THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

DEMYSTIFYING THE BLACK BOX

EXPLORING HOW USERS MAKE SENSE OF FULLY AUTOMATED VEHICLES

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ABSTRACT

Vehicles are becoming increasingly automated. Already today vehicles are able to take over and assist the human driver in certain driving tasks, and the scope of technical possibilities is rapidly expanding. However, for the proliferation of AVs to occur, there are several challenges that must first be overcome. These challenges are not only structural, including regulations and technological development, but also user-related, such as the adoption of and willingness of users to use the system. Previous research has identified the importance of user understanding of Automated Vehicles (AVs), as this affects usage directly as well as indirectly by impacting acceptance. In this thesis, a design approach has been chosen that uses a product semantic framework as the basis for addressing the issue of user understanding with the aim of exploring how users make sense of the AV. The research presented is based on data from a quasi-experimental study, conducted using a seemingly fully automated (WOz) vehicle on a test course where participants' understanding was investigated both during and after the test runs.

The findings show that use of the AV gave rise to several levels of meaning, based on two different processes. The main one was an external process, where integration of the participants' conceptual models of human drivers and AVs, artefactual signifiers, and situational signifiers in a context developed meaning. However, an internal process was also evident, where meanings themselves developed new meanings. This thesis presents a tentative model based on the findings, describing three important components: the user's conceptual model, the signifiers, and the meanings that arise during usage of the AV. The model illustrates the complex interplay between these three components and can be used to better understand and investigate how users make sense of AVs to aid the design and development of AVs.

The thesis also contributes to the field of product semantics through the practical application of product semantic theories, in addition to providing further insight into how users develop meaning and make sense of artefacts, by describing the processes and components which seem to be the foundation when making sense of artefacts.

Having said that, further studies need to explore in greater detail the dynamics of the process of making sense, the process of making sense in partially automated vehicles, and how meaning changes during a prolonged usage.

Keywords: Driving automation; Automated vehicles; Make sense; Product semantics; Understanding; Meaning; Signifiers; Conceptual model

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APPENDED PAPERS

PAPER A

Johansson, M., Ekman, F., Karlsson, M., Strömberg, H., & Bligård, L-O. (2020). Talking Automated Vehicles – Investigating Users' Understanding of an Automated Vehicle During Initial Usage. *Submitted to MOBITAS: 3rd international conference on HCI in mobility, transport and automotive system.*

Contribution: Johansson, Ekman, Karlsson, Strömberg and Bligård planned the study. Johansson and Ekman conducted the study and data analysis with assistance from Bligård, Karlsson and Strömberg. Johansson wrote the paper with guidance from Karlsson and feedback from the other authors.

PAPER B

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ADDITIONAL PAPERS

Ekman, F., Johansson, M., & Sochor, J. (2016). To See or Not to See: The Effect of Object Recognition on Users' Trust in Automated Vehicles. *In Proceedings of the 9th Nordic Conference on Human-Computer Interaction (p. 42). ACM.*

Ekman, F., Johansson, M., & Sochor, J. (2018). Creating Appropriate Trust in Automated Vehicle Systems: A Framework for HMI Design. *IEEE Transactions on Human-Machine Systems, 48(1), 95-101.*

Ekman, F., Johansson, M., & Karlsson, M. (2018). Understanding Trust in an AV-context: A Mixed Method Approach . *In Proceedings of the 6th Humanist Conference, The Hague, Netherlands, 13-14 June 2018.*

Strömberg, H., Ekman, F., Bligård, L-O., & Johansson, M. (2019) Keeping a finger in the pie - Exploring different collaborative interactions with autonomous vehicles. *In Proceedings of the 31st European Conference on Cognitive Ergonomics , p. 118-126*

Ekman, F., Johansson, M., Bligård, L-O., Karlsson, M., & Strömberg, H. (2019) Exploring automated vehicle driving styles as a source of trust information. *Transportation Research Part F: Traffic Psychology and Behaviour. Vol. 65 (August 2019), p. 268-279*

TABLE OF CONTENTS

"Now this is not the end. It is not even the beginning of the end. But it is, perhaps, the end of the beginning."

- Sir Winston Churchill

01
INTRODUCTION

1.1. Background

Automation in transportation has existed for more than 100 years, starting in aviation in the early 20th century. Already in 1914 Lawrence Sperry conducted the first flight with his gyroscopic stabilizer, designed to improve stability and control (Scheck, 2004). Later, in 1929, James Doolittle undertook a 15-minute flight and landed using navigational instruments only and in 1964 the first fully automated landing of an aircraft took place. More recently, automation has been adopted by the automobile and technology industries (for instance by software developers) to support human drivers and make traffic more efficient. The pursuit of automated vehicles (AVs) is mainly driven by potential benefits for the driver in reducing stress and improving productivity (Litman, 2018), by removing much of the previous primary task of driving, and with positive impact on traffic safety since driver errors are believed to be the main reason behind more than 90% of all collisions (Fagnant & Kockelman, 2015). Other potential benefits are inclusion of drivers with disabilities who are currently not able to drive by themselves (Dokic et al., 2015) and optimization of traffic flow, leading to reduced fuel consumption and less congestion (Anderson et al., 2016; Dokic et al., 2015).

However, for AVs to be fully implemented and for society to reap the benefits, there are several accompanying challenges that need to be overcome regarding data security, legal issues, liability and safety issues (Dokic et al., 2015). There are also other equally pressing challenges which are sometimes overlooked, relating to use of the technology, which are crucial in order for users to be willing to adopt and see the value of using the technology. One fundamental aspect that has been identified is user understanding of the AV. Understanding affects use not only in a direct way (e.g. users' understanding of the capabilities of the AV will affect their usage of the AV), but also in an indirect way by affecting users' trust in and perceived usefulness of AVs, which in turn may affect user acceptance of the technology (Ghazizadeh et al., 2012).

Regarding direct effect, it has been noted that initial understanding of the system affects how users later interact with and understand the system. It has also been found that even though insufficient understanding seems to calibrate over time, it is still a safety-critical issue (Blömacher et al., 2018). Furthermore, researchers have also highlighted the importance of users to understand their role in the AV and the need to make users aware of AV capabilities, adjusting their expectations

to match actual capability (e.g. Kyriakidis et al., 2019; Seppelt et al., 2017). There is some concern that confusion between how users understand a situation and the reality of that situation may cause automation-related collisions similar to what we have previously seen for instance in aviation (Kyriakidis et al., 2019; Stanton et al., 2011). Similarly, Saffarian et al. (2012) argue that automation does not control the vehicle in the same way as a human does and that unclear understanding of the automated system's functional limitations could induce a failure to reclaim control of the vehicle when operating outside its capabilities.

Furthermore, studies on the indirect effect of user understanding show that poor understanding of how automation and environment interact may lead to either too little or too much trust, which in turn may lead to misuse and disuse (Parasuraman & Riley, 1997; Seppelt & Lee, 2019), i.e. using the system in an unintended way or not using it. Increasing the user's understanding by providing information about the AV's capabilities has been shown to increase overall trust in the system (Khastgir et al., 2019). Moreover, a study by Seppelt and Lee (2019) showed that a more correct understanding, in the form of a more accurate mental model of AV behaviour, led to more appropriate reliance behaviour in situations where the system reached its operational limits.

Thus, previous research shows that users' understanding affects how they interact with AVs, making understanding a key aspect to investigate so as to be able to develop AVs that are safe and that users are willing to adopt. However, even though the importance of user understanding has been identified, only limited research has been conducted on how users actually understand AVs. Understanding is a very complex phenomenon that is hard to define, and different disciplines have different views. Previous research has had more of a human factors or cognitive science perspective, often focusing on users' mental models and knowledge about AV system capabilities, such as limitations. Many of these studies have investigated safety and performance-related aspects of AVs, where users often have a clearly defined task. However, they have not considered the effects of understanding on users' overall experience of the AV or the nature of this understanding itself. Furthermore, earlier studies have also often not considered how the AV, communicates its functions and purpose in different ways.

In this thesis, a product design perspective with product semantics as a theoretical framework has been chosen to broaden the concept of user understanding of AVs, by exploring the diversity of user understanding and by analysing how the artefact itself, that is to say the AV, communicates its functions and purpose. The way we understand artefacts is strongly connected to what artefacts mean, prompting us to always act in accordance with what that meaning is (Krippendorff, 2006). The meaning is believed to be developed in a process of making sense – in other words the process of developing a coherent understanding of the meaning associated with the artefact in a certain context (Evans & Sommerville, 2007; Krippendorff, 1989). The aim of this thesis is therefore to explore how users make sense of AVs and the meaning that arises when using the AV. The overarching research question of the thesis is thus as follows:

How do users make sense of the AV?

1.2. Thesis Structure

The thesis is organised into following six chapters:

01 Introduces the subject and the research question the thesis aims to answer.

02 Presents the theoretical framework that have been chosen to conceptualize users' process of making sense and to aid analyses of the findings.

03 Describes the research approach and the method used to answer the research question.

04 Presents and discusses the findings from the analysis in order to answer the research question.

05 Reflects on the implications of the findings and the relevance and consequence of the methodology used.

06 Presents the conclusions and contributions to the area of users' understanding of AVs and field of product semantics.

THEORETICAL FRAMEWORK

This chapter will present the theory considered for this thesis and the theoretical framework that is used to analyse the empirical research results in order to understand how users make sense of AVs, as well as to organize the findings into a coherent synthesis.

2.1. Understanding and Mental Models

Understanding is a very complex construct that is hard to conceptualize and define. In broad terms understanding can be defined as "the awareness of connections between internal mental structures" (Duffin & Simpson, 2000, p. 416). Thus, understanding about a certain domain can be considered as the knowledge about connections between the different phenomena in the domain (Gijsbers, 2013). Duffin and Simpson (2000) suggest that understanding is (i) a process framing the formation of the connections, (ii) the state of connections at a given time, and (iii) the use of available connections. Thus, understanding involves the development of, the state of, and the use of connections between different phenomena in a domain. There are numerous ways in which understanding has been conceptualized depending on the subject and purpose of the researchers.

In AV research, one common way to conceptualize and approach understanding is mental model theories (Wolf, 2016). Mental model is a concept originating from the field of cognitive psychology and originally often used for research into problem-solving. It can be defined as an internal representation of the environment that allows users to describe, explain and predict current and future states of a system (Johnson-Laird, 1983; Rouse & Morris, 1986). Several studies have investigated how mental models of AVs are affected by a variety of factors such as initial information (Blömacher et al., 2020), and feedback from the vehicle (Boelhouwer et al., 2020; Seppelt & Lee, 2019). As mentioned in the introduction, many of these studies have used mental models to investigate safety- and performance-related aspects of AVs but have not examined the nature of that understanding itself. However, to be able to develop successful artefacts it is important to understand the diversity of user understanding, especially when there are novel users (Krippendorff, 2004) as in the case of AVs. Therefore, it is important to understand how users understand the AV in order to know under which conditions users will use the artefact as intended by the developers. Furthermore, since earlier studies have also often focused on goal-oriented situations with clearly defined tasks, where cognitive model theories are

very helpful, they have not considered the effects of user understanding of AVs on their overall experience of the AV. Finally, earlier studies have often not considered how the artefact itself communicates its functions and purpose in different ways. This thesis aims to broaden the concept of user understanding compared with earlier studies by exploring the diversity of user understanding, and also by examining in what way the artefact itself communicates its functions and purpose. Therefore, a framework based on product semantics was chosen for the thesis.

2.2. Product Semantics

Product semantics originates from semiotics, i.e. the study of signs. Product semantics was originally defined as "the study of the symbolic qualities of man-made forms in the context of their use…" (Krippendorff & Butter, 1984, p. 4) and concerns how products communicate their function and purpose. This communication can be seen as the interplay between designer and user, where the designer has an intention that is embodied into an artefact which, in turn, a user makes sense of when interacting with it (Krippendorff, 1989). Something makes sense when "we understands the role it plays in a particular context or situation, when we have a coherent explanation of why it is there, what we do with it, and what it does to us" (Evans & Sommerville, 2007, p. 2). Making sense of artefacts is a circular cognitive process that may start by sensing something and imagining possible contexts. During the process, features of the artefact and contexts are distinguished and meanings are created in a hermeneutic circle, developing increasingly meaningful distinctions, until a sufficiently coherent understanding is reached (Krippendorff, 1989). Thus, making sense of an artefact is regarded as the process of developing a coherent understanding of the meanings associated with the artefact in a certain context.

> **Product Semantics** - the study of the symbolic qualities of man-made forms in the context of their use.

> **Making sense of an artefact** - the process of developing a coherent understanding of the meanings associated with the artefact in a certain context.

The designer's role is to design artefacts that are easy to make sense of so that intended use becomes clear and incorrect usage is prevented (Parmentier et al., 2020). However, meaning is inherently subjective. The meaning that will arise in the interaction with a product is difficult to predict and there are often considerable variations in how people make sense of things in their surroundings (Boess & Kanis, 2008). Additionally, the meaning users develop is often different from the intentions and expectations of the designer (Khalaj & Pedgley, 2019; Suchman, 1987). Therefore, the main focus of product semantics is to understand "how people attribute meaning to artefacts and interact with them accordingly" (Krippendorff, 2006, p. 2). Meaning therefore becomes a central concept in the process of making sense.

2.3. Artefact Meaning

The way we understand artefacts is strongly connected to what they mean to us. It is suggested that we do not perceive artefacts as pure form or unrelated objects but rather as meanings and, furthermore, that we always act in accordance with what that meaning is (Krippendorff, 2006). There is a wide range of approaches to, and

definitions of, meaning but product meaning has no universally accepted concept or definition (Kapkin, 2016).

The meaning of an artefact can be seen as subjective interpretations regarding what the artefact is and the artefact's relationship to the user and context. One artefact can thus consist of several types of meanings of different character. Khalaj and Pedgley (2019) identified four types of meaning: (i) connotative meaning (figurative descriptions and personality characteristics), (ii) sensorial meaning (literal descriptions of physical properties), (iii) meaning of interaction (descriptions of product functionality and usability arising through interaction), and (iv) affective meanings (emotive associations). Furthermore, Kapkin (2015) states that meaning might refer to utilitarian features and functions that users act upon, personalities of products, or an overall experience. In addition to describing different types of meaning , Kapkin (2016) also presents a model that suggests that meaning exists at three levels. At level one there are meanings that are evoked by affordances, functionality and utilitarian features as well as some meanings that result from sensorial experiences. Level two refers to meanings of how well the product informs about itself and its functions in a certain context. These meanings are often evoked during interaction and are solution-specific or may relate to style (e.g. 'modern' office chair). Lastly, third level meanings often occur after prolonged interaction or experience but can also be evoked spontaneously due to a match with the user's values or self-image. They may refer to cultural values and social status.

> Meaning of an artefact - subjective interpretations regarding what the artefact is and the artefact's relationship to the user and context.

A synthesis of the levels and different types of meaning is presented in Table 1. The table shows the different types of meaning, presented earlier in the section, organized into the three levels presented in Kapkin (2016), followed by the naming used in the thesis. The naming of the different types of meanings in the thesis are sometimes the same as or similar to concepts presented in earlier research but have other times been altered, to better fit the way the type of meaning is described in the thesis.

Kapkin, 2015; 2016		Khalaj & Pedgley, 2019	This thesis
Level 3	An overall experience	Affective meanings	Experience meaning
Level 2	Personalities of products	Connotative meaning	Artefact type meaning
		Meaning of interaction	Utilitarian meaning
Level 1	Utilitarian features and sensorial experience	Sensorial meaning	Sensorial meaning

Table 1
Synthesis of the different levels and types of meaning.

The first level of meanings consists of Sensorial meanings, which are interpretations of sensorial experiences. At level two there are two types of meaning related to interplay; meanings relating to (i) what the artefact is (Artefact type meaning), such as figurative descriptions and artefact characteristics, and (ii) the artefact's relationship with the user (Utilitarian meaning), such as descriptions about functionality, which often arise during interaction with the artefact. The third level meanings, Experience meaning, are often but not always evoked after a longer experience with the artefact and relate to an overall experience that may include emotive associations. An overview can be seen in Figure 1.

Lvl 3 — Experience

Lvl 2 — Artefact Type — Utilitarian — INTERPLAY

Lvl 1 — Sensorial
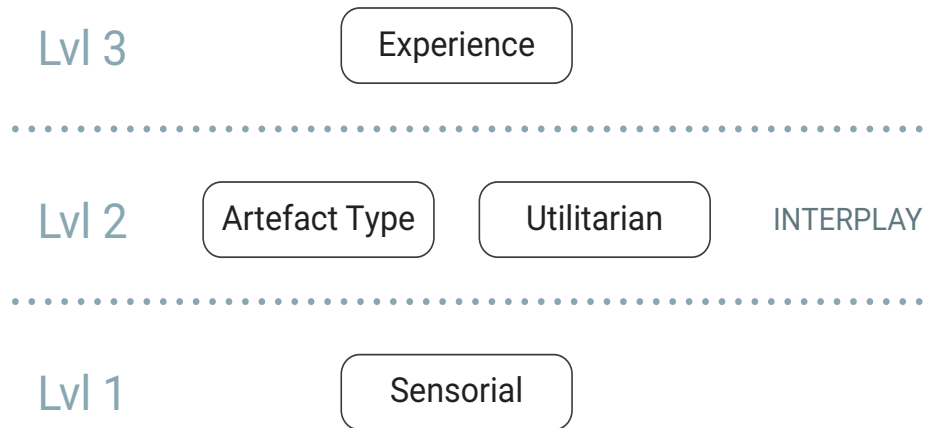
2.4. The product, its signifiers and functions

Product semantics advocate that the physical qualities of the product, the context of use and the user's cognitive abilities are all important influencers in the development of meaning (Kapkin, 2016). Therefore, it is important to take all these three components into consideration when investigating the meaning that arises during interaction with the artefact.

Every product has a practical function, i.e. the function which the product was intended to provide. As such the product serves instrumental needs such as being reliable and reparable. However, products can also be considered to work as signs, having a semiotic function. A sign is made up of a signifier, i.e. what can be seen, felt or experienced with the artefact, and a signified, i.e. the meaning that arises. Signifiers can be seen as perceptible signals to which users direct attention and interpret the artefacts in the context of their goals (Evans & Sommerville, 2007; Norman, 2013). Hence, an artefact's signifiers speak about something other than just the practical function of the artefact. These signifiers can be both

> **Signifiers** - perceptible signals to which users direct attention and interpret the artefacts in the context of their goals

intentionally designed (e.g. a symbol in the display indicating when it is time to change gear) but can also be unintentional (e.g. the sound of the engine informing the driver when it is time to change gear).

Verbeek (2005) distinguishes between two different semiotic functions: denotive and connotative. *Denotive functions* communicate the primary functions, for what and how the products are to be used in a context that allows it. He explains that "a chair refers to the possibility of sitting, at least in a context in which objects with that kind of shape are used for that kind of purpose" (p. 205). This does not only concern the product as a whole, even parts of the product can work as signifying denotive functions, showing how to interact with for example certain functions or parts of the artefact. The second semiotic category, *connotative functions*, can communicate socio-cultural values, making the product a symbol, referred to as qualities that are not literally part of the product appearance, such as 'inviting' or 'firm' (Van Rompay, 2008). However, these meanings are a substantial part of the user's experience with the product and have been seen to greatly motivate consumer

preferences (Creusen & Schoormans, 2005). In order to communicate intended meanings, via both connotative and denotive functions, designers use various "channels" (e.g. form and interface) and design elements (e.g. shape, colour and sound) to embody the artefact (Khalaj & Pedgley, 2019). However, the connection between the design of an artefact and the meaning that arises is not always obvious and even though most products are experienced as having a semiotic function, it is sometimes difficult to exactly pinpoint why that is or what in the design generates its meaning.

2.5. The users and their previous experience

Even if designers try to imbue artefacts with a certain intention through the embodiment of the artefact, meaning is not an inherent property of the product. Meaning is for example heavily influenced by geographical and cultural conventions. An artefact may mean something in one culture but something else in another but the meaning of an artefact may also differ between individuals in the same culture since users have different beliefs, motivations, expectations, capabilities and previous experiences with and understanding of similar products. Monö (1997) describes four layers that influence the attitude we have towards artefacts. The four layers are: (i) education/training, (ii) upbringing/experience, (iii) society, and (iv) the individual. Education and training give us skills to perform or understand certain tasks such as driving a car. Upbringing provides the individual with social norms and prepares them for social and professional roles. These roles give experiences that affect how we react to different situations and products. Society consists of numerous norms and values such as cultural, religious or political values, which affect how we behave and interpret the world. Individual qualities could be inherited traits, such as temperament, or physical limitations, such as colour-blindness. Thus, even if some meanings may be more general for specific signifiers, making sense is heavily influenced by individual and societal factors.

One important factor in the process of making sense is previous experiences with similar products, which creates expectations of what a product or parts of a product could mean in use. This simplified construction of reality is sometimes referred to as 'user conceptual models'. Krippendorff (2006) defines a user's conceptual model as a "network of operational concepts assumed to tell its beholder how an artefact could work, when to do what with it, and what to expect consequent to any actions taken" (p.99). Hence, the conceptual model can be seen as a collection of meanings that may arise in use, if the artefact enables the meaning to arise. Furthermore, the conceptual model is not static but is improved, revised,

> **Conceptual Model** - a complex network of meanings that may arise in use, if the artefact enables the meaning to arise.

and replaced by new ones, thus developing over time (Krippendorff, 2006). When artefacts are used, new meanings arise that may update or replace previous meanings in the conceptual model. Thus, the meaning that will arise is not only a result of the product's signifiers but also the conceptual model of the user, which is based on a complex network of experiences.

2.6. Context

However, the meaning that arises in the interaction between user and artefact is not only affected by the artefact itself and the user's experience but also by the context in which it is used. As mentioned previously, meaning is not something that is fixed – users create meaning in their interaction with product and context (e.g. Krippendorff, 1989; Suchman, 1987); context being "the surrounding conditions of something that shed light on its meaning" (Krippendorff & Butter, 2008, p. 10). However, in addition to the physical surroundings of the context, meaning is also affected by chronological surroundings (Monö, 1997). Thus, the meaning that arises when using a product can vary in different settings and also change over time. For example, a bicycle can in traffic be a means of transportation but when brought inside and hung on the wall, it can become a decoration and a bearer of socio-cultural meaning. Hence, making sense of an artefact is coupled with the context in which it is used.

> **Context** - the surrounding conditions of something that shed light on its meaning, both physical and chronological

2.7. Summary of the Theoretical Framework

To summarize the theoretical framework, the meaning of artefacts arises in a complex interplay between the user, the artefact and the context. Multiple meanings of diverse character can arise in this interaction. The meanings are the subjective interpretations of what the artefact is and its relationship to the user and context, and are suggested to exist on three levels: sensorial meanings, interplay meanings, and experience meanings. The meaning that arises is based on the artefact's signifiers, i.e. what can be sensed of the artefact, which communicates the artefact's denotive and connotative functions. The meaning that arises is equally affected by the user's individual characteristics such as preference, goals and especially their conceptual model, consisting of expected meanings based on previous experiences. However, the meaning that arises is also heavily influenced by the context, where other surrounding artefacts and users as well as time affect the meaning that arises regarding the artefact. These meanings are continuously developed, creating a process of making sense until a sufficiently coherent understanding of the meanings is reached.

RESEARCH APPROACH

This chapter describes the research approach selected for this thesis and presents the data collection methods and analysis used to answer the research question.

3.1. Introduction

This thesis is built on an analysis that was conducted using a product semantic framework as a foundation, based on data that was collected in a study as part of the HaTRIC project. The overall goal of the HaTRIC project was to generate design principles, test methods, and prototypes to understand what constitutes good HMI design for AVs. The project involved three stakeholders: Volvo Car Corporation, VTI (Swedish National Road and Transport Research Institute), and Chalmers University of Technology. Several studies were performed, from one of which the data presented in this thesis were collected. This study was carried out in cooperation with another PhD student and with several focus areas and aims that shaped the selected research approach. The study, which was conducted by simulating two different AV driving styles on a test course, aimed primarily at investigating how driving behaviour affects trust and secondarily how users understand AVs.

3.2. Data Collection

Since the technology under consideration – fully automated vehicles – does not yet exist it is impossible to study the phenomenon in a fully naturalistic setting. It was therefore necessary to simulate the technology to create an artificial future in order to place the user within a naturalistic context. A *Wizard-of-Oz approach* was used to simulate an AV so as to capture the participants' experiences in as naturalistic a setting as possible. The Wizard-of-Oz approach has been used in several AV studies to investigate parameters such as user interfaces, driving behaviour and secondary tasks (Müller et al., 2019). The Wizard-of-Oz approach used in the HaTRIC study utilized a modified car with a driver in the back seat of the vehicle, controlling the vehicle with hidden control devices. Furthermore, the study had a *within-subject design* where participants experienced the *two distinctly different driving styles*, aggressive and defensive (further explained in Paper B), on two separate test runs, in order to create different nuances of driving behaviour to see what shapes the meaning and also to see if specific configurations of driving properties give rise to specific meanings. The driving styles differed with regard to: (i) starting/stopping behaviour, (ii) acceleration/deceleration, (iii) lane positioning, and (iv) distance to

other objects (e.g. cars or pedestrians). Each test run took approximately 15 minutes and was conducted on a *test course* consisting of both a bidirectional rural road and a city area. During each test run, the participants encountered different situations such as overtaking a car or stopping for a pedestrian at a pedestrian crossing.

Eighteen participants between 20 and 50 years old with different occupations (including students, engineers, administrators, and economists) took part in the study. All participants had a valid driver's license but a mixed level of previous experience with driver assistance systems. Most had experience with cruise control, some with advanced cruise control and steering assist, and some had no experience at all. As for driving frequency, half the participants drove almost every day and the other half drove from a couple of times a week to a couple of times per year.

In order to capture rich participant narratives and acquire rich data describing their process of understanding and how they make sense of the AV, *qualitative data collection* methods were chosen. Data was collected using two qualitative data collection methods, a think-aloud protocol (cf. Charters, 2003) during the test runs and a semi-structured interview after experiencing both driving styles, in order to obtain the participants' interpretation and experiences of the AV. Thus, data collection took place both *during and after* the test runs to capture instantaneous interpretations as well as comparisons between styles and deeper reflections. The recordings of think-aloud sessions and interviews were transcribed and later analysed, grouping the data into themes, using a grounded theory approach where the themes are not predefined (Creswell & Plano Clark, 2017).

3.3. Analysis

A first analysis, described in appended Paper A, was initially conducted to explore the users' understanding of the AV. It identified the effect of pre-existing knowledge and also the influence of driving behaviour on how the AV was perceived. As a result, a second analysis, presented in Paper B, was conducted to further explore the relationship between driving behaviour and user interpretation of the AV. However, based on initial analysis of the data, it was found that cognitive model theories, usually used in AV research, were not sufficient to explain the data since a lot of the data referred to characteristics of the artefact. A product semantic framework was therefore instead chosen for the overall analysis in this thesis in order to answer the overarching research question.

The entire analysis process was divided into four steps: (i) identification, (ii) clustering, (iii) labelling, and (iv) contextualizing (illustrated in Figure 2). The two first steps were performed to explore how the participants communicated about, that is to say referred to, the AV (described in Papers A and B). However, to understand the complex construct of making sense, it is important to identify what the users' referrals could represent in that process. Therefore, the latter two steps were performed with the product semantic framework as a theoretical lens, to investigate what the referrals reveal about the users' process of making sense.
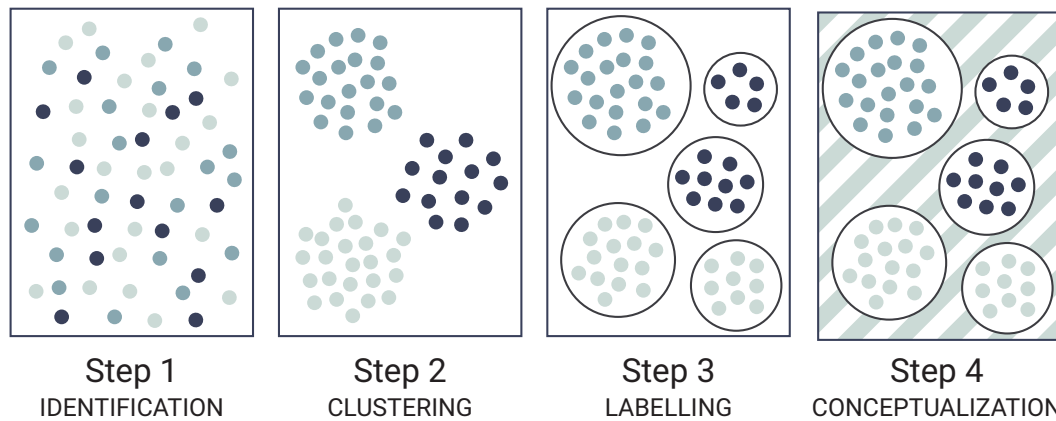
Step 1	Step 2	Step 3	Step 4
IDENTIFICATION	CLUSTERING	LABELLING	CONCEPTUALIZATION

The **first step** of the analysis – Identification – was conducted using a general inductive approach, where no predefined categories were used (cf. Thomas, 2006) and focused on identifying how users commonly referred to the AV in different ways. These referrals include ways of describing the AV (using certain pronouns and assigning attributes), the AV's driving behaviour (using similes and assessments of driving properties) and notions of what capabilities the AV has (using descriptions of what are machine-like characteristics).

The **second step** of the analysis – Clustering – revolved around clustering the referrals, identified in the first step, in order to answer how the participants refer to the AV. This was done by comparing the findings from Step 1 and clustering them into broader categories.

After the different ways of referring to the AV had been identified, the **third step** – Labelling – consisted of labelling the identified clusters in order to determine how the empirical data relates to the theory. This was conducted using more of a deductive approach, where the theoretical framework was used as a theoretical lens. The clusters identified in Step 2 were compared to the framework to identify commonalities between the character of the clusters and the theory, in order to determine what the referrals reveal about the participants' development of meaning, and also in order to discern dissimilarities between clusters and theory with the aim of identifying what is not explained by the theory. In this step, it was noted that some of the clusters fitted the theory well while others did not. Therefore, some clusters had to be split up and restructured into several new clusters since they related to several different aspects of the theory. For example, the use of similes referring to other human drivers to describe certain driving characteristics did indicate both some sort of meaning and the use of conceptual models.

In the **fourth and final step** – Conceptualisation – connections and relations between and within the clusters were analysed using the previous findings and the theoretical framework to synthesize the research. The possible connections that were identified from the way participants referred to the AV were compared with and complemented by relationships identified in the theory in order to elucidate the process of making sense.

Figure 3 shows a schematic overview of how the different parts of the analysis relate to each other and the research question.
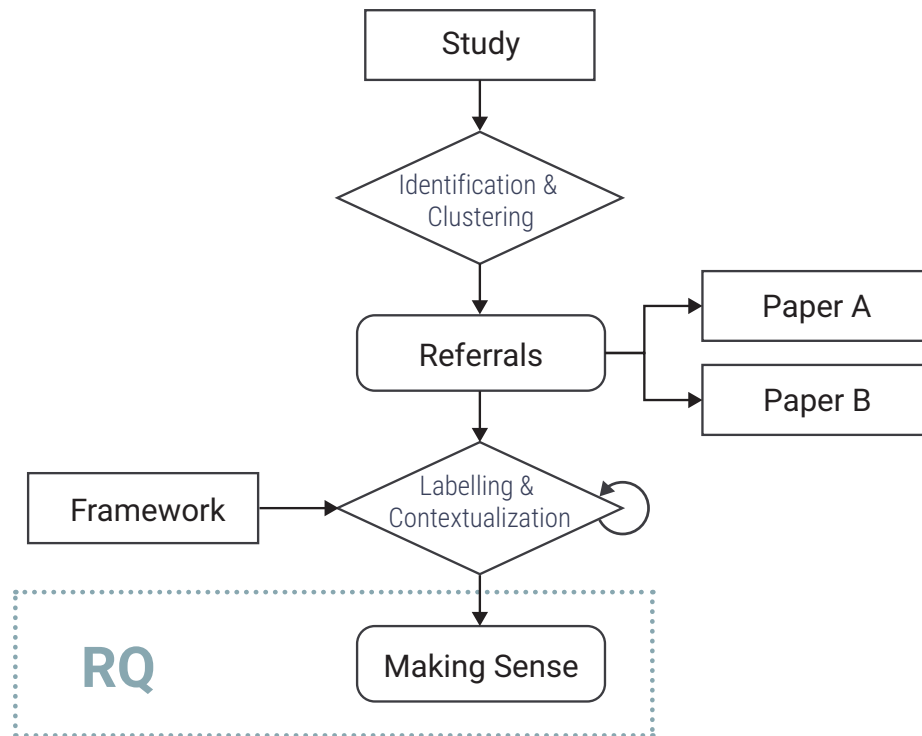
FINDINGS & DISCUSSION

This chapter aims to answer the research question 'How do users make sense of the AV?'. The theoretical framework has been used as a basis for analysing the participants' referrals in order to identify what they reveal about how users make sense of the AV and to tie the findings together into a synthesis. This is necessary in order to better understand how the user makes sense of the AV.

This chapter presents and discusses the outcome of an analysis, using referrals from the study as illustrative examples. First, the chapter presents the different meanings that are identified and their interrelations. After this the external process is presented followed by the internal process of making sense. Lastly, an identified and connected assessment process is presented and discussed.

4.1. Developed Meanings and Interrelations

The referrals the participants used indicate that different kinds of meanings arose during use of the AV, ranging from sensorial meanings to meanings about the overall character of the AV. In general, the meanings that are identified are interpretations of what the AV is rather than its relation to the user.

Meaning on all three levels, presented in the theoretical framework, could be identified. The most common meanings that arose were **meanings relating to the sensorial experience**, i.e. Level 1 meaning (to the left in Figure 4). These meanings were interpretations of, and associations with, sensorial impressions, often describing interpretations of the driving properties such as 'aggressive', 'soft' or 'jerky' (see Paper B for more details on in the interpretations of driving properties).

Furthermore, several types of meanings about the interplay, i.e. Level 2 meaning, arose, including meanings relating to functionality, abilities, awareness, and character traits, further described in paper B (in the middle in Figure 4):

- **Meanings relating to functionality** described a decision-making process that the vehicle had in order to be able to carry out the driving actions. For example, functionality such as 'seeing', 'thinking' and 'evaluating'. One participant said: "*I got the feeling that the car had seen the pedestrian*" (P8).

- **Meanings relating to abilities** involves the AV's ability to perform controlled actions and to signal intent to internal (driver) and external (other road user) actors. One participant discussed the AV's ability to have control: "*I believe that you perceive it as having more traffic control if it drives more smoothly*"

(P6) and another participant discussed the signalling: "It did not warn me that it was planning to do that. It probably reacted in a correct way but could have informed me a bit earlier so I would be prepared that something would happen" (P2)

- **Meanings relating to awareness** were interpretations of the AV being aware of itself and of its surroundings as well as understanding rules. For example, some participants interpreted the vehicle's awareness based on its movements: "*The pedestrian crossing felt very calm and safe in the first lap [referring to the defensive driving style], it really felt like it was aware of the person's position and where it was supposed to stop*" (P16).

- **Meanings relating to character traits** consisted of interpretations such as the AV being smart or professional. For example, one participant described the action of the AV as unprofessional: "*It [referring to the AV with aggressive driving style] cut corners and I do not like that. I do not think it is a professional way of driving even if it is 100 percent safe*" (P20).

In summary, the interplay meaning are interpretations of how the AV is able to perform the driving task and why it drives as it does.

Lastly, **meanings relating to the overall experience** of the AV also sometimes arose, i.e. Level 3 meaning, being an interpretation of the AV's overall character (to the right in Figure 4), where the capability and consideration of the AV can vary. This was not only evident from the way the participants described the AV using several different character traits but also in that they used similes, for instance of a 'Father', where they used past knowledge of human drivers to explain the character of the AV. Experience meanings were by far the least common, which is probably an effect of the study, where participants experienced an AV for the first time and only for a rather short period of time, thus not having the prolonged use which is often needed for this kind of meaning to develop (Kapkin, 2016).

Furthermore, it seems as though the meanings differ in abstraction, where the lowest-level meanings relate to one or several signifiers or a certain action while the highest-level meanings relate to the more overall character of the AV. These levels also differ in the temporal aspect, where the lowest-level meanings often contain statements that refer to short-term single actions, while the highest level often describes more long-term situations, such as a whole test run, or behaviours (both indicated by the scale in Figure X). This is consistent with Kapkin's (2016) three levels of meaning, which also differ in abstraction and temporal aspects.
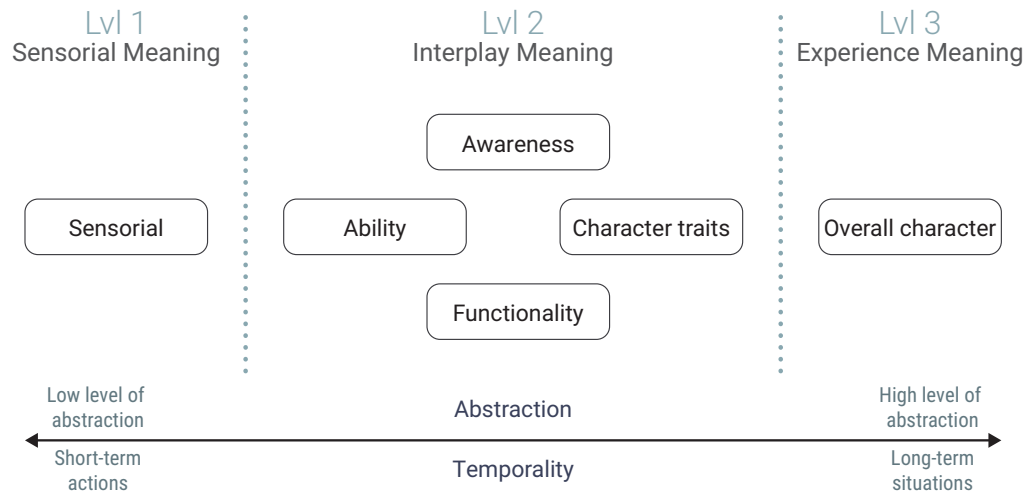
Lvl 1	Lvl 2	Lvl 3
Sensorial Meaning	Interplay Meaning	Experience Meaning

Awareness

Sensorial Ability Character traits Overall character

Functionality

Low level of abstraction — Abstraction — High level of abstraction

Short-term actions — Temporality — Long-term situations

Studies of mental models have similarly identified that users' mental models seem to consist of several abstraction levels. Hmelo-Silver and Pfeffer (2004) suggest three levels: structure (elements of the system), behaviour (how structures of a system achieve their purpose) and function (why an element exists in a given system). Similarly, Andersson (2010) proposes five levels; structure, process, function, task and situation. Because the notion of mental models shares similarities with product semantics' view of users' conceptual models, it could suggest that users' conceptual models are partly structured on abstraction levels. Consequently, a conceptual model that is structured on abstraction levels may result in meanings being distributed on several abstraction levels, since the meaning that arises during usage of the AV is partly affected by the users' conceptual model as well (as discussed later in the section 4.3). Furthermore, it is also suggested that the user's conceptual model is constantly updated with continuous experience of an artefact (Krippendorff & Butter, 2008). Hence the formation of the conceptual model may also be affected by the meanings that arise, in other words meaning distributed at different abstraction levels forming a conceptual model at different abstraction levels. This process most likely goes both ways, where the meaning and the conceptual model are mutually dependent on each other.

It is therefore evident that the meanings that arose in the interaction between the participants and the AV were diverse, ranging from sensorial meanings that often referred to short-term single actions, to experience meanings that were often more abstract and related to more long-term situations.

4.2. The Relation between Signifiers and Meaning

The analysis indicates that meanings continuously arose based on a combination of the AV's signifiers and participants' conceptual model, forming an external process of making sense. As expected because of the study setup, the driving properties were the signifiers that were noticed the most, which was evident in the large number of referrals that mentioned driving properties (see Paper B). However, even though not to the same extent, participants also sometimes mentioned other signifiers, such as the sound of the vehicle or its physical form (interior and exterior). For example, participants interpreted

17

the sound of the car shifting gear as a signal that it was preparing itself for an action.

Seemingly, signifiers gave rise to meaning in a direct way, where meaning on different levels arose based on a single signifier or a combination of several signifiers. This was most evident for the sensorial meanings which were interpretations of signifiers themselves (e.g. "*it drove smoother*" or "*the acceleration was hard*"), but it could also be seen in the higher levels of meaning. For example, for one participant meaning regarding awareness of the AV arose based on the driving property signifier: "*I believe it is driving quite smoothly and carefully since it is so much more aware of where it is*" (P12).

This makes the driving properties one of the main sources for the development of meaning in this study and an important component in making sense. This can be partly explained by the study setup, since it did not contain for example any graphical user interfaces that would otherwise probably have been important signifiers. However, the numerous meanings that arose still show that driving properties are important signifiers when participants make sense of an AV.

It is not possible to determine from the data which meaning arose from which specific signifier or combination of signifiers. However, similar sensorial meanings were often evoked by a certain driving style (e.g. acceleration was almost invariably interpreted as 'slow' in relation to the defensive driving style and 'powerful' in relation to aggressive driving). It also appears that specific combinations of signifiers resulted in different interpretations, since each of the similes used by the participants was only used in connection with a specific driving style. As described in paper A, The participants used five different similes: Driving Student and Senior Citizen were used when describing the defensive driving style, and Taxi Driver, Father and Friend Who Likes to Drive Fast were used when describing the aggressive driving style (see Figure 5 for a summary). It is therefore probable that the signifiers in the AV's driving behaviour will give rise to several different meanings for different users, because of individual conceptual models and the specific situations encountered. However, it also seems that the signifiers of the driving behaviour may give rise to certain meanings that are more general for several users, indicating that a certain embodiment of the artefact may develop specific meanings for a majority of users.

Figure 5
Summary of identified similes and associated driving styles.

Simile	Driving Student	Senior Citizen	Taxi Driver	Father	Friend
Description	Drives according to the rules but has less control of safety margins and placement.	Drives slowly and tries to drive safely but does not have full control.	Drives aggressively but at the same time comfortably.	Drives fast, with hard acceleration and deceleration, but at the same time safely.	Drives fast, with hard acceleration and deceleration, but may not have control.
Associated driving style	Defensive	Defensive	Aggressive	Aggressive	Aggressive

The outcome of the analysis also reveals that the meanings are affected by the context in which the AV operates. Context was referred to in connection with the signifiers and the meaning, and included the situations encountered (e.g. road conditions) and other road users (e.g. pedestrians and bicyclists).

18

Context seems to affect the development of meaning in two ways: firstly, since the meaning is affected by the signifiers (i.e. driving properties) which in turn are dependent on the context (e.g. other road users), the meaning becomes indirectly affected by the context. For example, the way the driving actions will be performed depends on the immediate surroundings of the AV and for the AV to be perceived as considerate towards external actors, the context needs to contain other road users. Secondly, the context also seems to affect the development of meaning in a more direct way by acting as situational signifiers, that is to say signifiers that are not part of the artefact itself. The perception of the vehicle does not seem to be affected only by driving behaviour but also by how the user interprets the AV in the context, evoking one meaning in a context with certain situational signifiers but another meaning in another context with different situational signifiers. For example, slow acceleration could in a situation involving other road users be interpreted as having control but in a situation without other road users be interpreted as 'stupid'. Thus, the context will affect the process of making sense by affecting the AV's movement and actions but also by providing situational signifiers, making it hard to separate the context and signifiers in the process of making sense.

4.3. The Influence of the Conceptual Model

As indicated in the previous section, the external process of making sense is not only affected by the direct influence of the signifiers but also by the participants' conceptual model. Several of the findings from the analysis shed light on the conceptual model of the participants in the study. Findings indicate that participants use past meanings to make sense of their interaction with the AV, which is considered to be especially important in the exploration phase in the usage of an artefact (Krippendorff, 2006), when users interpret and explore the meaning of an artefact. A finding that clearly reveals the participants' conceptual models is their preconceptions about the driving behaviour and capabilities of an AV, which is evident from the differentiation between human and machine-like characteristics of the driving behaviour (see Paper A). Thus, even if they had previously never experienced a vehicle with as high a level of automation, certain driving behaviour was regarded as machine-like which shows that prior to first usage, the participants had an idea of what it means to drive as a machine or more specifically drive as an AV. This conceptual model created expectations of driving behaviour, which could be seen in referrals where participants stated that an action or behaviour did or did not feel like a machine or an AV, that is to say matched or not match the conceptual model. For example, one participant compared their expectations about the AV's driving to a human by stating: "*It was quite jerky, and I do not expect that from a self-driving car in the same way. You expect it to be smooth and pleasant, and that the vehicle will be aware of everything. I do not expect it to drive this way, because this is something that I would associate with a human driver*" (P12).

However, besides using conceptual models of AVs, it was evident from the use of human similes and human-like characterizations (see Paper A for further details) that participants also used past experience of human driving behaviour to explain and/or interpret the AV's signifiers: "*It drove quite fast, braking, overtaking. It felt like driving with your father who was in a hurry but still drove at a speed that*

allowed you to see everything. The road was flat and there were no cars around, so it felt quite safe" (P5), indicating that the experience of human drivers is a part of the conceptual model used to interpret usage. Similar indications were present when referring to the functionality, where the participants used both human-related terms: "*it seems like he <u>saw</u> the person*" (P9) and machine-related terms: "*I believe that the technology is so good that it can <u>calculate</u> the trajectory for the roundabout without having to make sudden adjustments*" (P10), showing a technical vocabulary with varying degrees of development and probably a conceptual model of AVs whose development varies to a greater or lesser extent.

Furthermore, the descriptions inherent in the various similes used to describe either the defensive or aggressive driving behaviour differed in how much control the vehicle was perceived to have, even if the main characteristics were similar. One user could interpret the driving properties as slow and (almost too) controlled: "*The drive felt good and very respectful but to me it was a bit exaggerated. A bit like when you have just got your licence*" (P4 referring to the Defensive AV), while another participant also interpreted it as slow but considered this not safe: "*You may think that the fact that it drives slowly would give you a feeling of safety, but it also made it feel like a grandma*" (P11). In line with what was stated in the previous section, this indicates that the same signifiers could evoke different meanings about overall character in different users, possibly because of different notions about what a "good" driver is, based on individual experiences.

Hence, the conceptual model used is not only constructed based on previous meanings of the same and similar artefacts but also similar experiences and probably meanings arising from social interactions and other information sources, such as news media. This in accordance with Krippendorf's theory about meaning in language, which states that meaning is developed not only in interaction with the artefact but during other interactions as well (Krippendorff, 2006).

Thus, the **external process of making sense** consists of a continuous direct influence of signifiers that affects mostly the development of lower-level meanings but also higher-level meanings. This external process is also heavily influenced by the users' conceptual model of both human drivers and AVs.

4.4. Internal Process of Making Sense

Thus far the external process has been described, where meanings were developed based on the signifiers. However, the different levels of meaning seem to have also been affected by each other, where meanings were sometimes based on each other like a chain, thus also forming an internal process of making sense. For example, for one participant several different meanings arose based on signifiers: "*My interpretation is that it [the AV] has not noticed it [the roundabout] early enough and therefore did not have enough foresight. That is why it [the manoeuvre] becomes a bit jerky*" (P10).

From the data, it is not possible to conclude if the meanings are formed in a process which begins from the lower-level meanings and on that basis forms higher-level meanings, or if the formation process occurs in the opposite direction. Krippendorff (1989) describes instead a circular process where features of the artefact and context are distinguished and meanings are created and used to distinguish

further features, developing an increasingly meaningful understanding. This implies that the participants may have distinguished first the lower-level meaning, interpreting certain signifiers to mean something (e.g. by braking, the AV signals the vehicle's intention to the user), leading to higher-level meaning comparable to an overall artefact character (e.g. that the AV is considerate towards the user). This is comparable to the meaning attribution process that is described by Kapkin (2016), who states that the meaning may first be triggered by a sensorial mechanism but with experience, the meaning evolves and if the overall experience is satisfactory, the product may be considered "pleasurable", for example. The process can be described as in Figure 6, where the initiation, starting from low-level meaning based on sensorial influence, is depicted by the lower right arrow that starts at the signifier. However, in in the field of consumer research, it is suggested that intangible attributes (further explained in paper B) – subjective meaning – is likely to be perceived in a gestalt-like, instantaneous and holistic way since the attributes are tied to specific configurations of tangible attributes, i.e. signifiers (Allen, 2000). This implies that the higher-level meanings may also arise first, through a gestalt-like interpretation of several signifiers, creating a process of making sense that starts from higher-level meaning, depicted by the upper right arrow in Figure 6. For example, meaning initially arises regarding character, such as "competent", based on several signifiers in several situations (e.g. parts of or a whole drive), which in turn may cause meaning to arise regarding the AV's awareness and abilities. Furthermore, it is possible that a process of making sense starting from a higher level may be reinforced by pre-existing higher-level meanings in the user's conceptual model which can be seen in the participants' expectations of machine-like driving behaviour, depicted by the left arrow in Figure 6. For example, one participant described high expectations regarding the awareness of AVs: "*I think it drives calmly and carefully but I also believe that it is so much more aware [than a human driver] of where it is. I probably expect more from a car [than from a human driver]*" (P11), which may in turn evoke meanings about certain abilities that the participant expects of an aware AV, and so forth. In conclusion, it is possible to see that there exist several levels of meaning and that they affect each other in an **internal process of making sense** of the AV, which can start both from higher-level meaning and lower-level meaning.
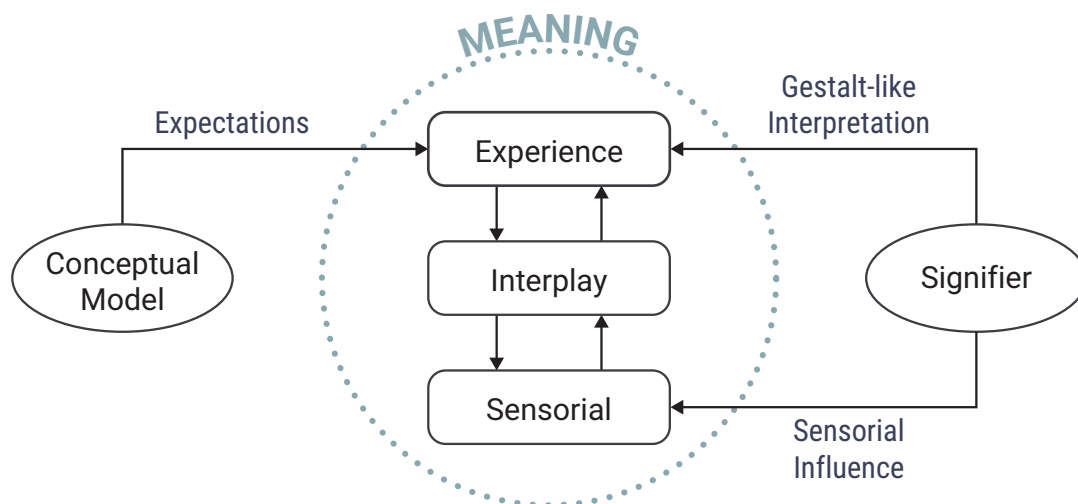
4.5. Assessment process

The findings thus indicate that there exist both an internal and an external process of making sense, but it is also evident from the analysis that there exists some form of assessment in the process of making sense. The outcome of the analysis shows that the meaning was often not neutral but had a positive or negative connotation, especially the higher-level meanings (e.g. professional or not professional). This was evident in the previously described similes were certain signifiers could evoke different meanings where the AV was regarded as performing actions that were controlled to a greater or lesser degree. Furthermore, the sensorial meanings influenced the way the participants talked about the meanings in positive and/or negative terms (Figure 7). For example, a driving property interpreted as 'slow' mostly generated positive connotations for the meaning relating to awareness, while a driving property interpreted as 'jerky' generated negative connotations. Overall, the sensorial meanings associated with the defensive driving style (e.g. slow acceleration and long distance to objects) had a more positive effect on the appraisal of the AV linked to the development of meanings than those associated with the aggressive driving style (e.g. powerful acceleration and close distance to objects).
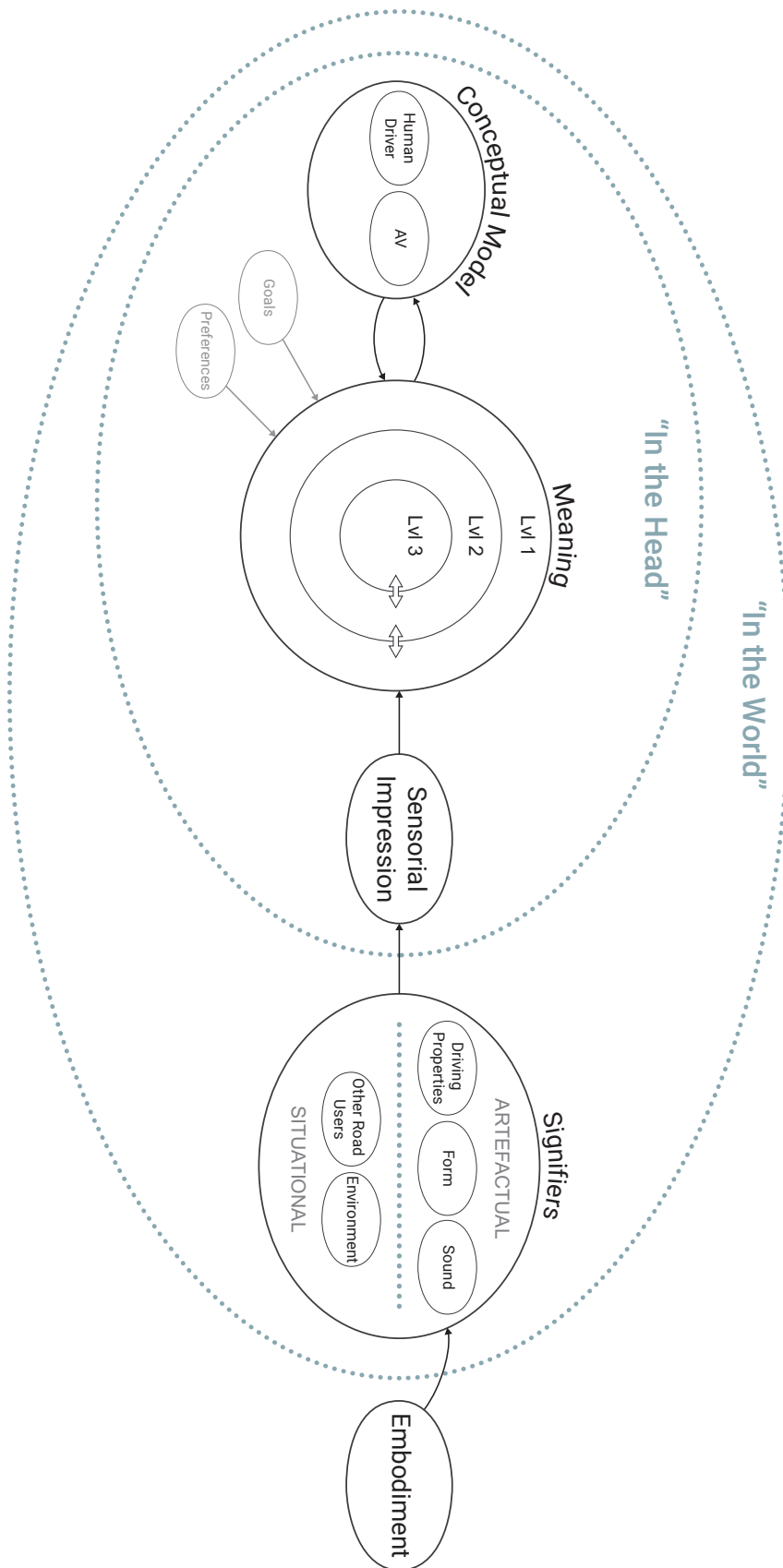

Figure 7
The effect of signifiers on the connotation of meaning.
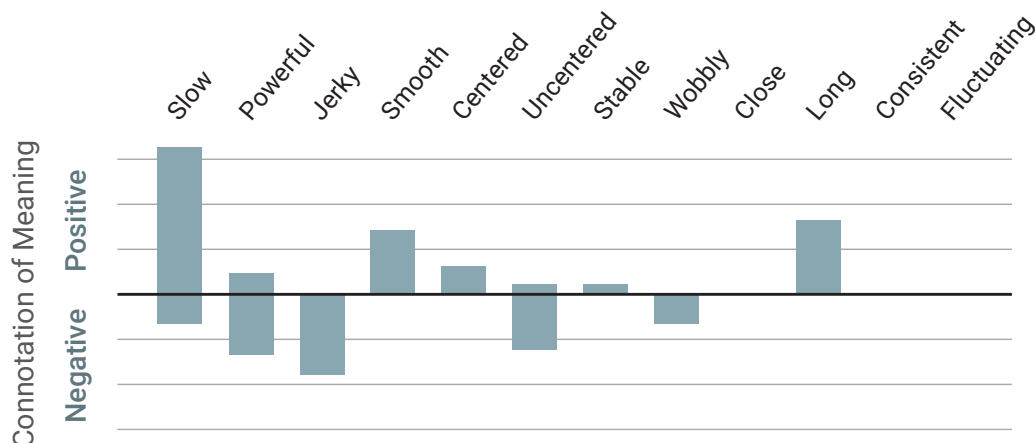
4.6. Tentative Model of Making Sense of AVs

This section presents a tentative model of the process of making sense and the key components (see Figure 8). Several different meanings were identified from the study, belonging to three levels of meaning: (i) sensorial meanings, (ii) meanings about the AV's ability and awareness, and (iii) the AV's overall character, illustrated in the centre of the model. It was noted that the most common signifiers relating to the AV were driving properties, but also that there were other signifiers such as sound and form, i.e. artefactual signifiers, as well as situational signifiers in the form of the environment and other road users, all of which affected the meaning that arose. The artefactual signifiers can be intentionally designed through the embodiment of the artefact (represented to the right in the model). Furthermore, two different processes were identified, showing the complex nature of the process of making sense. First, an external process, where integration of the participants' conceptual models of human drivers and AVs, artefactual signifiers, and situational signifiers in a context developed meaning. The conceptual model continuously affects the

22

23

meaning that arises by providing expected meanings and is updated with new meanings that arise, creating a circular relationship between the meaning and conceptual model (shown to the right in the model). Indications of goals and preferences were also present but the way they are evinced was not evident in the empirical data, therefore represented in grey in the model. Second, there was an internal process where meanings, at different abstraction levels, developed new meanings. However, the findings do not reveal if this process starts from low- or high-level meanings, although there are discussions that suggest that the development probably goes in both directions initiated from either sensorial influence or gestalt-like interpretation of signifiers, or expectations from the conceptual model (shown by the bi-directional arrows between the levels of meaning). Moreover, the model also differentiates between what is "in the world" and what is "in the head" (terms borrowed from Norman (2013)) and indicates which components that resides internally within the head of the user and which resides externally, in the world. Finally, even if the analysis shows that the meanings are highly subjective, findings also indicate that a certain embodiment of the artefact may evoke more general meanings by affecting the signifiers that the user senses.

05
REFLECTIONS

This chapter reflects on the implications of the findings and the relevance and consequence of the methodology used.

5.1. Implications

As mentioned earlier, even if the meanings that arise are subjective and may differ from one user to another, the findings also show that some meanings are more general. Therefore, since the concept of product semantics is used not only to investigate meaning but also when designing for artefact meanings (Krippendorff, 2006), it might be relevant to identify the more general meanings of an artefact to be able to understand what meaning the intended message from the designer will evoke in the majority of users, and consequently design for those, as illustrated in Figure 9. However, at the same time one needs to be aware of infrequent meanings that can arise, be aware of the diversity of the users' understanding, and be able to identify undesired meanings. Even if it is not possible to prevent all the unwanted meanings to arise, it is important to understand them in order to develop artefacts that encourage appropriate conceptual models and discourage harmful ones (Krippendorff & Butter, 1993). Undesired meanings can be discouraged either in a semantic way, that is to say by adding or removing perceptual cues (signifiers), or in a physical way, by adding physical constraints (Parmentier et al., 2020).
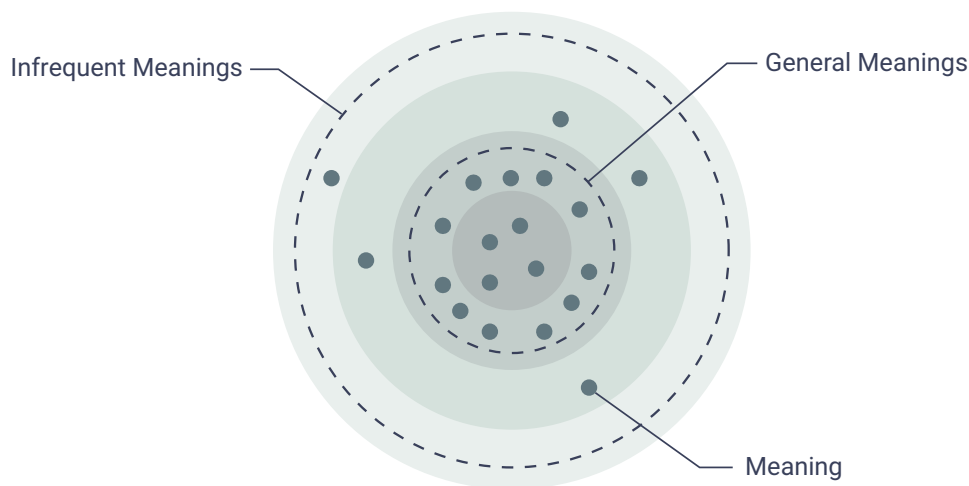
Infrequent Meanings — General Meanings — Meaning

Figure 9
Illustration of general and infrequent meanings. Dots symbolize different meanings and the shade of the background indicates similarity between meanings within (the darker the more similar).

Furthermore, in order to provide a tool to design for appropriate meaning, future work should not only consider the user in the meaning-making process but also consider the designer, in order to understand how the designer's intended message can be embodied into the design of the AV, and to permit evaluation of the meaning that consequently arises for the user when using the AV. This is highly important since the designer can not communicate directly with the user but only through the embodiment of the artefact (referred to as system image by Norman) (Norman, 2013).

This thesis also reveals more holistic implications for what to consider in the development of AVs. The analysis identified many different meanings relating to the character of the AV and higher-level meanings. In contrast, very few meanings discovered related to the underlying functionality of the AV and even fewer related to the purpose of the AV or how to operate it. One reason is probably the nature of the test setup, in which participants did not have to operate the AV at all, and thus were not triggered to generate meaning relating to how and why to operate the vehicle. However, since the study reflects how vehicles will work in an assumed future, it is probable that future AVs, especially fully automated vehicles, will neither evoke lower-level meanings and instead higher-level meanings relating to what the AV is. In the future users will be as disconnected from the dynamic driving task as in the study presented here, since AVs will demand fewer operations at lower control levels, such as steering and accelerating, making much of the driving task more intangible and (possibly) harder to understand. Consequently, this will leave the users unable to develop meaning based on the direct feedback from performing the dynamic driving task itself, and instead lead them to focus on other signifiers when making sense of the vehicle.

Furthermore, many of the higher-level meanings in the study also had a human-like association for the users, for example referring to the AV using human-like characteristics such as 'professional' and 'intelligent' or using human drivers as similes when describing the AV. Possibly since the only previous experience similar to the higher level of agency the fully automated vehicle has, is with human drivers. It is therefore probable that artefacts with higher levels of agency, such as AVs (especially fully automated vehicles), will be assigned more human-like higher-level meanings about character traits and overall character, as seen in the findings. Thus, the way we experience and understand AVs in the future may differ from how we currently experience and understand manually driven vehicles. It is therefore probable that what the user needs to, and will, understand about the AV will vary with how advanced the AV is and consequently the level of agency, but that the process by which they make sense of the AV will most likely remain the same.

Lastly, similar to what was indicated in the internal process, where users generated meaning based on other meanings at different levels (represented by the black arrows in Figure 10), it is highly likely that meanings about the AV's relationship with the user and context (e.g. utilitarian meaning) and the meanings about what the AV is (e.g. Artefact type meanings) will affect each other (grey arrows in Figure 10). For example, interpretations about how aware and intelligent the AV is will possibly affect how users believe they should interact with the AV. It is therefore probable that not only the different levels of meaning affect each other but also the different meanings on the same level, such as Artefact type meaning and Utilitarian

meaning. It is therefore important to consider all levels of meaning both regarding what the AV is and its relationship to the user and context when investigating user understanding, since they are all interconnected.
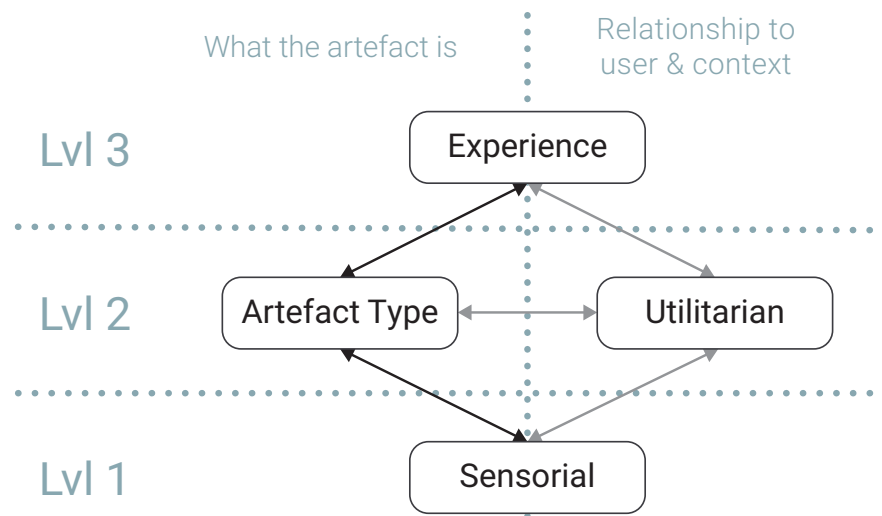
5.2. Method

The WOz method used in the study presented in this thesis seems to have been an effective way of eliciting information about the users' process of making sense of the AV. Several different types of meanings as well as indications of conceptual models were identified in the study. However, since the users experienced a fully automated vehicle for the first time and only for a short period of time, it was not possible to investigate any temporal effects on meaning. The focus of the study was therefore only on the initial exploration phase. Even if this represents a small part of interaction with the artefact, it is at the same time a very important part of the relationship between the user and artefact (Krippendorff, 2006). Nevertheless, it is also important to investigate how meaning changes over time in order to better understand the process of making sense, since it is recognized that meaning is affected by the temporal context (Monö, 1997) and that higher levels of meaning arise after extended experience with the artefact (Kapkin, 2016). Therefore, future research should focus on longitudinal studies with longer exposure to AVs.

Furthermore, the method used in the study did not allow for more in-depth questions about users' understanding as the study had multiple focus areas and aims. The time allocated for each focus and aim was therefore limited so as not to exhaust the participants with an excessively long study procedure. This has probably not affected the validity of the overall findings but maybe the level of detail. Being able to pose more in-depth questions could possibly have clarified certain aspects of the findings, which are now inferred, and may have provided an even richer result.

Finally, using a product semantic framework in the thesis has worked well for structuring the findings and for providing a holistic overview of the users' development of meaning. This was achieved during Steps 3 and 4 of the analysis, where the identified clusters of referrals were compared with the product semantic framework in order to relate the empirical findings to the theory. Since the framework focuses on both the artefact and the user as part of making sense, much of the

data was able to be explained and fitted into the model presented in the findings. Furthermore, based on the complexity of the process of making sense that is evident from the findings, a framework that takes into account the artefact, context and user is necessary so as to understand how users make sense of AVs and capture a rich understanding of the users' understanding.

However, even if the product semantic framework proved to be very useful, it had some shortcomings in accounting for an artefact with a high level of agency, such as the highly automated vehicle in the study. Product semantics often concern everyday artefacts with less agency and with which users interact in a more direct and tangible way. The participants in the study presented in this thesis did not have the possibility of performing any driving task actions, which were instead (seemingly) performed by the AV itself. This led participants to develop meanings about the AV's intentions regarding the driving actions that they usually would have when performing the dynamic driving task themselves. This phenomenon of projecting intentions of actions is not covered by product semantics, which mostly views the user, not the artefact, as the agent that performs actions. It becomes even more complex if the user undertakes some of the driving task, creating a situation where both the artefact and the user perform actions. Therefore, to improve the framework, future research needs to investigate partially automated vehicles so as to also incorporate the aspect of manipulation (e.g. activating system), in developing further understanding of how users create meaning about what the AV is and its relations to the user and context.

06
CONCLUSION AND CONTRIBUTIONS

This thesis presented the outcome of an analysis of data from a quasi-experimental study using a seemingly fully automated vehicle, with the aim of exploring how users make sense of AVs, applying a product semantics framework as a theoretical foundation. The thesis illustrates the complex process by which users make sense of an AV and also proposes a tentative model to study the interrelations between the user, artefact and environment in which it operates.

From the participants' referrals, the findings identified several different meanings of different character. It is suggested that these meanings exist on three levels: (i) sensorial meanings, (ii) interplay meanings, and (iii) experience meanings. This includes meanings relating to sensorial impressions, the AV's ability and awareness, and the AV's overall character. It was also noted that the most common signifiers were the driving properties but also that there were other signifiers, such as sound and form, as well as situational signifiers in the form of the environment and other road users. Furthermore, the analysis uncovered two different processes by which the participants made sense of the AV: firstly, an external process, where integration of the participants' conceptual models of human drivers and AVs, artefactual signifiers, and situational signifiers developed meaning. Secondly, an internal process where meanings, at abstraction levels, developed new meanings.

The analysis suggests that even if meanings are highly subjective, certain embodiment of the artefact may evoke more general meanings which should be identified and designed for. However, one also needs to be aware of the diversity of meanings that can arise so as to identify undesired meanings and discourage them either in a semantic or physical way. Additionally, the internal process indicates that one needs to consider not only the interrelations between meanings on different levels but also how meanings about what the AV is affect meanings about the AV's relationship to the user and context. Moreover, the analysis suggests that the shift to more automated vehicles will lead users to focus on other signifiers when making sense of the vehicle compared with today, and that what users need to, and will, understand about the AV will change but the process by which users make sense of the AV will most likely remain the same.

The thesis contributes to the area of users' understanding of AVs by describing the complex interplay between components in the process of making sense of AVs and also by identifying several types of meaning that may arise in the usage of AVs.

Furthermore, the thesis provides a tentative model aimed to be developed into a tool for practitioners to use when investigating the user's process of making sense, in order to aid the design and development of AVs.

The thesis also contributes to the field of product semantics through the practical application of product semantic theories, especially in an area of research where the theories are not widely used. Additionally, the thesis provides further insight into how users develop meaning and make sense of artefacts by describing the internal and external processes, as well as the effect of the components, which seems to be the foundation of the process of making sense. However, future work should further investigate the dynamics of meaning making, using the framework. More specifically, future work should look into the interdependencies between context, conceptual model, artefact and meaning, and also the effect of meanings on other meanings.

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PAPER A

Johansson, M., Ekman, F., Karlsson, M., Strömberg, H., & Bligård, L-O. (2020)

Talking Automated Vehicles – Investigating Users' Understanding of an Automated Vehicle During Initial Usage

PAPER B

Capable and Considerate: Exploring the Assigned Attributes of an Automated Vehicle