided with Fika.

1. *Present Thesis*

Present yourselves!

3 min - We are currently doing our Master's thesis in which we are investigating how different levels of anthropomorphism (human-likeness) in Human-Machine Interfaces affects variables such as trust and acceptance in relation to highly automated vehicles.

There are 6 levels of automation in vehicles. 0 is fully manual, and 5 is fully autonomous. We are looking at level 3, which is characterised by the fact that vehicle can drive autonomously in specific environments, that have been approved for autonomous driving, while the driver still is expected to retake control within a reasonable timeframe when prompted to do so.

What we want to do here today is to get your help on the way to defining a scenario that we can use in our future HMI user tests. We also want to identify critical events during a scenario that can have a big negative impact on trust.

2. *Warm-up Exercise*

2 min - "What can make you angry or annoyed on a regular day at school?" Come up with as many suggestions as possible and present the worst one to the group afterwards.

3. *Present Scenario*

3 min - Use Ekman & Johansson's scenario to present the whole drive scenario and highlight autonomous mode as the scenario we want to focus on.

This is how a potential journey may look like for a driver of a level 3 automated vehicle. In the pre-use phase, information is gathered that builds the expectations on how the experience will be like and how to operate the vehicle. In the learning phase, the driver enters the vehicle, starts the engine, enters manual mode and when reaching an area that is approved for autonomous driving, enters autonomous mode after a first control transition. After a while, the driver transitions back into manual mode again, and having reached the destination, shuts off all systems and finally exits the vehicle. The performance phase includes events that has to do with continuous usage, change of context and incidents.

We want to focus on the autonomous mode and develop a scenario that further describes events that might happen within it.

4. Session 1 - Ideate

3 min - Question 1: "What planned actions can the vehicle perform during autonomous mode?"
3 min - Question 2: "What actions might the vehicle have to take as a result of events in the environment around the vehicle?"

Ideas to question 1 and 2 are put down on two different coloured post-its.

Brainpool with post-its

2 min - Another round after looking at all the post-its.

5. Session 2 - Cause-Effect

5 min - Do a "Cause-Effect" table
Where necessary, categorise the post-its based on similarity and give the new head event a name.

6. (Session 3 - Map)

Explain the idea of mapping the events onto the time diagram.
3 min - Distribute the head events into a scenario by placing the post-its in a time diagram.

7. Info - Trust & Reliance

2 min - **Trust** - "the attitude that an agent (ed: vehicle) will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability" (Lee and See, 2004).
Overtrust can lead to misuse, which means that the user thinks that the vehicle or some of its functions are more competent than they actually are, and relies on it to perform over its capacity.
Undertrust can lead to disuse, meaning that the user does not make use of all functionality because they do not trust it to perform a task, even though it is competent enough to do so.

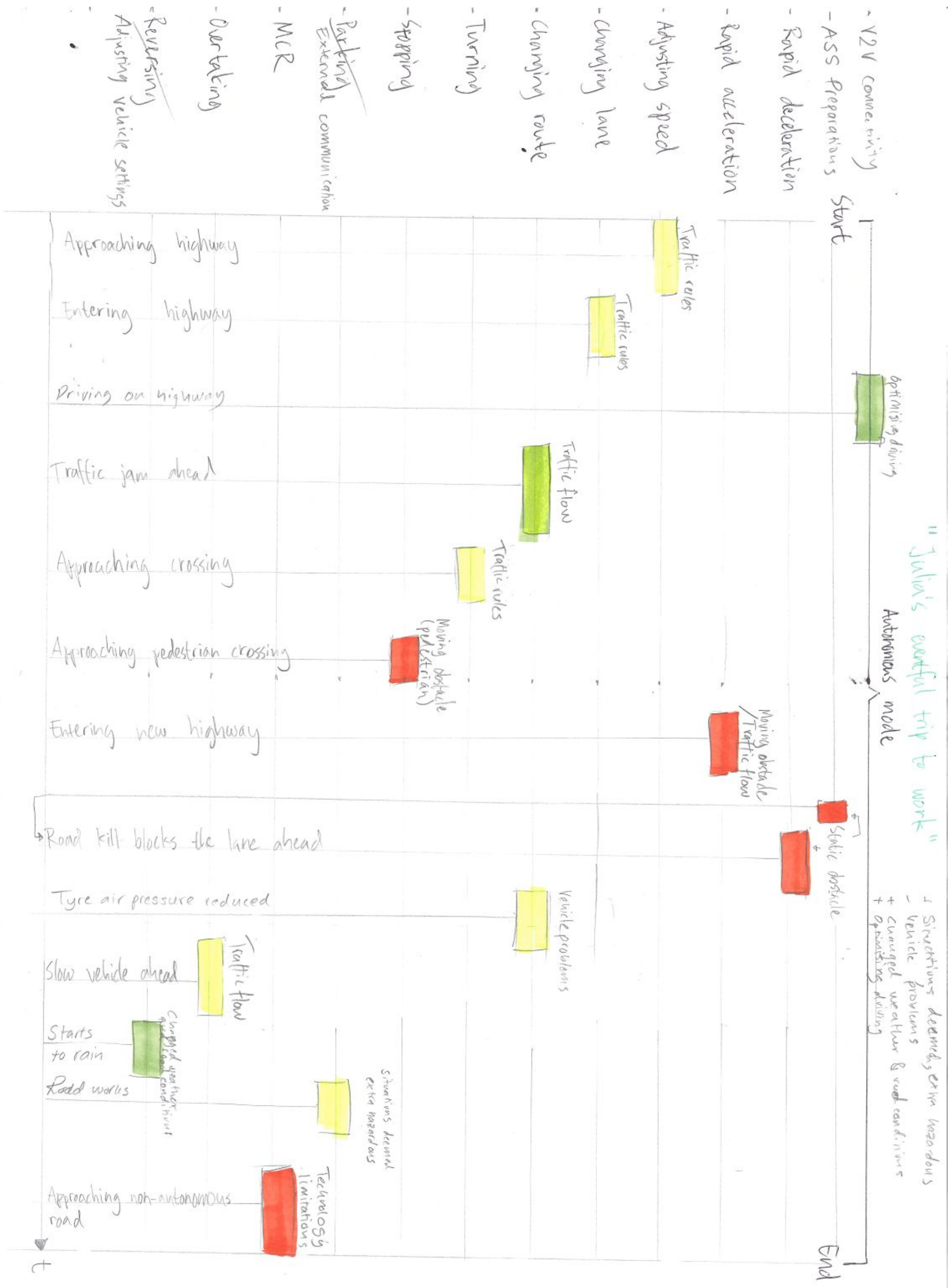
8. Session 4 - Rank

3 min - How much would inaccurate or lack of feedback from the system in this specific event negatively impact your level of trust to the vehicle?

Highest impact is on the top of the list. Rank from low, medium high..

Let participants first write their own ranking on paper, and then summarise and discuss on the screen.

Appendix IV - Scenario & Events



The table displays a summary of plausible events that might occur during a drive in autonomous mode. Each event's impact on trust is estimated based on its time-to-effect and the perceived vulnerability of the driver. From this, the events are placed in three categories, ranging from direct and lethally dangerous situations to the driver to minor continuous situations involving a low level of safety risk. As can be seen in the table, critical events are associated with causes such as moving obstacles, static obstacles, and technology limitations.

Category	**Cause**	**Time-to-effect**	**Perceived Vulnerability**	**Effect (Actions)**	**Trust importance**
Direct and lethally dangerous situations to driver	**Moving obstacle** (Running animal, cyclist, pedestrian)	Short	High	Rapid deceleration, Rapid acceleration, Overtaking, Changing lane, Turning, Stopping, External communication, MCR, ASS preparations	High
	Static obstacle (roadkill, parked vehicle, debris)	Short	High	Rapid deceleration, Rapid acceleration, Changing lane, Turning, Stopping, MCR, ASS preparations	High
	Technology limitations (drivable vs non-drivable roads, environment and conditions)	Varies	High	MCR	High
Indirect or potentially dangerous situations to driver	**Traffic flow** (Slow vehicle in front, traffic jam, emergency vehicles)	Moderate	Low	Overtaking, Changing lane, Adjusting speed, Stopping, Changing route, External communication	Medium
	Traffic rules (Road sign prompt, Traffic code of conduct)	Long	Low	Adjusting speed, Changing lane, Turning, Stopping, Adjusting lights	Medium
	Situations deemed extra hazardous (limited sight, areas with risk for crossing pedestrians, cyclists, and animals, road works	Moderate	Medium	Adjusting speed, Changing lane, Turning, Stopping, External communication, MCR	Medium
	Vehicle problems	Varies	Varies	Changing route, Turning, Stopping, MCR	Medium

Minor continuous situations involving a low level of safety risk	**Destination reached**	Long	Low	Stopping, Parking, MCR	Low
	Changed weather and/or road conditions	Moderate	Low	Adjusting speed, Changing route, Adjusting vehicle settings	Low
	Navigation plans (change of/adjustment to)	Long	Low	Changing route, MCR	Low
	Optimising driving	Short	Low	V2V Connectivity, Adjusting vehicle settings, Adjusting speed, Changing lane	Low

Appendix V - Pre-test Questionnaires

Frågeformulär före användartest

Vad kul att du vill vara med på vårt användartest!

Det här formuläret skickar vi till dig för att samla in relevant information om dina erfarenheter och attityder, så att du ska slippa göra det vid testtillfället. Formuläret består av tre delar och innehåller både flervalsfrågor och frågor som besvaras kortfattat i fritext. I sin helhet tar det ungefär fem minuter att genomföra.

Vänligen besvara frågorna så ärligt du kan.

*Obligatorisk

1. **Namn** *

2. **Hur länge har du haft körkort?** *
   Markera endast en oval.
   - 0 - 2 år
   - 3 - 10 år
   - 11 - 20 år
   - Mer än 20 år

3. **Har du tillgång till bil?** *
   Markera endast en oval.
   - Ja
   - Nej

4. **Hur många dagar i en genomsnittlig vecka kör du bil?** *
   Markera endast en oval.
   - 0
   - 1 - 2 dagar / vecka
   - 3 - 4 dagar / vecka
   - 5 - 6 dagar / vecka
   - 7 dagar / vecka

5. **Om har tillgång till bil, har den några automatiserade funktioner? Exempelvis adaptiv farthållare (ACC), avåkningsvarnare (Lane Keep Assist), parkeringshjälp (Automatic Parking) etc.**
   Markera endast en oval.
   - Ja
   - Nej
   - Vet ej

6. **Har din tillit till bilen någon gång påverkats av någon/några av dessa funktioner?**
Markera endast en oval.

- Ja, på ett positivt sätt
- Ja, på ett negativt sätt
- Ja, både på ett positivt och ett negativt sätt
- Nej

7. **Om du svarade ja på föregående fråga, beskriv den/de händelse(r) som hade störst påverkan på din tillit.**

Del 2

Du ska nu få ta ställning till fyra påståenden. Markera den cirkel som överensstämmer bäst med din egen uppfattning.

8. **Vid varje valt tillfälle skulle jag hellre styra en bil själv än att överlåta styrningen till ett självkörande system.** *
Markera endast en oval.

	1	2	3	4	5	6	7	
Håller inte alls med								Håller helt med

9. **En självkörande bil är säkrare än en manuellt styrd bil.** *
Markera endast en oval.

	1	2	3	4	5	6	7	
Håller inte alls med								Håller helt med

10. **Om körningen vore monoton skulle jag hellre delegera den till en självkörande bil än att göra det själv.** *
Markera endast en oval.

	1	2	3	4	5	6	7	
Håller inte alls med								Håller helt med

11. **Om jag hade passagerare i min självkörande bil skulle jag hellre köra själv än delegera körningen till bilen.** *
Markera endast en oval.

	1	2	3	4	5	6	7	
Håller inte alls med								Håller helt med

Del 3

Du ska nu få ta ställning till tio påståenden. Markera den cirkel som överensstämmer bäst med din egen uppfattning.

12. **I vilken utsträckning har teknologi intentioner? Exempel på teknologi är apparater och maskiner för tillverkning, underhållning och produktionsprocesser (t.ex. bilar, datorer, TV-apparater)** *

Markera endast en oval.

	1	2	3	4	5	6	7	
Ingen alls	◯	◯	◯	◯	◯	◯	◯	Mycket stor

13. **I vilken utsträckning har den genomsnittliga fisken fri vilja?** *

Markera endast en oval.

	1	2	3	4	5	6	7	
Ingen alls	◯	◯	◯	◯	◯	◯	◯	Mycket stor

14. **I vilken utsträckning har det genomsnittliga berget fri vilja?** *

Markera endast en oval.

	1	2	3	4	5	6	7	
Ingen alls	◯	◯	◯	◯	◯	◯	◯	Mycket stor

15. **I vilken utsträckning har den genomsnittliga roboten medvetande?** *

Markera endast en oval.

	1	2	3	4	5	6	7	
Ingen alls	◯	◯	◯	◯	◯	◯	◯	Mycket stor

16. **I vilken utsträckning har en bil fri vilja?** *

Markera endast en oval.

	1	2	3	4	5	6	7	
Ingen alls	◯	◯	◯	◯	◯	◯	◯	Mycket stor

17. **I vilken utsträckning har havet medvetande?** *

Markera endast en oval.

	1	2	3	4	5	6	7	
Ingen alls	◯	◯	◯	◯	◯	◯	◯	Mycket stor

18. **I vilken utsträckning har den genomsnittliga datorn egna tankar?** *

Markera endast en oval.

	1	2	3	4	5	6	7	
Ingen alls	◯	◯	◯	◯	◯	◯	◯	Mycket stor

19. **I vilken utsträckning känner miljön känslor?** *
Markera endast en oval.

	1	2	3	4	5	6	7	
Ingen alls	◯	◯	◯	◯	◯	◯	◯	Mycket stor

20. **I vilken utsträckning har ett träd egna tankar?** *
Markera endast en oval.

	1	2	3	4	5	6	7	
Ingen alls	◯	◯	◯	◯	◯	◯	◯	Mycket stor

21. **I vilken utsträckning har den genomsnittliga reptilen medvetande?** *
Markera endast en oval.

	1	2	3	4	5	6	7	
Ingen alls	◯	◯	◯	◯	◯	◯	◯	Mycket stor

Appendix VI - User Test Guide

1. Pre-test

Vad kul att du vill vara med på vårt test!

Vi heter Erik och Martin, och läser teknisk design på Chalmers. Det här testet är en del av vårt examensarbete, som vi gör på institutionen för Design & Human Factors på Chalmers.

Innan vi börjar ber vi dig att läsa igenom det här avtalet noga och sedan bestämma dig för om du ger ditt samtycke eller inte.

Bilen som vi kommer använda idag har vissa självkörande funktioner, och det vi ska testa är olika sätt som bilen kan kommunicera med dig som förare vid användning av dessa funktioner.

Du kan börja med att ta på dig bältet. Under testets gång kommer vi hela tiden att övervaka situationen, men om du av någon anledning någon gång under testet känner att du vill avbryta trycker du bara på den gröna knappen som sitter på instrumentbrädan, så kommer bilen att stanna. Jag kommer att sitta i baksätet och leda testet, och Erik kommer att sitta på andra sidan skynket och se till så att allting fungerar som det ska och att det är säkert. Vi har satt upp skynket mellan er för att Erik inte ska störa dig, så att du kan fokusera på testet.
Vi kommer börja med att åka ett varv på den utmarkerade banan, utan att testa något koncept. Det är för att du som testperson ska få lära känna hur bilen kör och hur den visar att den registrerar omgivningen. Sedan kommer vi köra tre rundor på samma bana, ett med varje koncept, och du kommer att få fylla i en enkät mellan varje runda. När vi har testat alla tre koncept kommer vi att avsluta med en kortare intervju innan vi är klara. Som tack för att du deltar får du en biobiljett. Innan vi kör igång vill jag bara påminna om att det är helt frivilligt för dig att deltaga, och att du när som helst kan avbryta testet om du vill det. Det gör du genom att trycka på den gröna knappen framför dig i 2-3 sekunder, så kommer bilen att stanna.

Är du redo att börja? … Då startar vi bilen.

Erik startar bilen

Det du ser framför dig på skärmen är en representation av bilen ovanifrån. Ringen runt bilen indikerar med hjälp av olika färgfält att den känner av omgivningen omkring sig. Som du ser lyser två fält snett framför bilen oranget, vilket indikerar att den känner av testbanans gränser. Så länge de lyser oranget är allt okej. Fältet mellan dessa fält lyser upp från grått till rött om ett större föremål dyker på vägbanan. Så här det ut:

Visa Ring animation

Ovanför ringen kan även bilens intentioner visas i form av symboler.

Visa stopp, höger och vänster, undviker höger och vänster

Nu ska vi åka ett varv på testbanan, så tryck och håll inne den gröna knappen i 2-3 sekunder så startar testet.

2. Test

Säg: "koncept #, runda #

Nu är det dags att testa det första konceptet.

Knacka på axel när testpersonen trycker på knappen

Test 1 genomförs

Lämnar över clipboard med enkät och penna

Nu vill jag att du fyller i hur du kände dig under testrundans gång.

Figurerna representerar olika upplevda känslomässiga reaktioner. Den första mäter behag och går från välbehag till obehag. Den andra mäter upprymdhet och går från upprymd till lugn. Den tredje mäter kontrollkänsla, dvs. din upplevda känsla av kontroll över situationen, och går från liten kontroll till stor kontroll. Kryssa i den cirkel som du känner stämmer bäst. Säg till när du är klar.

Om du vänder på pappret hittar du ett antal påståenden som jag vill att du tar ställning till genom att kryssa i den ruta som du känner stämmer bäst in på din inställning.

Tre efterföljande frågor

1. Vad representerar det du såg på skärmen?
Presentera sedan följande skala:
(1) Bilens självkörande funktionalitet - (2) All bilens funktionalitet - (3) Bilen som helhet - (4) Har ingen uppfattning
Varför valde du detta alternativ?

2. Finns det något du gillar med det här konceptet? Varför?
3. Finns det något du ogillar med det här konceptet? Varför?

Upprepa "2. Test" för andra och tredje konceptet.

Nu är vi färdiga med testet.

Appendix VII - Consent Form

Samtyckesformulär

Namn: ________________________________

Ålder: ________________________________

Datum: ________________________________

För att delta i studien behöver vi ditt godkännande enligt nedan:

- Du samtycker till att medverka i detta test samt svara på ett antal frågor i enkät- och intervjuform.
- Du samtycker till att vi får spela in testet samt dina åsikter på ljud och video, och ta anteckningar.
- Du samtycker till att dina personuppgifter lagras enligt personuppgiftslagen (1998:204).
- Du samtycker till att deltagande i studien sker under ett så kallat ”tystnadsavtal”. Du får inte prata om studien eller använda den kunskap du får genom att delta i denna studie till nytta för dig själv eller din arbetsgivare innan resultaten från studien är publika.

Jag har läst och förstått förutsättningarna för deltagande i denna studie. Alla mina frågor har blivit besvarade.

Välj ett alternativ nedan:

- ❏ Jag samtycker
- ❏ Jag samtycker inte

Underskrift: ________________________________

Appendix VIII - Questionnaire

Ta ställning till följande påståenden:

Jag förstår den information som bilen ger mig.								
Håller inte alls med	○	○	○	○	○	○	○	Håller helt med
Jag förstår bilens intentioner.								
Håller inte alls med	○	○	○	○	○	○	○	Håller helt med
Jag tycker att bilens gränssnitt är onödigt komplext.								
Håller inte alls med	○	○	○	○	○	○	○	Håller helt med

Kryssa i den ruta som bäst stämmer överens med din upplevelse av systemets utseende

Maskinlik	○	○	○	○	○	○	○	Människolik
Stel	○	○	○	○	○	○	○	Dynamisk
Artificiell	○	○	○	○	○	○	○	Naturtrogen
Omedveten	○	○	○	○	○	○	○	Medveten

Ta ställning till följande påståenden:

Bilen kan känna av vad som händer omkring den.								
Håller inte alls med	○	○	○	○	○	○	○	Håller helt med
Bilen kan förutse potentiellt riskfyllda situationer.								
Håller inte alls med	○	○	○	○	○	○	○	Håller helt med
Bilen kan planera en rutt väl.								
Håller inte alls med	○	○	○	○	○	○	○	Håller helt med
Bilen är kompetent.								
Håller inte alls med	○	○	○	○	○	○	○	Håller helt med

Ta ställning till följande påståenden:

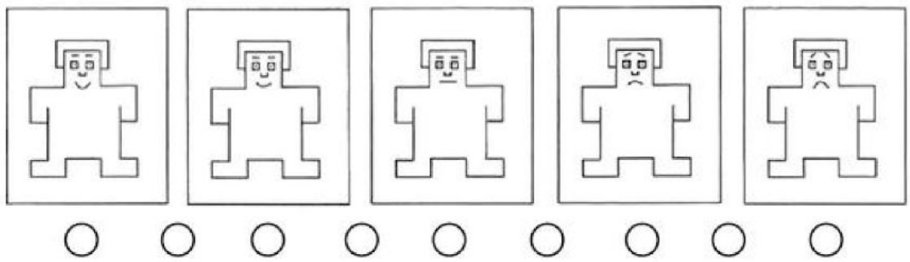
Jag skulle vilja använda systemet om det var tillgängligt i min egen bil.								
Håller inte alls med	○	○	○	○	○	○	○	Håller helt med
Jag tror att systemets handlingar kommer ha en positiv inverkan på min egen körning.								
Håller inte alls med	○	○	○	○	○	○	○	Håller helt med
Jag anser att systemet tillför säkerhet i körningen.								
Håller inte alls med	○	○	○	○	○	○	○	Håller helt med
Jag anser att systemet är driftsäkert.								
Håller inte alls med	○	○	○	○	○	○	○	Håller helt med
Jag kan lita på systemet.								
Håller inte alls med	○	○	○	○	○	○	○	Håller helt med

Jag anser att det jag ser på skärmen representerar:

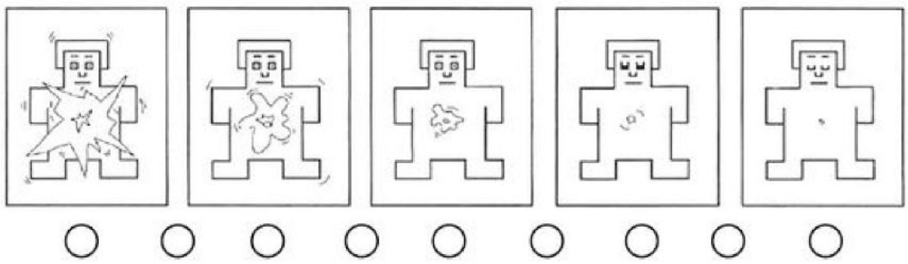
○ Bilen ○ Någon/något som kör bilen åt mig ○ Annat: ________________ ○ Har ingen uppfattning

TS: C: R:

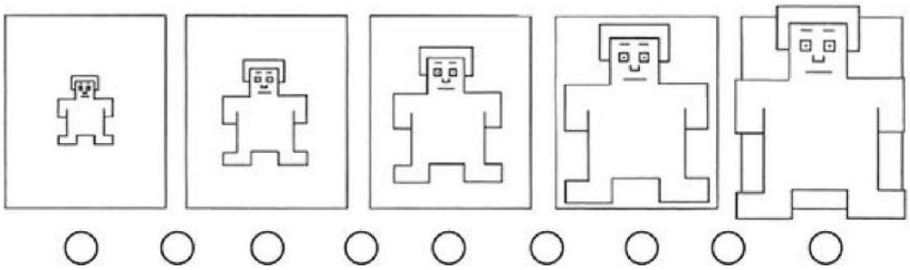
Behag



Upprymdhet



Kontrollkänsla



Appendix IX - Post-test Interview Guide

Post-test

1. Hur kändes det här? Öppen fråga
2. *Introducera medierande objekt: Bilder på de tre koncepten.*
3. Rangordna koncepten utifrån hur mycket du gillar vardera koncept (1=gillar mest, 3=gillar minst). Tänk högt!
4. Varför rangordnade du koncepten på detta vis? (Vad är positivt/negativt med koncepten?)
5. Rangordna koncepten utifrån hur mycket du litar på vardera koncept (1=litar mest på, 3=litar minst på).
6. Varför rangordnade du koncepten på detta vis?
7. Är det någonting i något av koncepten som du hade velat förändra? Varför?
8. Hur självkörande tror du att bilen är?
9. Har det här ändrat din bild kring autonoma bilar? Varför?

Appendix X - Affinity Diagram

Legend		**Criteria**	
Required		How applicable is the consideration to HMI design / this project?	
Desired		How severe may the consequences be if one overlooks this consideration?	
Cosmetic or N/A		How many times has it been mentioned?	
Condition	**#**	**Finding**	**# Subjects /11**
1. Trust & Perceived Competency			
1	1:1	Specificity in object recognition may lead to a higher level of trust in the system	3
2	1:4	Conveying non-human characteristics may be meaningful in order to achieve an appropriate level of trust in the system	
All	1:5	Trust in the system may decrease if the system does not consider when or if the driver needs information. Mutual trust between driver and system is hence needed for trust to grow	2
	1:15	If the perceived competency of the vehicle is lower than the driver's own perceived ability, they will distrust the system which may lead to disuse	
2	1:17	The quality of the visual appearance and the verbal communication of an agent has a high impact on perceived competency	8
2	1:2	Communication that gives associations to old technology may decrease trust in the system	
3	1:6	A high degree of anthropomorphism may lead to an increased level of trust	
3	1:7	A high degree of anthropomorphism may lead to overtrust in the system	
3/All	1:8	The system may not need to be embodied as an agent in order for trust to grow. Trust in the system may not depend on the embodiment of an agent, but rather ...	6
	1:10	...the interface content	
	1:11	A high degree of anthropomorphism may lead to a decreased level of trust due to the association with the human factor.	
	1:14	Low perceived reliability of automation may lead to low trust in the system	
2	1:16	A higher degree of anthropomorphism may be associated with a higher degree of consciousness	
2	1:3	Initally low trust in technology in general may lead to decreased trust in the system, especially when the system is embodied with no or low degree of anthropomorphism	
	1:9	...the underlying functions	

	1:12	Choices made by the vehicle and their alignment with the driver's driving pattern and moral standpoints may affect trust in the system	
	1:13	The predictability and repetitiveness of automation may lead to higher trust in the system, compared to human drivers	
2. Usability			
All	2:1	Visual information can be perceived more rapidly compared to auditory information	2
All	2:3	The driver may want interface content such as vehicle speed, acceleration, destination, ETA, surrounding environment (with classification)	5
All	2:4	A high frequency of information prompts may lead to distraction or annoyance	5
1	2:5	The interface content may have been perceived as ambiguous	1
1	2:6	Consise text may be efficient for rapid perception of interface content	2
2	2:7	A face and its expressions, e.g. staring, may distract the driver	10
	2:9	Higher degree of anthropomorphism in terms of visual embodiment attributes means that more information is presented to, and needs to be interpreted by, the driver	3
	2:10	Vehicle intentions may be less distracting if presented in different ways based on the urgency of the situation	3
	2:11	Colours used in visual presentations of interface content need to be clear and contrasting to each other	
	2:12	The system cannot rely on auditory or visual information alone	2
	2:13	Knowledge in the head: drivers may be more prone to understand and prefer information presented in ways they are accustomed to	2
All	2:2	An icon based interface may lead to a more efficient perception of interface content	3
	2:8	A combination of natural verbal information and an icon based visual representation may be optimal to achieve efficient communication and a high level of system awareness	3
3. Personalisation			
	3:1	The driver may, due to passengers, impairments, personal preferences, driving situation etc., want to customise interface settings such as...	8
	3:2	...auditory alerts	
	3:3	...verbal information	
	3:4	...voice	
	3:5	...language	
	3:6	...text	

	3:9	The content and characteristics of the interface may have to change over time as a result of the driver experience.	3
	3:7	...text format, such as font, size, and colour	
	3:8	...agent face	
	3:10	People may want to drive manually because they enjoy driving, or because they like to be in control	
	3:11	People may want the option to regain control by having access to a steering wheel and pedals	
4. Modalities			
			8
	4:1	Verbal communication needs less interpretation compared to icons and earcons	
	4:2	Verbal communication facilitates the driver's visual scanning of the environment surrounding the vehicle	
	4:3	A highly anthropomorphic agent (verbal and visual representation) may be more effective in conveying instructions	5
	4:4	Visual information may be more easily overlooked than auditory information	4
	4:5	Visual information may be less intrusive but available on demand for the driver	
	4:6	Auditory alerts may be considered annoying	3
	4:7	Auditory alerts are not direct carriers of information and require knowledge in the head to be interpreted	
	4:8	Auditory alerts may be effective in capturing the driver's attention	
5. Emotions (SAM)			
	5:1	A notion of not being in control may lead to frightened drivers	
	5:2	Concise information may lead to satisfaction	
	5:4	The feeling of being stared at may be unpleasant	3
	5:3	A high degree of anthropomorphism may lead to a notion of less control for the driver	
	5:5	The notion of that an agent is staring at the driver, will decrease with the degree of anthropomorphism of the agent.	
6. Embodiment			
	6:4	If the embodiment does not correspond to the expectations related to the mental models of the driver, it may lead to a negative reaction	
	6:6	A high degree of anthropomorphism may increase the intensity of a focal point	

	6:1	People's preconceptions about technology/automation may play a big part in if they see the interface characteristics as a representation of an an agent or not	5
	6:2	A high degree of anthropomorphism may lead to a conception of the vehicle and the agent as two separate entities	6
	6:3	An insufficient mental model of the vehicle and its functions may lead to uncertainty regarding the agency	1
	6:5	The self driving functions may, as a means of explaining the vehicle's behaviour, be interpreted as an agent driving the vehicle	4
7. Test Design			
	7:1	The test was not successful in creating situations perceived as safety critical, i.e. situations where accurate and timely feedback from the system has a big impact on trust	
	7:3	Test setting (sealed off area, test course, regular people, technology problems) may have contributed to a feeling of safety	
	7:2	Short exposure to the test situation may not have been sufficient in order to make a judgement of trust in the system	
	7:7	Test subjects not starting the car themselves may have led to a feeling of test leaders being in control	
	7:4	Not being able to drive in exactly the same manner between laps may have contributed to a feeling of the car not being self-driving	
	7:5	Although the pedestrian locations were randomised between concepts, the subjects learned what would happen and could anticipate what was going to happen on the second and third laps	
1	7:6	One test subject perceived one of the concepts to be of higher quality, which affected their view of the system performance	

Appendix XI - Evaluation of Metaphors

Metaphors

TEAM PLAYER

HUMAN: TEAM PLAYER
VEHICLE: TEAM PLAYER

"Good team players make their activities observable for fellow team players, and are easy to direct"

Dekker & Woods, 2002

"users need to be able to see what the automated agents are doing and what they will do next relative to the state of the process, and users need to be able to re-direct machine activities fluently in instances where they recognize a need to intervene."

Christoffersen & Woods, 2004

The team player metaphor is concerned with how to make humans and automation get along together, instead of dividing up work between them. The team player proposal involves a blend of human and vehicle action throughout the driving subtasks, including shared authority. Still, human operators preserve their strategic role in managing system resources as they see fit given the circumstances.

The metaphor points to specific qualities of team work such as communicating in terms of intentions, agreeing on a common ground, showing reasoning, expressing limits of performance etc.

Personal Assistant

Human: Boss
Vehicle: Personal Assistant

The human driver is superior to the vehicle, but relies on it to perform everyday tasks efficiently. As a secretary can bring you coffee and remind you of a meeting, the vehicle may suggest ordering take away on your way home or remind you to pick up your dry cleaning.

THE H-METAPHOR

HUMAN: RIDER
VEHICLE: HORSE

"Pull up the slack, and you're in control. Let them loose, then the car is. The point of the metaphor isn't just control, but also safety: With a horse, even when it's trotting on loose reins, you know that it's own self-preservation will stop you both from going over a cliff."
Kuang, 2016

Likens the operation of an autonomous vehicle to riding a horse, as the horse is currently the best example of a means of transportation with non-human intelligence. The metaphor focuses on the multimodal experience of the direct interaction between human and horse: the physical control by means of reins, feel of movement, horse's ears, spoken commands etc. This interaction lets the rider shift their attention elsewhere, without loosing awareness of what the horse is doing. The metaphor also covers collaboration in a wider perspective including learning how to ride, and long term aspects like social bonding.

THE OTHER H-METAPHOR (HUSBAND METAPHOR)

HUMAN: MARITAL PARTNER
VEHICLE: MARITAL PARTNER

"My husband is an autonomous driver. I trust him to drive by himself every day; I never worry once about his capabilities. However, when I sit next to him in the passenger seat, I also participate in driving. I help make decisions about where to go, and suggest alternative routes to take. I warn about potential issues and point out latent hazards that I think my husband might not see."
Ju, 2015

Proposed as a reaction to the original H-metaphor, which was perceived too focused on wresting of control and tightly mointoring actions in dangerous situations. The husband metaphor instead highlights the tasks of negotiating activities, communicating and reconciling disparate perceptions of the environment, anticipating actions and managing attention to foster a collaboration that combines the vehicle's and the user's talents synergistically.

Mapping of metaphor characteristics

STEP 1: EXPLORE THE METAPHORS

Metaphors used:

- Team player/Captain
- Personal Assistant
- The Horse
- The Husband

DISCUSS AND ENACT THE METAPHORS

Look at the suggested metaphors and try to identify which you think are relevant to act as a starting point for the interaction between human and a SAE level 3 automated vehicle. Explore and discuss the metaphors, maybe try to enact. Do a play exploration with the different scenarios. Do one enactment for 2-3 of the metaphors and see how they differ.

Make short notes of the discussion:

Customisation: to what extent can the driver affect the vehicle's communication?

not at all — very much

Adaptability: how well does the vehicle adapt to the individual driver's needs and preferences?

not at all — very much

Identity: which level of identity does the agent have?

no identity — vehicle identity — separate identity

TRANSLATE THE METAPHORS INTO INTERACTION PARAMETERS

Consider the metaphors that you have chosen, and rate them on the scales below by placing an X. What does the metaphor say about how the vehicle should behave in relation to the human for these parameters?
Rate different metaphors using different colours!

Transparency: how much information does the vehicle share in terms of intentions and motivations?

vehicle very restrictive — vehicle very open

Proactivity: when does the vehicle provide information; proactively when it sees fit or only upon request?

reactive vehicle — proactive vehicle

Representation: in what way is the intelligence of the vehicle represented/embodied?

abstract form — human-like

Intimacy/familiarity: what should the tone of the interaction be?

warm and friendly — professional/systemlike

Medium: which mode of communication does the interaction rely on?

spatial and physical (body language) — verbal/language-based

Hierarchy: who makes the decisions?

vehicle submissive — vehicle & human peers — vehicle dominant

Evaluation of metaphors

Table: Evaluation matrix of the four metaphors, selecting Personal Assistant as the most suitable metaphor.

Metaphor/Criteria	**Team player/Captain**	**Personal Assistant**	**The Horse**	**The Husband**
Adaptability	3	5	4	2
Customisability	3	5	1	2
Personality intrusiveness	4	4	2	4
Total score	**10**	**14**	**7**	**8**

Appendix XII - Full AVID Model

AVIDModel

Visual · Auditory · Haptic · Attention · Information

External State	Initial Strategy	Final Strategy (Cabin State): Noisy & Distracted Limited attentional resources and distracted driver	Final Strategy (Cabin State): Noisy & Focused Limited attentional resources but focused driver	Final Strategy (Cabin State): Calm & Relaxed Driver relaxing and not focusing on driving situation	Final Strategy (Cabin State): Calm & Focused Driver monitors environment and is not distracted
Imminent Need Immediate driver action required <1 min	Intrusive auditory display to capture driver's attention. Concise and easily perceived visual display.	Haptic display added to capture attention.	Haptic display added to capture attention.	Haptic display added to capture attention.	Initial strategy unchanged
Impending Need Driver action required soon 1-10 min	Semi-intrusive auditory display to capture attention and inform driver. Redundant visual display.	Haptic display added to capture attention.	Haptic display added to capture attention.	Haptic display added to capture attention.	Initial strategy unchanged
Distant Need Future driver action required for vehicle to function >10 min	Non-intrusive auditory display to capture attention. Consise and optionally detailed visual information is accessible.	Initial strategy unchanged	Initial strategy unchanged	Initial strategy unchanged	Initial strategy unchanged
Voluntary Action Driver action not required, but may be desired	Non-intrusive auditory display to capture attention. Consise, and optionally detailed, visual information is accessible.	Initial strategy unchanged	Initial strategy unchanged	Initial strategy unchanged	Initial strategy unchanged
No Action Driver action not required or desired	Continuous, consise, and optionally detailed visual information is accessible.	Initial strategy unchanged	Initial strategy unchanged	Initial strategy unchanged	Initial strategy unchanged
Training Driver training required	Explanatory visual and auditory display, accessible depending on situation.	Initial strategy unchanged	Initial strategy unchanged	Initial strategy unchanged	Initial strategy unchanged

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2017

Phone: + 46 (0)31 772 10 00
Web: www.tekniskdesign.se