THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

MAKING SENSE OF MAKING SENSE

EXPLORING USERS' UNDERSTANDING OF AUTOMATED VEHICLES DURING USE

MIKAEL JOHANSSON

CHALMERS
UNIVERSITY OF TECHNOLOGY

Department of Industrial and Materials Science
Division Design & Human Factors
CHALMERS UNIVERSITY OF TECHNOLOGY
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Mikael Johansson

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ABSTRACT

Automation has for a long time been embraced by the vehicle industry and in recent years, the amount and sophistication of automation in vehicles have rapidly increased, creating more advanced automated vehicle (AV) systems. The entry of automation into vehicles also creates new dynamics in human-vehicle interaction, introducing new complexities when the human and automation need to cooperate to accomplish the driving task. Previous research has identified the importance of user understanding of Automated Vehicles, as this affects usage directly as well as indirectly by impacting trust and acceptance.

In this thesis, a human-centred design perspective 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 during use. The research presented is based on data from three empirical user studies conducted with users of a (i) seemingly fully automated vehicle, (ii) vehicle with two different levels of automation, and (iii) an automated driving system for docking buses.

The findings indicate that use of the AVs gave rise to several levels of meaning, based on a two-part process. One was an intermeaning process, where integration of the participants' conceptual models, artefactual signifiers and situational signifiers in a context developed meaning. However, an intrameaning process was also evident where meanings themselves developed new meanings. The findings also show that usage of the AV itself is an integral part of the process of making sense, where both processes affect how the system is used and the usage prompts new meaning to arise. This thesis presents a model based on the findings, describing four important factors: the user's conceptual model, the signifiers, the meanings that arise during use of the AV, and the context in which it is used. The model illustrates the complex interplay between these four 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, how meaning changes during prolonged usage, and how the model could be advanced to be able to be used in AV development and evaluation processes.

Keywords: Automated vehicles; Driving automation; Sense making; Product semantics; Understanding; Meaning; Signifiers; Conceptual model

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APPENDED PAPERS

PAPER A

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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.*

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01
INTRODUCTION

This chapter introduces the subject of interest in the thesis – users' understanding of AVs- and presents the aim and overarching research question of the thesis.

1.1. Background

Ever since the early 20th century, automation has been regarded as an effective way of improving the performance of human-machine systems, by either replacing or enhancing the human user. Automation can broadly be defined as "a device or system that accomplishes (partially or fully) a function that was previously, or conceivably could be, carried out (partially or fully) by a human operator" (Parasuraman, Sheridan, & Wickens, 2000, p. 287). However, adding automation does not always replace human work but instead changes the character of the work and sometimes even contributes to more work (Dekker, 2004). Automation may therefore introduce new complexities, where humans and automation need to cooperate to accomplish the goal of the system, changing the previous role of the user and creating new types of relationships between user and automated system.

Automation has long been embraced by the vehicle industry and as early as 1958 the first cruise control*, able to maintain a set speed, was available in the Chrysler Imperial. In more recent years, the amount and sophistication of automation in vehicles has been rapidly increasing and today most car companies are competing to develop and manufacture ever more advanced Automated Vehicle (AV) systems**, such as Tesla's Autopilot (Tesla, 2022) and Cadillac's Super Cruise (Cadillac, 2022). This development is mainly driven by the expected benefits of improved comfort and productivity (Litman, 2018); improved traffic safety (Fagnant & Kockelman, 2015); inclusion of drivers with disabilities who are currently not able to drive by themselves (Dokic, Müller, & Meyer, 2015); and optimisation of traffic flow (Anderson et al., 2016; Dokic et al., 2015).

However, AVs are not homogenous but are of a very varied character (Morris, Craig, & Mirman, 2021) which exists on a continuum, often operationalised as

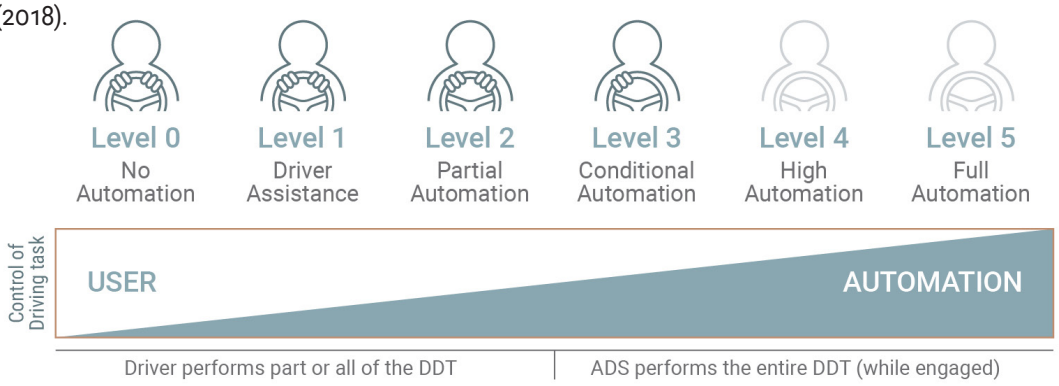
* Even though initially referred to as "Auto-pilot".

** A note on the denotation of AV and AV system. The thesis considers the AV as a whole as one artefact but due to earlier research having looked into both AVs as a whole and AV systems and users fluently changing between describing the vehicles and AV systems, both terms will be used. However, I will try to be clear on what is specifically referred to.

Levels of Automation, where the SAE (2018) is the most common taxonomy (see Figure 1).

On the lowest levels of automation, the driver assistance systems assist the driver with lateral or longitudinal control (SAE L1) or a combination of both (SAE L2) – Advanced Driving Assistance Systems (ADAS). On these levels, the driver is fully responsible for driving and is supposed to be engaged in the dynamic driving task (DDT), i.e., operational and tactical functions required to operate a vehicle safely, all the time. On the intermediate levels, the AV system can perform the entire DDT in a sustained manner within a certain operational design domain (e.g., certain traffic or weather conditions) during which the driver needs to be ready to resume control (SAE L3), or the AV being able to come to an emergency safe stop (SAE L4). The highest level of automation is full automation (SAE L5), where the AV is able to take the user from point A to point B without assistance from the user. AV systems on the intermediate and highest levels of automation (SAE L3-L5) are referred to as Automated Driving Systems (ADSs).

Figure 1
Levels of automation adapted from SAE (2018).



In addition to different levels of automation, AV systems within each level may also greatly differ. They can for example differ as regards the traffic conditions in which the AV is designed to be used, for example condensed or free-flowing traffic; as regards certain specific limitations, such as not able to operate without sufficient lane markings; and as regards the way in which feedback to users is provided. Adding to the complexity of AVs, is that future AVs will probably not consist of a single level of AV systems but multiple levels of automation (Forster, Hergeth, Naujoks, Krems, & Keinath, 2020), where users need to understand how the different modes work and to differentiate between, for example, an assistive function that that can be used all the time, such as lane keeping assist, and a function that takes over the entire driving task when on highways and above a certain speed.

As mentioned earlier, the entry of automation into vehicles creates new dynamics in human-vehicle interaction that in turn introduce new demands on the user*, where the user and AV system need to cooperate to accomplish the driving task. Due to this increased technical complexity and the safety-critical environment in

* User being the person using the AV, which can involve segments of performing the DDT, i.e. being a driver. Therefore, users are sometimes referred to as drivers, when describing users of ADAS, where the user is responsible and in overall control of the DDT.

which AVs (mostly) are intended to operate, one factor that has been considered as crucial in order to reach the intended benefits is users' understanding of these AV systems.

1.2. Influence of user understanding on AV use

Users' understanding of AVs have been found to influence the use of AV systems in two ways. Firstly, users' understanding of AV functions seems to directly influence the users' ability to use the AV appropriately (Pradhan et al., 2020), where a lack of understanding may reduce the possible safety benefits of the AV (Dickie & Boyle, 2009; Martens & van den Beukel, 2013). Appropriate use being when the AV system is not used outside of the operating conditions which it is designed to function and is optimally utilised within these conditions (Boelhouwer, 2021). Earlier studies have shown that initial understanding impacts effectiveness of the interaction with the ADAS and how well users learn to use the system (Beggiato & Krems, 2013; Rossi et al., 2020). Aspects of users' understanding that have often been emphasised as important are users' understanding about system capabilities and limitations (e.g. Seppelt & Lee, 2007). In a study by Zhou, Itoh, and Kitazaki (2021) instructions about typical take-over situations before using an ADAS increased successful take-over procedures, when necessary, from 55% to 95%. Similarly, Krampell, Solís-Marcos, and Hjälmdahl (2020) identified that improved understanding about the system through a pre-study training session led to higher inclination to retake control in critical situations when using an ADS. A more accurate understanding has also been found to improve the performance in transitions between manual driving and an ADAS and ADS (Forster et al., 2020). Another study by Forster, Hergeth, Naujoks, Beggiato, et al. (2019) found that initial poor understanding of system functionality and how to operate the AV system negatively affected how well users operated the system but that understanding and performance increased with repeated experience of the system, illustrating the challenges that initial experience with AV may pose for users. Thus, understanding of the AVs capabilities, functionalities and how to operate the AV seemingly influence how well users operate the system and are able to intervene when needed.

Secondly, understanding of the AV also influences system use indirectly by mediating trust and acceptance. Users' understanding of AV system functionality is important for the appropriate development of, and consequently the level of trust in, the AV (e.g. Kazi, Stanton, Walker, & Young, 2007; Seppelt & Lee, 2019). A study by Beggiato and Krems (2013), investigating the effect of initial information on trust in and understanding of advanced cruise control (ACC) found that users' understanding converged to a similar level over time regardless of how correct the initial information was. However, for a group who received incomplete information, their level of trust in and acceptance of the AV decreased. Trust and acceptance can in turn influence use of the automation and are considered essential to maintain safe driving, especially when overall control of the vehicle is shared between the vehicle and driver (Hancock et al., 2020). The influence of trust on use has been identified in several studies of AVs, for example reliance behaviour during cut-in situations when using ACC (Rajaonah, Anceaux, & Vienne, 2006) and driver monitoring and reliance on a conditionally automated vehicle (Körber, Baseler, & Bengler, 2018).

The connection between understanding, trust and use of the system were illustrated in Seppelt and Lee (2019), who found that a more accurate understanding resulted in more stable trust and appropriate reliance behaviour when the AV system reached its operating limits. Thus, inadequate understanding of the system may lead to over- or under-trust which in turn could lead to users using the system in an unintended way or not to its full potential or even not using it at all (Lee & See, 2004; Parasuraman & Riley, 1997).

Several of the identified issues related to users' understanding are already prevalent in the use of ADAS systems currently deployed in vehicles. Many users are not aware of what ADAS they have in their vehicles and how to appropriately use these systems (Harms & Dekker, 2017), and in addition indicate tendencies to overly rely on the system (McDonald, Carney, & McGehee, 2018). Likewise, other studies on ACC systems show that many users are not aware of or do not understand the systems' limitations (Dickie & Boyle, 2009; A. B. McDonald et al., 2016), especially in the beginning of the use (Larsson, 2012). Additionally, investigations of interfaces for currently deployed ADAS noted that the meanings of some icons used in in-vehicle displays were ambiguous, generating a wide range of ideas about the meaning (Richardson, Revell, Kim, & Stanton, 2020); and that a best practice for human-machine interaction (HMI) design was often lacking, with the potential to confuse users (Carsten & Martens, 2019). This indicates that users may lack the appropriate understanding to exploit the potential benefits of the AV systems already deployed in vehicles today and underscores a need for improved HMI design.

Previous research therefore shows that users' understanding seems to directly affect users' ability to safely and efficiently use AVs and also indirectly by mediating trust and acceptance, making understanding a key aspect to investigate so as to be able to develop AVs that are used in a safer manner and that users accept and choose to integrate into the appropriate context, i.e., adopt (cf. Straub, 2009). Furthermore, many users seem to lack the understanding to appropriately use currently deployed AVs, indicating that users are not adequately supported by existing design and information solutions in assisting their development of an appropriate understanding of the AV. Hence, enhancing knowledge about users' understanding of AVs is essential to be able to design AVs that users understand and consequently are willing to adopt and can use safely.

Furthermore, much of the research has often investigated safety and performance-related aspects of AVs and had something of a "problem-solving" perspective, with a focus on goal-oriented situations with clearly defined tasks (for instance to intervene and take over control when system limits are reached) (e.g. Krampell et al., 2020; Zhou et al., 2021). These studies have often focused on users' mental models and knowledge about AV capabilities, such as limitations, investigating the effect of providing instructions or training (e.g. Beggiato & Krems, 2013; Rossi et al., 2020). However, the studies have not to the same extent considered aspects of users' understanding of the AV that does not concern a clear task and how this understanding is developed when using the AV, especially not in normal everyday driving. In addition, since users today largely do not consult the instruction manuals that are often the main source of information regarding the AV systems, as seen in earlier research (Mehlenbacher, Wogalter, & Laughery, 2002), it is crucial to

understand how the AV itself can communicate its purpose and functionality. This is especially true since AVs will in many cases be operated by non-professional users, making it particularly important to understand the diversity of user understanding to be able to design successful artefacts that are used as intended by their developers (Krippendorff, 2004). Moreover, previous research has often investigated the effect of individual factors on users' understanding (e.g. Blömacher, Nöcker, & Huff, 2020; Boos et al., 2021), such as the effect of initial information on users' understanding but has not to the same extent examined how different factors interact and influence each other, something that is important since when sitting in the AV there is a system of factors that interact.

1.3. Aim and overarching research question

The aim of this thesis is therefore to develop knowledge that can facilitate the design of AVs that users understand by exploring how users make sense of AVs and the meaning that arises when using the AV under normal traffic conditions. The overarching research question of the thesis is thus as follows:

How do users make sense of AVs during use?

Given the aim and overarching research question, a human-centred design perspective with product semantics as the theoretical framework is chosen to broaden the concept of user understanding of AVs. This is done 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 during use. The way users understand artefacts is strongly connected to what artefacts mean to them, which is believed to develop in a process of making sense (e.g. Evans & Sommerville, 2007; Krippendorff, 1989); what the artefact means to the users in turn influences how they act (Krippendorff, 2006). Users' process of making sense and consequently the meaning that is associated with the artefact is highly affected by the design of the artefact itself. Design can be seen as a communication process consisting of an interplay between designer and users, where designers try to communicate an intended meaning through the artefact which users makes sense of both before and during use. In order to understand how the design of the AV itself can better facilitate the development of users' understanding; this thesis has focused on how users make sense of the AV during use.

1.4. Thesis Structure

The thesis is organised into following seven chapters:

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

02 Presents the theoretical framework, based on product semantics that have been chosen to conceptualise the user's process of making sense and to aid analysis of the findings; as well as introduces two supplementary research questions, in order to answer the overarching research question.

03 Describes the research approach including the methods and analysis used to answer the research question.

04 Presents the findings from three empirical user studies, which are analysed using the theoretical framework.

05 Presents the outcome of the cross-study analysis and synthesis in the form of a model, in order to answer the supplementary research questions.

06 Describes the design implications of the thesis and prescribes design considerations.

07 Discusses the findings from the empirical studies; research approach used; contributions of the thesis; and future work; as well as presents the conclusions made.

02
THEORETICAL FRAMEWORK

The research in this thesis embraces a human-centred design perspective with product semantics as the foundation for the theoretical framework. In this view the AV is considered an artefact that users interpret and make sense of when using it. This chapter describes the theoretical framework which is used as a lens to analyse and contextualise the data from the empirical studies presented in the thesis.

The chapter first presents the underlying perspective of the theoretical framework, product semantics, and the process of making sense. It then continues by describing the central factors in the process of making sense: artefact meaning, the artefact, the user, and the context.

2.1. Product semantics & making sense of artefacts

A product semantic perspective is chosen in order to understand the relation between user and the artefact in use, which in this thesis is AVs. Product semantics has been defined as "the study of the symbolic qualities of man-made forms in the context of their use…" (Krippendorff & Butter, 1984, p. 4) and was one of the influential focus areas early in the development of human-centred design. In product semantics, it is argued that users do not perceive artefacts as pure form or physical qualities but rather as what they mean to them and therefore the main focus in product semantics is on how users associate these meanings with artefacts (Krippendorff, 2006). Users are believed to act on the meaning that arises resulting in new meaning being developed, creating a meaning-action circularity (cf. Krippendorff, 1989), in which users make sense of artefacts while using them. Thus, the meaning that users associate with artefacts is central to how they interpret the artefacts and consequently use them.

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

Krippendorff suggests that making sense of an artefact occurs in a circular cognitive process which starts with a sensorial impression and continues in a process where the perceived parts of the artefact, the artefact as a whole and the way it relates to other artefacts, mutually impact each other until a sufficiently coherent understanding is reached (Krippendorff, 1989, 2006). Hence, the design elements*

* In the thesis design elements are considered to be properties of the artefact that is designed, such as the handle of a cup or an icon in a display, in contrast to what design elements often refer to in visual design, e.g., colour and scale.

of the artefact, e.g., icons, are interpreted in relation to the artefact as a whole and vice versa as well as the way it relates to other artefacts around it. Moreover, artefacts make sense when they are recognisable and understandable (Krippendorff, 1989). In other words, when the user can identify what the artefact is, what to do with the artefact, what the artefact does for you and the role the artefact plays in a certain context (Evans & Sommerville, 2007). *Thus, making sense of an artefact is regarded as the process of developing meanings associated with the artefact in a certain context until a coherent understanding is reached.*

However, the notion of making sense can be expanded to also include the process of designing the artefact. This wider process can be seen as a communication process consisting of an interplay between designer and users (Crilly, Good, Matravers, & Clarkson, 2008; Monö, 1997). In this communication process, designers attempt to communicate an intended meaning through the design of the artefact, of which the user then tries to make sense when using it (see Figure 2).

Making sense of artefact - the process of developing meanings associated with the artefact in a certain context until a coherent understanding is reached

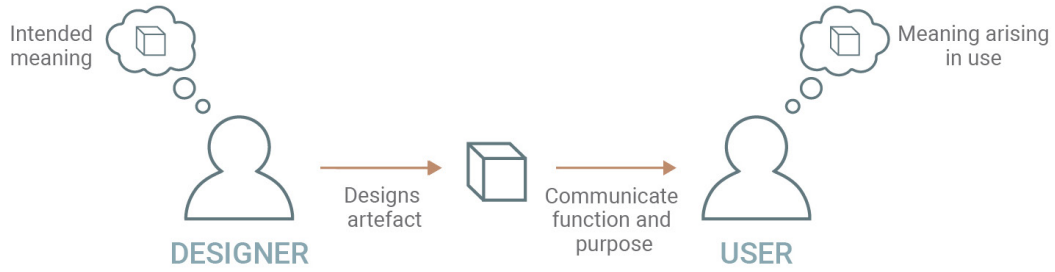


Figure 2
Relation between designer and user of artefact.

Therefore, the designer's role is to design artefacts that on their own can communicate their function and purpose, rendering them understandable or meaningful to the user, so that intended use becomes clear and incorrect usage is prevented (Parmentier, Van Acker, Saldien, & Detand, 2020).

However, this is not easily achieved since it is not possible to design meaning into an artefact; meaning is inherently subjective, always residing in users' understanding, making the meaning that will arise when using an artefact difficult to predict. As a result, meaning is not always shared between users, instead there can be considerable variations in how people make sense of one and the same artefact, with the meaning users develop sometimes being different from the intentions and expectations of the designer (Boess & Kanis, 2008; Khalaj & Pedgley, 2019). Nevertheless, for artefacts to be successful, with users understanding them and wanting to incorporate them into their everyday life, the artefacts need to make sense to most users, ideally to all (Krippendorff, 2006).

Therefore, in order to be able to design meaningful artefacts, it is crucial for designers to obtain a comprehensive understanding of users' understanding, referred to as second-order understanding, which is distinguished from the first-order understanding that is obtained from only observing the user as a subject (Krippendorff, 2004). This includes understanding the diversity of meanings that

the users may associate with the artefact. To be able to develop this understanding, it is important to research the use of an artefact in its real environment (Norman, 1999), testing if intended meanings arise when users experiences the artefact (which can also be an concept or prototype). This implies that investigation of users' process of making sense of the artefact during use in the context in which it is meant or believed to be used is crucial in order to be able to design meaningful artefacts.

In this thesis, the main focus will be on the process in which users make sense of AVs but attention will also be given to how this process affects and is affected by the design. The following sections describe the central factors in the process of making sense: artefact meaning, the artefact, the user, and the context.

2.2. Artefact meaning

One of the most central factors in the process of making sense is meaning. As mentioned before, it is argued that artefacts are perceived as meanings, what something "is" being the sum of all meanings associated with the artefact, (Krippendorff, 1989). Therefore, there is not only one meaning associated with an artefact; rather, a variety of meanings can be associated with one and the same artefact, e.g., distinguishing it from other artefacts and interpreting how to use it. For example, a thermos flask can be interpreted as something meant to protect a user from hot beverages or something meant to keep the temperature of cold drinks but possibly also as something meant to express an identity.

Even if there is a wide range of approaches to and definitions of artefact meaning*, there is no universally accepted concept or definition (Kapkin, 2016). One artefact can be associated with several types of meanings of different character and it has been suggested that there are different layers or levels of meaning (Kapkin, 2016; Vlist, Niezen, Hu, & Feijs, 2010). Based on a review of several frameworks, Kapkin (2016) has proposed a categorisation of artefact meaning into three levels. At level one there are meanings that are evoked by affordances, i.e., perceived use possibilities (later described), and as a result from sensorial experiences; level two refers to meanings relating to how the artefact informs about itself and its functions in a certain context, often evoked during use of the artefact; and third level meanings may refer to cultural values and social status and might relate to the overall experience after a certain period of time (Kapkin, 2015). Similarly, Khalaj and Pedgley (2019) synthesised from literature four types of meaning: (i) *sensorial meaning* (literal descriptions of physical properties), which shares similarities with Kapkin's level 1 meaning, and (ii) *affective meaning* (emotive associations), which shares similarities with Kapkin's level 3 meaning. The last two meanings, (iii) *meaning of interaction* (descriptions of product functionality and usability arising through interaction) and (iv) *connotative meaning* (figurative descriptions and personality characteristics), both share similarities with Kapkin's level 2 meaning. However, these two types of meanings highlight two important dimensions of meaning on that level, regarding the artefact itself and the artefact's relationship to the context, which use is an important part of. The two categorisations of different types of meanings share several similarities, even if they also consider different aspects of artefact meaning

* Often referred to as product meaning in product design literature.

and have therefore been combined to facilitate the conceptualisation of different types of meaning used in the thesis.

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, organised into the three levels proposed in Kapkin (2016)*.

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

	Kapkin, 2016	Khalaj & Pedgley, 2019
Level 3	Meanings relating to cultural values and social status.	Affective meanings.
Level 2	Meanings informing about the artefact and its functions in a certain context.	Connotative meaning
		Meaning of interaction
Level 1	Meanings relating to sensorial experiences.	Sensorial meaning

Thus, the overarching conceptualization that will be used in the thesis is that meanings of an artefact can be seen as *subjective interpretations regarding what the artefact is and the artefact's relation to the context (of which use is a part of), which resides on three levels*.

2.3. Artefact affordances and signifiers

As mentioned earlier, the meanings that arises have a significant impact on how users use the artefacts. This occurs in a meaning-action circularity, where the meaning that arises from a sensorial impression determines how we act (and what sensorial impression we anticipate), which in turn creates new sensorial impressions and meanings (Krippendorff, 2006). One concept that has often been used to describe how humans perceive and consequently interact with artefacts is that of affordances, popularized in design by Donald Norman. The term was first introduced by Gibson (1979), and grew out of aviation experiments that he performed during World War II and described the concept as "the affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill" (Gibson, 1979, p. 127). He proposed that we perceive combinations of mediums, surfaces and substances in terms of what they afford, what we can do with them (McGrenere & Ho, 2000). The concept was developed to link perception and actions (Flach, Stappers, & Voorhorst, 2017) and an attempt to study perception as not purely subjective or objective, affordances being neither a physical property of the artefact nor purely subjective (McGrenere & Ho, 2000). Affordances are therefore a relationship between the artefact (or environment) and the user, dependent on properties of both. An affordance for one user does not necessarily need be an affordance for another user. Krippendorff

Artefact meaning - subjective interpretations regarding what the artefact is and the artefact's relation to the context, which resides on three levels.

* Terminology used in the thesis has been altered when merging ideas; naming of the different types of meanings is sometimes different from earlier research, to better fit the way the type of meaning is described in the thesis.

(2006) suggested that perceived affordances are the perception of uses and the set of imaginable uses. A chair could, for example, afford sitting, lifting, or standing but only if the user has the physical and cognitive conditions to perceive the affordances. Thus, affordances can be seen as the *perceived uses of an artefact*.

Artefact affordance - perceived uses of an artefact

With more complex and digital artefacts, the functions become more abstract and affordances often harder to discriminate and if not noticed, designed affordances are not acted upon (Flach et al., 2017). Flach et al. (2017) state that there has been confusion between possibility of actions and expression of possibilities, something that Norman (2008) has tried to solve by proposing the concept of signifiers*. Signifiers are a signalling component of the affordances, that is to say any "perceivable indicator that communicates appropriate behaviour" (Norman, 2013, p. 14). Signifiers are emerging properties of the artefact and guide users to understand, for example, what actions are possible and how to perform them. They direct the attention of the users and they signify meanings (Evans & Sommerville, 2007). This makes signifiers important communication devices for designers to use, in order to communicate the intended meaning of the artefact. These signifiers can be deliberately placed, i.e., intentionally designed**, such as a symbol in the in-vehicle display indicating when it is time to change gear. However, they can also be incidental (cf. Norman, 2013), resulting from elements of the artefact that were not intended as signifiers or to signify meaning that was not intended by the designer, for example the sound of the engine informing the driver when it is time to change gear. In this thesis, a broader conceptualisation of signifiers is used, not limiting them to signify meaning regarding use but also other meanings, for example signifiers serving as character traits or identifiers as proposed by Evans and Sommerville (2007). Thus, signifiers are *perceptible signals to which users direct attention and use to interpret the meaning of an artefact*. These being either intentionally designed or incidental.

Signifier - perceptible signals to which users direct attention and use to interpret the meaning of an artefact

Signifiers can originate from various information channels. Most of the studies in product semantics concern the visual appearance of the artefact. However, designers can also use for example the sound, physical form, and smells of an artefact to communicate intended meanings (Monö, 1997). Van Rompay and Ludden (2015) also emphasise the importance of the meaning that arises from artefact movement. It is therefore important to consider a broad spectrum of information channels, not just the visual elements of the AV system.

Moreover, even if signifiers are important influences on the meaning that will arise when using an artefact, meanings are also constructed based on associations drawn from prior experience (Demirbilek & Sener, 2003). Users also tend to act according to what they wish to accomplish and are affected by their motivation. Thus, the individual factors of the user are highly influential in the construction of meaning.

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* Used slightly different from the original meaning of the semioticians.

** Intentionally designed signifier refers to a design element or several in combination that are intended to signify a certain meaning when the user perceives or uses the artefact.

2.4. User conceptual model

Meanings of artefacts are influenced by cultural conventions and individual differences. An artefact may mean one thing in one culture yet something else in another culture, but the artefact may also mean different things to different users within the same culture, due for example to different experiences, motivations, and capabilities (Crilly, Maier, & Clarkson, 2008). Monö (1997) describes that users' understanding of artefacts is influenced by: (i) *society* – which consists of numerous norms and values governing how to behave and interpret the world; (ii) *upbringing/ experience* – which provides the individual with social norms that affect how we react to different situations and artefacts; (iii) *education/training* – gives us skills to perform or understand certain tasks and artefacts; and (iv) *the individual* – qualities can be inherited traits such as temperament, or physical limitations. Thus, even if some meanings may be more general, for example a red light at a traffic light signifies that passing may imply danger and violation of laws, making sense is heavily influenced by individual and societal factors.

One individual factor that is regarded as especially important for the development of meaning associated with the artefact, and consequently its use, is the user's conceptual model of the artefact. Users develop abstract cognitive models consisting of numerous artefact meanings, including assumptions of how the artefact works and how to interact with the artefact, from previous experiences of interacting with other, similar or different, artefacts (Krippendorff, 2006). These models are not true or false but can be more or less workable when using an artefact (Evans & Sommerville, 2007). The conceptual model allows the user to act in anticipation and predict consequences of actions, and, especially early in the use process, aids recognition and understanding of what the different parts could possibly mean (Krippendorff, 2006). However, it is not certain that assumptions that users have will arise when using an artefact. For example, if a cup is assumed to be held with two hands but nothing signifies that it is meant to be held with two hands, the expected meaning may not arise. The conceptual models are also constantly updated, being improved, revised and increasing in complexity through continuous experience with the artefact (Krippendorff & Butter, 2008). Thus, the user's conceptual model can be considered as *a network of meanings that may arise in use, if the artefact enables the meaning to arise.*

Users' conceptual model - network of meanings that may arise in use, if the artefact enables the meaning to arise.

2.5. Context

Meanings are not fixed and are highly context-dependent, changing in different contexts. Context being "the surrounding conditions of something that shed light on its meaning" (Krippendorff & Butter, 2008, p. 10). A variety of different contexts exist that are important for the meaning that is associated with the artefact. One context is the environment, that is to say the physical surroundings, in which the artefact is used. This is relevant since artefacts mean different things in different situations and parts of the artefact receive meaning in context, from other parts of the artefact and from other artefacts in the environment (Krippendorff, 2006). Therefore, both the environment and other artefacts that it includes will affect the process of making sense.

In addition to the physical surroundings, Monö (1997) emphasises the chronological surroundings of the artefact, that is to say the temporality of the artefact. Meanings are initially influenced by earlier experiences with other artefacts and may change with use of the artefact, as we learn. This means that an artefact may have several different meanings during its lifetime without any design elements changing. A third important context is the use* (Krippendorff, 1989). Meanings associated with the artefact relate to how the artefact is meant to be used. However, the way the artefact is used also affects meaning that arises, where possibly different meanings arise when using the artefact in different ways. Additionally, the actions performed will result in new sensorial impressions leading to new meanings arising.

For this reason, meaning that arises when using an artefact can vary in different environments and different uses and may also change over time.

2.6. Summary and implications of the theoretical framework

To summarise the theoretical framework, the meanings associated with artefacts are continuously developed in a process of making sense, which is a complex interplay between the user, the artefact and the context and largely determine how users act. Multiple meanings of diverse character can arise based on the artefact's signifiers, which may have been intentionally designed to communicate a certain meaning or are incidental, and are affected by the individual factors of users, especially their conceptual model, consisting of expected meanings based on previous experiences. The factors described in the theoretical framework are illustrated in figure 3.

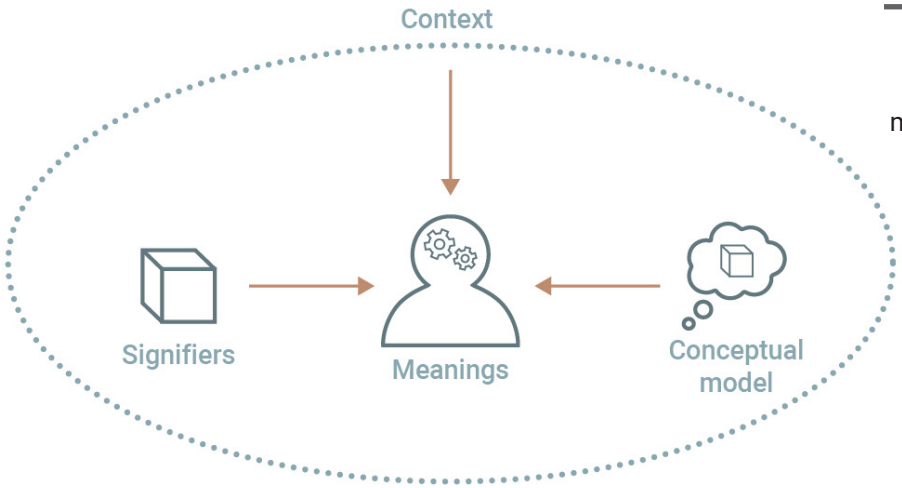

Figure 3
Illustration of factors affecting the process of making sense of artefacts.

The theoretical framework has provided a terminology and a set of factors and their relation to each other. It has earlier been used to describe users' relation to and understanding of artefacts. However, the theoretical framework has not been used as starting point when investigating more technically complex artefacts with high level of agency, i.e., the that an artefact is "guided by some form of internal design to achieve certain goals" (Janlert & Stolterman, 2017, p. 49). This thesis explores the outcome of applying the theoretical framework on a complex artefact with high

* Referred to as operational context by (Krippendorff, 1989).

level of agency that also encloses its user, namely an AV, in order to enhance subject knowledge regarding users' understanding of AVs and theory.

The implications of the theoretical framework on the thesis are twofold. First, since the theoretical framework is intended to be used as a lens to analyse and contextualise the data from the empirical studies, it provides factors and relationships that are important in the process of making sense. These factors and relationships are used to formulate two supplementary research questions in order to answer the overarching research question. The framework establishes four main factors influencing the way users make sense that are considered in the analysis: (i) the meaning itself that is associated with the artefact, (ii) context of use, (iii) users' conceptual model and (iv) the signifiers of the artefact. Therefore, the first supplementary research questions are:

RQIa – (How) do these four factors influence how users make sense when using an AV? and

RQIb – Are there other and/or additional factors?

The framework also illustrates relationships between the factors that are fundamental for the process of making sense. It is important to identify these because it is likely that this is where mismatches and issues may occur in the process of making sense. Making sense is described as a circular process where parts of the artefact and the artefact in the context interact, creating meaning that is associated with the artefact. As part of this overall process, three other relationships are described: the action-meaning circularity, where user actions lead to new meaning arising; a relationship between meanings and signifiers, where for example design elements signify meaning; and a relationship between users' conceptual model and meaning, where assumptions may affect the rise of meaning and the meaning that arise ma update users' conceptual model. Therefore, the second supplementary research question is:

RQII - How do the factors identified interact in the process of making sense of AVs?

The theoretical framework also provides considerations for the research approach and methodologies chosen. Because meanings are inherently subjective and multifaceted, information needs to be elicited by allowing the users to verbalise in an open way, to capture a broad spectrum of meanings. Furthermore, meaning that is associated with the artefact is influenced by the context, where other surrounding artefacts affect the meaning that arises, which implies that the context in which the AV is investigated is crucial for the meaning that arises and should therefore be as similar as possible to the context in which the AV is intended or believed to be used. The research approach will be described in the following chapter.

03
RESEARCH APPROACH

This chapter describes the research approach used in the thesis work in order to address the aim and answer the research questions posed. The research approach has been primarily influenced by three factors: (i) my educational background and professional setting, (ii) the research collaboration context, and primarily (iii) the research topic. This chapter presents the overall methodological approach and the research methods used for data collection and analysis.

3.1. Methodological approach

3.1.1. Personal and educational setting

The world view of the researcher is part of what influences the research approach and therefore it is important that it is acknowledged (Creswell, 2014). My worldview is strongly influenced by my educational and professional setting, with my educational background in industrial design engineering and my professional setting with its focus on design and human factors, both of which share a user-centeredness and design perspective. A design perspective is prescriptive in nature, not only trying to explain what is, as in many other research paradigms, but also what could or ought to be: "the natural sciences are concerned with how things are… Design, on the other hand, is concerned with how things ought to be, with devising artefacts to attain goals" (Simon, 1988, p. 69). This general idea of design, in other words to change an existing situation into a preferred one (Simon, 1988), has strongly influenced my mindset, thereby shaping my worldview. Even if this thesis ultimately does not prescribe solutions, my goal with the thesis has been to develop knowledge which can be utilised in the process of designing AVs, the foundation of a methodological approach or design tool. In chapter 6 Implications for design of AVs, I discuss how the knowledge generated in the thesis could be utilised in the design process of AVs, by prescribing design considerations based on the findings and synthesis.

3.1.2. Research collaboration context

The work presented in this thesis is based on three studies which were all performed in collaboration with other stakeholders. **Study 1** (presented in Papers A and B) was conducted within the HaTRIC project (www.saferresearch.com/projects/hatric-hmi-autonomous-vehicles-traffic) where the overall goal was to generate design

principles, test methods, and prototypes to understand what constitutes a good HMI 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, one of which is presented in this thesis. This study was carried out in cooperation with another PhD student and was aimed primarily at investigating how driving behaviour affects trust and secondarily how users understand AVs.

Study 2 (presented in Papers C and D) was conducted together with another PhD student in collaboration with Volvo Car Corporation as part of the SAMU project (www.chalmers.se/en/projects/Pages/Semi-autonomous-driving-and-its-effect-on-mode-awareness-and.aspx). The interests of different stakeholders within the company made the scope of the study broad, but the main aim was to investigate how users understand and experience an AV with two levels of automation.

Study 3 (presented in Paper E) was carried out in cooperation with Volvo Buses. The study was part of the KRABAT project (www.drivesweden.net/en/projects-5/krabat) and the purpose of the study was to investigate how drivers experience and understand an automated system that can dock a bus at bus stops and what benefits, if any, they expect from using it. Thus, all the studies were highly collaborative with multiple stakeholders and as a consequence, multiple interests, where one of the interests was to develop further knowledge regarding users' understanding of how they make sense of AVs. However, the different focus areas have largely shaped the selected research approach in order to accommodate the multiple aims.

3.1.3. Empirical user studies

The three studies from which the findings of the thesis are derived, in order to answer how users make sense of AVs, are quasi-experimental and observational studies with different AVs. They were all conducted between 2017 and 2021, in mixed levels of naturalistic settings. The context of use is highly important in the process of making sense (Krippendorff, 1989) and therefore, as naturalistic a setting as possible is beneficial to elicit an in-depth contextual understanding of how users make sense of AVs. However, since the AVs under consideration in the thesis work did not yet exist or were not yet fully developed, it was impossible to study the phenomenon in a fully naturalistic setting. It was therefore necessary to simulate parts or all of the technology, and in one case use a test track, to create an artificial future in order to place the user within a setting perceived as phenomenologically real, i.e., natural to the participants (cf. Goodman, 1970). This was achieved using Wizard-of-Oz (WOz) approaches in which different types of AVs were simulated. Degree of simulation and details of setups are presented in Chapter 4 Empirical studies. The WOz approach has been used in several earlier AV studies to investigate aspects such as user interfaces, driving behaviour and secondary tasks (Müller, Weinbeer, & Bengler, 2019). A WOz approach entails that the artefact the participants' experience, either in its whole or in part (e.g. a sensor or a mode, as in Study 2) is controlled by a human operator, with or without the participants being aware of it. In the studies presented in this thesis, the participants were not aware that a human simulated parts or all of the driving functionality*.

* Participants were informed about the WOz-approach after each test.

However, the character of the studies also differed in several aspects: vehicle type, level of automation, participants' automation experience, and study context (see Table 2 for overview).

Table 2 Overview of empirical studies.

Studies	Vehicle type	Level of automation	Participants	Study setup
Study 1 – Full automation (2017).	Car.	Full driving automation (L5).	19 non-professional drivers with mixed experience of AV systems.	Test course with on bidirectional rural road and urban streets, including staged traffic situations.
Study 2 – Mixed automation (2019).	Car.	Partial driving automation (L2) and High driving automation (L4).	20 non-professional drivers with experience of driver assistance systems.	Real traffic conditions on motorways and urban streets.
Study 3 – Conditional automation (2021).	Bus.	Conditional driving automation (L3).	10 professional bus drivers with little to no experience of automation in buses.	Real traffic conditions in an industrial area with five bus stops.

Two of the studies were conducted using automation in private cars, one with simulated full driving automation (Study 1); one with both partial driving automation and high driving automation (Study 2), and one using a conditionally automated system in a bus, in other words a system that could automatically dock the bus at bus stops (Study 3). Consequently, the users in Study 3 were professional bus drivers, in contrast to Studies 1 and 2 where the participants where non-professional users, even if it should be noted that the bus drivers had little to no experience with AV systems in buses. Hence, even though some participants in the studies had previous experience of automated systems, they had not experienced as a high level of automation as they did in the studies and could therefore be regarded as novice users.

Furthermore, as earlier mentioned, all the studies strived to have as naturalistic settings as possible but due to the constraint of an as yet non-existent AV system, Study 1 was conducted on a test course with bidirectional rural road and urban streets, where different traffic situations were staged to resemble everyday traffic. The other two studies were conducted under real traffic conditions, Study 2 on motorways and urban streets with dense traffic and Study 3 in an industrial area with light traffic. The difference in character enabled an exploration of how users make sense of AVs in different contexts and also enabled a comparison between different aspects of factors influencing how users make sense of AVs, such as automation level.

3.2. Data collection

The overall process of the thesis project has been of an explorative character (cf. Jupp, 2006); the phenomenon of interest in the thesis – how users make sense of AVs – has received little attention in earlier research, which makes an explorative approach useful (Jupp, 2006). The data collection procedure evolved during the process of the thesis project based on reflections on earlier studies.

An overview of the data collection methods used is found in Table 3.

Table 3
Overview of data collection methods used in the empirical studies.

Studies	Data collection methods
Study 1 – Full automation (2017).	Think-aloud protocol. Individual interviews (before and after test runs).
Study 2 – Mixed automation (2019).	Think-aloud protocol. Individual interviews (before and after test runs), using mediating objects and a simplified version of ACTA.
Study 3 – Conditional automation (2021).	Individual interviews (before and after test runs). Observations.

The way users make sense of artefacts is a complex process that is not observable, and may be hard for users to verbalise or sometimes even be aware of. Therefore, to capture participant narratives that could elucidate their process of making sense of the AV, qualitative data collection methods were primarily chosen. In order to be able to elicit rich data, revealing the complexity and richness of the phenomenon (Given, 2008), multiple data collection methods were used such as think-aloud protocols and interview techniques with mediating objects (e.g. Ekman, Johansson, Bligård, Karlsson, & Strömberg, 2019; Johansson & Ekman, 2021), such as templates of the interface to trigger reflection. The methods were used both during and after use of the AV in order to elicit different aspects of the complex process of making sense. However, some quantitative data capturing user actions was also collected in order to compliment the qualitative data, since it may indicate meanings relating to how the AV should be used, that are not verbalised by the users. The specific data collection processes are presented in Chapter 4 Empirical studies.

Furthermore, the part concerning users' understanding in the first study was explorative, with data collection methods broadly focusing on users' understanding and data analysis methods with an inductive character concerned with discovery. Along the way it was possible to focus the methodology, with more deliberate choices of data collection and data analysis methods. Data collection methods that were deemed as effective in eliciting in-depth data, useful to describe how users understood the AV, were used in succeeding studies, and slightly modified to be even more effective. For instance, the think-aloud protocol (cf. Charters, 2003), where participants verbalised their thoughts when using the AV, was used again in Study 2, after being used in Study 1, but with added trigger questions that were intended to elicit certain specific aspects of users' understanding. The multiple studies also made it possible to focus the data collection and analysis on aspects that earlier studies had not explored. For example, the first study did not involve any actions by the participants, the data collection and analysis in Studies 2 and 3 could focus more on how users understood and acted on their understanding of the AV. However, it should be noted that the choices of data collection methods were always balanced against other interests and aims of the studies, as an effect of the research collaboration context, in order for the methods not to conflict or exhaust the participants.

3.3. Data analysis

In qualitative research it is considered essential to not only clearly state why and how the research has been conducted but to also provide a clear description of analysis methods (Braun & Clarke, 2013). The following section describes the analysis of the data in the thesis, which was divided into three phases.

3.3.1. Initial analyses

In the first phase, an analysis was performed of each of the studies, focusing on the different aspects of the studies, in order to contribute to the specific aims of each study, e.g., the effect of two levels of automation on users' understanding in Study 2. An overview of what aspects of the theoretical framework the papers concerned is found in Table 4.

Table 4
Overview of the aspects of the theoretical framework that each of the appended papers concerned.

Study	Paper	Aspects of the theoretical framework concerned
Study 1	Paper A	• Effects of signifiers originating from the AV driving behaviour on meanings associated with the AV • Influence of the conceptual model.
	Paper B	• Meanings on all three levels associated with the AV and influences between meaning. • Signifiers originating in the AV driving behaviour.
Study 2	Paper C	• Dimensions of meaning associated with the AV, how they relate and influence each other.
	Paper D	• Dimensions and types of meaning associated with the AV • The effect of signifiers originating from several information channels. • Action-meaning circularity
Study 3	Paper E	• Effect of users' conceptual model and signifiers on meaning associated with the AV. • The effect of context (use and work context).

The findings from the appended papers contribute to different parts of the specific interest of the thesis but in order to contextualise and identify patterns between the studies, an additional analysis was performed using a common framework for all three studies. The additional analysis, a descriptive analysis (Phase 2, in the middle of Figure 4, together with a cross-study synthesis (Phase 3, at the bottom of Figure 4) were performed to answer the overarching and supplementary research questions.

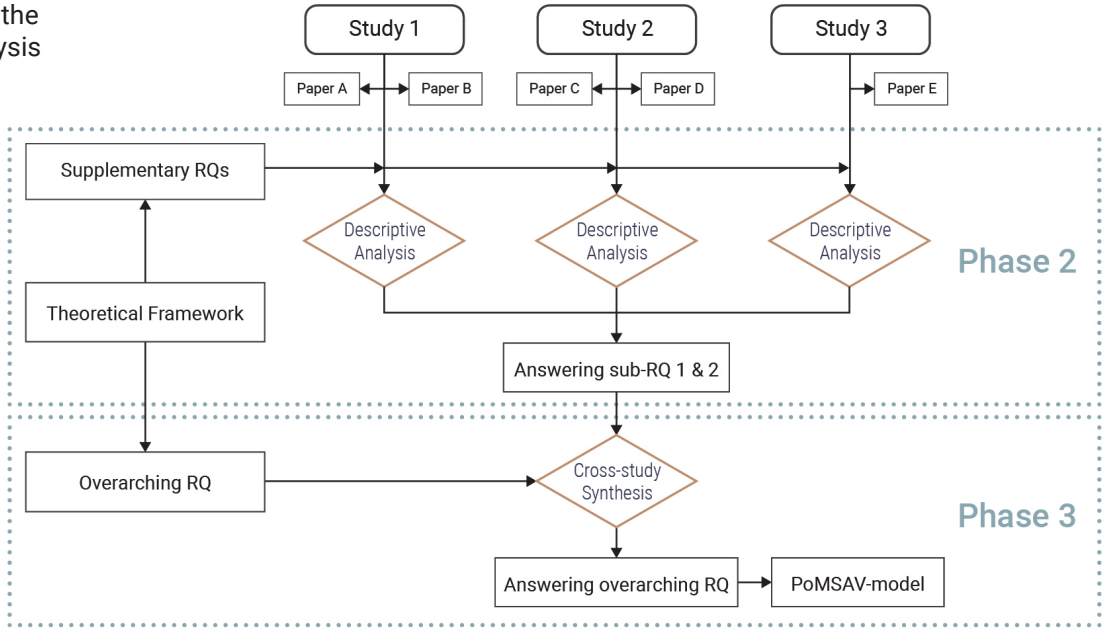

Figure 4
The process for the descriptive analysis and cross-study synthesis.

3.3.2. Descriptive analysis

The aim of the Phase 2 analysis was to identify what the findings from the studies could represent in the process of making sense, by analysing and summarising the results from the empirical studies using the theoretical framework as a theoretical lens with the two research questions as guiding questions. The focus of the analysis was to identify similarities between the data and theory to identify and describe factors and relations from the theoretical framework using the specific artefact of interest in AVs; develop existing theory by further describing earlier identified factors and relations; and discern dissimilarities between the empirical findings and theory to identify new factors or relations that have not previously been explained in theory.

The descriptive analysis conducted used a thematic analysis adopted from Fereday and Muir-Cochrane (2006), involving both inductive and deductive coding and theme development. The thematic analysis is a systematic approach that involves the identification of themes in data, such as interview transcripts, which are important to the description of the phenomenon (Mills, Durepos, & Wiebe, 2010). This section describes the four-step process used to analyse mainly the verbal statements of the participants in the three empirical studies* (see Figure 5). As also noted by Fereday and Muir-Cochrane (2006) in their description of the procedure, even if the analysis is presented as a step-wise process, the analysis was highly iterative.

In the **first step**, a code template was developed based on the theoretical framework and the research questions of the thesis. The four factors (meaning, signifiers, conceptual model, and context), including sub-factors, and relations (action-meaning, conceptual model-meaning, and signifiers-meaning) from the theoretical framework formed broad code categories making up the code template later used in Step 3.

* It should be noted that because of the theoretical framework used in the thesis, concepts and naming may differ from the papers.

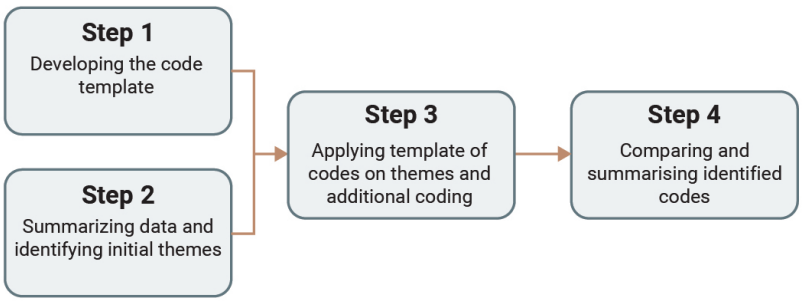

Figure 5
The four steps of the descriptive analysis.

The **second step** of the descriptive analysis had an inductive approach, which was performed through a detailed reading of the raw data, i.e., transcripts, to derive themes based on interpretations of the data, allowing findings to emerge from the data based on frequent, dominant, or significant themes (cf. Thomas, 2006). This was done through a rigorous and systematic reading of the participants' statements, taking into account different meanings, where segments were coded regarding what they referred to about users' understanding of the AV, for example understanding the functionality of the AV or what the various design elements meant; comparing to other artefacts; or explanations of how they understood a certain aspect of the AV. These codes were then clustered together based on mutual similarities, which allowed themes to emerge from the data. This was initially done in Phase 1 but was reiterated to compile the findings from the different papers and to explore whether complementary data existed that had not been used in the initial analysis but were deemed to be relevant for the aim of the thesis. Toward the end of the second step of the descriptive analysis no new themes emerged, suggesting that major themes were identified. The themes that emerged in Step 2 provided an overview of what the participants referred to about the AV but also sorted out statements that were considered as not relating to users' understanding of the AV, working as a form of data reduction (cf. Miles & Huberman, 1994).

After different themes had emerged, **step 3** focused on what the statements in the themes could represent regarding the process of making sense. This was conducted using a deductive approach, where the code template based on the theoretical framework was used as the theoretical lens. In Step 3, the analysis aimed at answering the three supplementary research questions by comparing the statements in the themes identified in Step 2 with the broad code categories in the code template developed in Step 1 and coding the statements that were representative for each code category. This was done to identify commonalities between the character of the themes and the factors and relations previously described in the theoretical framework. The analysis in Step 3 first focused on the factors influencing how users make sense, e.g., indications of signifiers and conceptual models, and then on how the factors interact. The analysis in this step was guided but not confined by the codes in the template, and inductive codes were also assigned to the statements which were either separate from earlier code categories or expanded existing ones (cf. Fereday & Muir-Cochrane, 2006). This included, for example, expansions of factors such as sub-categories of meaning, and identification of new relations

between and within factors. In the **fourth and final step**, a cross-study analysis was conducted to compare and summarise the descriptive analysis of each respective study in order to answer both research questions.

The outcome of the descriptive analysis of the respective study is presented in Chapter 4 Empirical studies, where referrals from the studies are used as illustrative examples and for the transparency of the analysis, in order to enhance the readers' understanding of my own interpretations and improve the interpretive rigour (cf. Fereday & Muir-Cochrane, 2006). The outcome of the cross-study analysis is presented in chapter 5 Answering research questions.

3.3.3. Cross-study synthesis

After the cross-study analysis was completed, a cross-study synthesis was conducted to interpret and synthesise the findings in order to describe how the factors and relationships relate to each other and could be organised into an explanatory framework consistent with the participants' statements. This was done to answer the overarching research question – *How do users make sense of AVs during use* – by synthesising the findings of the supplementary research questions. The synthesis is presented as a model that is intended to illustrate the process itself, as well as the factors and relations that are important to consider when designing and investigating how users make sense of AVs. The model was developed in an iterative interpretation process, which organised the identified factors in accordance with the identified relationships, forming a momentary cross-section of the process. Therefore, the synthesis also aimed to identify indications of any temporal affects in the factors and relationships to elucidate the process of making sense over time. Moreover, the synthesis iteratively compared the model that emerged with the findings from the empirical studies and existing theory utilised in the theoretical framework, in order to reavaluate the earlier information in the light of the new knowledge that was generated. The proposed model of how users make sense of AVs is described in Chapter 5.3 PoMSAV – process of making sense of AVs.

04
EMPIRICAL STUDIES

This chapter describes the outcome of the descriptive analysis of individual studies, based on the initial analysis, by providing a summary of the method used and the findings from each of the three empirical studies that formed the basis for the cross-study analysis presented in Chapter 5 Answering research questions. The findings presents the identified factors influencing how users make sense of the AV and the relations between them, using the theoretical framework as a lens.

4.1. Study 1 – Full automation

The description of Study 1 is a summary of the study and the analysis based on the descriptive analysis that complements the analysis described in papers labelled A and B:

- Paper A - Johansson, M., Ekman, F., Karlsson, M., Strömberg, H., & Bligård, L. (2021). *Talking Automated Vehicles: Exploring Users' Understanding of an Automated Vehicle During Initial Usage*. 3rd International Conference on HCI in Mobility, Transport, and Automotive Systems, MobiTAS 2021, held as part of the 23rd International Conference, HCI International 2020.
- Paper B - Johansson, M., Ekman, F., Strömberg, H., Karlsson, M., & Bligård, L. (2021). Capable and considerate: Exploring the assigned attributes of an automated vehicle. *Transportation Research Interdisciplinary Perspectives*, 10, 1-10.

4.1.1. Method

In order to explore how users understand AVs, Study 1 was conducted with a simulated fully automated AV system, with two different driving styles, on a test track. A *Wizard-of-Oz approach* was used to simulate the AV, utilising 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), in two separate test runs. 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 (see Figure 6). During each test run, the participants encountered different situations such as overtaking a car or stopping for a pedestrian at a pedestrian crossing.

Figure 6
Test route in Study 1.

Nineteen participants between 20 and 50 years old (M = 36.7, SD = 11.1) with different occupations (including students, engineers, administrators and economists) took part in the study. All participants had a valid driver's licence 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.

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 experience of the AV. Thus, data collection took place both *during and after* the test runs to capture instantaneous interpretations as well as comparisons between driving styles and deeper reflections. The recordings of think-aloud protocols and interviews were transcribed and later analysed.

4.1.2. Findings

The findings from the analysis reveal several meanings associated with the AV, indications of users' conceptual models and signifiers, and the effect of the environment as well as several relationships, both within and between the different factors.

Developed meanings and interrelations

Analysis of the participants' statements indicated that different kinds of meanings arose during use of the AV, ranging from sensorial meanings to meanings relating to an overall character of the AV. In general, the meanings that were identified were interpretations of the AV itself rather than its relation to the user.

Meanings on all three levels, presented in the theoretical framework, could be identified. The most common meanings that arose were about the sensorial experience, i.e., Level 1 meaning. 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 the interpretations of driving properties).

Furthermore, several types of interplay meanings, i.e., Level 2 meaning, were identified based on the participants' statements, which were categorised into (further described in Paper B):

- *Meanings relating to functionality* described a decision-making process that the vehicle used 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), due to the braking of the AV.
- *Meanings relating to abilities* involved the AV's ability to perform actions and signal intent to internal (driver) and external (other road user) actors. One participant explained how the behaviour of the AV signalled its intent: "*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 could be prepared*

for something to 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 on 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 actions of the AV when turning 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 meanings are interpretations of how the AV is able to perform the driving task and why it drives as it does. This was the level where the most diverse meanings could be identified, and different types were discerned.

Lastly, meanings relating to the overall experience of the AV were also identified, i.e., Level 3 meaning, being an interpretation of the AV's overall character where the capability and consideration of the AV varied. 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, i.e. comparisons of two unlike things (see more in paper A), for instance that of a 'Father', where they used past knowledge of human drivers to explain the character of the AV.

These different levels of meaning seem to have affected each other, where meanings were sometimes based on each other like a chain (Paper B). For example, for one participant several different meanings arose in the same situation: *"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 was not possible to conclude if the meanings are formed in a process which begins from the lower-level meanings (e.g., interpreting jerky behaviour) and on that basis formed higher-level meanings (e.g., not having foresight), as the process started from sensorial impressions described in the theoretical framework. In contrast, the formation process may have occurred in the opposite direction, starting from a higher level, reinforced by pre-existing higher-level meanings in the user's conceptual model, which could be seen in the participants' expectations of machine-like driving behaviour. 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 have evoked meanings about certain abilities that the participant expected from an aware AV, and so forth. In conclusion, based on the available data, it was possible to derive several levels of meaning, as suggested by the framework, and to see that they affected each other, but not in which order.

The relation between signifiers and meaning

As seen in earlier section of the findings, meaning often arose based on signifiers originating from AV driving behaviour, which was evident in the large number

of referrals that mentioned different properties of the driving behaviour (further explained in Paper B). However, even though not to the same extent, participants also mentioned other signifiers such as sounds from the vehicle or its physical form (interior and exterior). For example, participants interpreted the sound of the car shifting gear as a signal that it was preparing itself for an action. It was not always possible to determine from the data which meaning arose from which specific sensorial impressions. 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 properties of the driving behaviour resulted in different interpretations, since each of the similes used by the participants to explain and compare the AV's behaviour was only used in connection with a specific driving style (further described in Paper A).

Thus, even though meaning is highly subjective, a certain configuration of the properties in the driving behaviour, in other words driving style, seem to have evoked similar higher-level meanings.

Furthermore, the meaning that is associated with an artefact is believed to be influenced by the environment in which it is used. This was evident in the analysis. Environment included the situations encountered (such as road conditions) and other road users (e.g., pedestrians and bicyclists). The perception of the vehicle did not seem to be affected only by driving behaviour but also by how the user interpreted the AV in the environment, evoking one meaning in an environment with certain signifiers but another meaning in another context with different signifiers. For example, in a situation involving other road users slow acceleration was interpreted as the AV 'having control' but in a situation without other road users it was interpreted as 'stupid'.

The environment seems to have affected the development of meaning by acting as signifiers, therefore proposing a distinction between artefactual signifiers (i.e. signifiers originating from the artefact) and what I refer to as environmental signifiers, that is to say specific signals that participants used to interpret the AV that were not part of the artefact itself.

The influence of the conceptual model

As indicated in the previous section, the process of making sense was not only affected by the direct influence of signifiers but also by the participants' conceptual model, as expected. Several of the findings from the analysis of Study 1 shed light on the conceptual model of the study participants. Findings indicate that participants use past meanings to make sense of their interaction with the AV. This was identified in the participants' preconceptions about the driving behaviour and capabilities of an AV, indicated by the differentiation between human and machine-like characteristics of the driving behaviour (as described in 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 as an AV. This conceptual model created expectations of driving behaviour, which was noticeable in referrals where participants stated that an action or behaviour did or did not feel like that of a machine or an AV, that is to say matched or did not

match their conceptual model. For example, one participant stated: *"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), where the meaning arising (jerky) did not match the user's conceptual model of how an AV should drive (smooth and aware).

However, besides conceptual models of AVs, the use of human similes and human-like characterisations and terms (see Paper A for further details) indicate that participants also used conceptual models of human driving behaviour to explain and/or interpret the AV's driving behaviour: "*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).

Hence, the conceptual models used were not only constructed based on previous experiences of the same and similar artefacts but also similar experiences, in other words one's own and other humans' driving.

Assessment process

The identified meanings were often not neutral but had a positive or negative connotation, especially the higher-level meanings (for example the AV being perceived as professional), indicating some form of assessment in the process of making sense (see Paper B). These positive or negative connotations seem to have been affected by the sensorial meanings that arose, which influenced the way the participants talked about other meanings in positive and/or negative terms. Overall, the meanings associated with the defensive driving style (such as 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 (such as powerful acceleration and close distance to objects). However, even if the main characteristics were similar in the previously described similes, 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. One user interpreted 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 indicated that similar AV driving behaviour could evoke different meanings relating to overall character in different users, possibly because of different notions about what a "good" driver is based on individual experiences. Thus, similar sensorial impressions seem to lead to similar negative and/or positive connotations in meanings, although the influence of users' conceptual models on the assessment of higher-level meaning was also identified.

Summary

In summary, the analysis of Study 1 identified meanings on several levels, as described in the theoretical framework, and showed that the meanings affected each other. Even though meaning is highly subjective, a certain configuration of the AV driving behaviour seems to have evoked similar higher-level meanings. Furthermore, the environment affected the process of making sense by providing environmental signifiers. Lastly, the users' conceptual model was seemingly not only constructed based on previous experiences of the same and similar AVs but also on the participants' own and other humans' driving, which seem to have affected the assessment of higher-level meanings.

4.2. Study 2 – Mixed automation

The description of Study 2 is a summary of the study and the analysis based on the descriptive analysis that complements the analysis described in papers labelled C and D:

- Paper C - Novakazi, F., Johansson, M., Strömberg, H., & Karlsson, M. (2021). Levels of what? Investigating drivers' understanding of different levels of automation in vehicles. *Journal of Cognitive Engineering and Decision Making*, 15(2-3), 116-132.
- Paper D - Johansson, M., Novakazi, F., Strömberg, H., & Karlsson, M. (2022) Piecing the Puzzle – Exploring the influence of different information sources on users' understanding of an automated vehicle. *(Submitted to Behaviour & Information Technology)*.

4.2.1. Method

In order to investigate how users understand multiple levels of automation in the same vehicle, Study 2 was conducted, using a *WOz setup* where users experienced an ADAS and a simulated ADS. The WOz setup involved two "wizards", one wizard who simulated the ADS from the back seat with hidden equipment and one wizard who controlled the in-vehicle interface by initiating the hand-over and take-over sequence, when availability conditions were met or no longer met. *The two levels of automation* consisted of: (i) a fully functioning ADAS that supported the driver, who was still in control of the dynamic driving task, by maintaining a set speed and adjusting the speed with regard to vehicles in front as well as providing steering assistance through lane-keeping support; and (ii) a simulated ADS that performed the dynamic driving task (full lateral and longitudinal control) when active, where the participants were able to engage in non-driving related activities such as using the phone. The function was only available in congested traffic.

The driving sessions were conducted on *public roads* in San Francisco Bay Area, USA in the morning and afternoon during *rush hour* on highways and in urban areas and each session took approximately 1.5 h (see Figure 7). Before the driving session, participants received oral and written instructions regarding the AV systems' functionality*, both in an interview room and inside the vehicle.

* The instructions included information: (i) that the ADS completely takes over the driving task in congested traffic conditions (but the participant did not receive information about the detailed availability conditions); (ii) that the ADS will notify the driver when available and when conditions were no longer met, and the driver then needs to take over; (iii) about how to activate and deactivate both modes and where notifications would be available (but not what the

Figure 7
Test route in Study 2.

Twenty participants took part in the study, 11 male and 9 female, ranging from 22 to 62 years old (M = 41.5, SD = 13.74). All participants: (i) held a valid driving licence, (ii) commuted by car daily, and (iii) drove a car equipped with automatic gearbox and cruise control, and (iv) had an occupation outside of vehicle manufacturing and development.

Data was collected using *several qualitative data collection methods*. During the driving session, the participants were encouraged to think aloud (cf. Charters, 2003), i.e., verbalise their thought processes. If not already mentioned by the participants themselves, the test leader also posed questions at predefined situations during the ride to trigger the participants to verbalise their thoughts (e.g. what cues made them aware of system status). After the driving session the participants were interviewed using several different interview techniques, such as a *simplified version of ACTA*[*] and interviews using mediating objects, i.e., paper template of the in-vehicle display, regarding how they understood the AV system during the driving session. The recordings of the think-aloud sessions and interviews were transcribed and later analysed.

4.2.2. Findings

The findings describe a multitude of meanings that arose regarding the AV itself and its relation to the user; relationships between and within meanings and signifiers; and the influence of user actions.

Meanings regarding AV itself and its relation to context

The participants referrals indicate that meaning arose regarding the AV itself (e.g. how the system worked), similar to the meanings identified in Study 1, but also to the second dimension of meaning in the framework, how the AV related to the user and context (e.g. where and how the system could be used). The different types of meanings[**] are further described in papers C and D.

The meanings regarding the AV itself, included:

- *Meanings relating to system role,* were interpretations of what type of AV system it was and how much control of the driving it had. One participant described the ADAS as: *"helps keep you safe when you're driving by being kind of a second pair of eyes while you drive"* (P17).
- *Meanings relating to its functionality,* such as being aware of the surroundings and what actions the AV was able to perform: *"[the ADAS] will keep you in the same lane, but I assume that the [ADS] can move us over so..."* (P4).
- *Meanings relating to current system state*. consisted of interpretations of the current state of the system: *"it said [ADS] activated and now it's moving by itself so I'm going to assume it's working unless this is a possessed car"* (P19).

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notifications would look like); and (iv) that the ADAS was available all the time.

* The method used was an adaptation of the Applied Cognitive Task Analysis (ACTA) (Militello & Hutton, 1998) and was an interview technique that aimed at eliciting information regarding users' understanding of the general idea of what the system does; expected and surprising situations; and how they knew that the situation occurred and what would possibly make it hard to notice.

** In papers referred to aspects of understanding.

The meanings that arose regarding how the AV related to the user and the context in which it was meant to be used included:

- *Meaning relating to user role* described the role the participants believed they had when the system was activated. One participant described the role when using the ADAS as being a navigator: *"I don't worry about the speed, I don't worry about braking, I don't worry about that, I just worry about going straight; you know, I'm just the navigator"* (P8).
- *Meaning relating to use domain* were interpretations of where and when the system was intended to be used and under which circumstances: *"I thought I would use it when traffic is dense. I mean, I thought in these small areas I might do it myself"* (P18).
- *Meaning relating to user actions* involved interpretations of how to operate the system, including how to activate and deactivate the system, and how to operate parts or all of the dynamic driving task. *"I still have to drive and steer the car to where it is supposed to go, but it assists in the overall process; in essence, it is a kind of smarter cruise control"* (P2).

Moreover, the two dimensions of meanings regarding the AV itself and its relation to the context and user seem to have affected each other, indicating a relationship between the two. For example, one participant interpreted that the AV was able to maintain lateral control but was unsure how that affected their own actions: *"It's keeping me in the lane; does that mean I don't have to [have the hands on the steering wheel]"* (P15). Contrarily, for another participant, meaning relating to system role was affected by how they believed they were supposed to act: *"It's kind of the same function because it's like... [both are] kind of hands free"* (P12), believing they were the same AV systems because the participant thought they could act in the same way when using them. Thus, meaning regarding how the AV relates to the context and user seems to affect participants' interpretation of what the AV is and its functionality, and vice versa.

Intentionally designed and incidental signifiers

Meanings arose seemingly based on signifiers originating from various in-vehicle interfaces (displays, seat belt, auditory signal, and steering wheel) and vehicle behaviours (lateral and longitudinal movement), as well as environmental signifiers* (the road and other road users), which are further described in Paper D.

Some of the signifiers noticed and mentioned by the participants were intentionally designed, such as a hands-on-wheel icon in the display that was meant to inform the user that they were supposed to keep their hands on the steering wheel. However, unsurprisingly, it was evident that the intentionally designed signifiers were not always interpreted by participants as intended by the designers. One example is the earlier mentioned hands-on-wheel icon. Most participants interpreted this signifier as intended but some interpreted it slightly differently to what was intended by the designers. For example, one participant who thought the need for hands on the steering wheel was only temporary, believed the system needed assistance during a certain part of the drive: *"It's telling me to put my hands on the steering wheel,*

* Signifiers originating in the environment, as defined in Study 1.

maybe for safety precautions, maybe it's not fast enough to brake [during these conditions]" (P8), referring to the ADAS as not being able to handle the combination of high speed and dense traffic (meaning relating to functionality). Thus, even if the driver was intended to control the DDT all time when the ADAS was active, some participants believed drivers' assistance was only needed temporarily. On some other occasions participants were not able to interpret the signifiers at all. For example, one participant did not manage to interpret what an auditory signal meant: "*Oh wait, is that a bad sound?"* (P13), understanding that it signified something but not what. Thus, even if often interpreted as intended, the intentionally designed signifiers were sometimes not understood at all and in other cases interpreted almost as intended but not to the full extent.

Other signifiers that influenced the participants' interpretation were, as described in the theoretical framework, incidental signifiers, that is to say not intentionally designed. For example, one participant believed that when the ADS was activated and apps appeared in the centre stack display, it signified that the user was no longer responsible: *"It tells me I can watch YouTube"* (P13). The assumption was true, but the system designer's intention behind displaying the apps was not to signal responsibility but simply to enable the use of the apps. Thus, existing design elements signified additional meanings than those originally intended by the designers.

In other cases, participants used signifiers that were not intended to signify any meaning about the AV system at all but were instead designed for other unrelated functions. For example, one participant believed that since the whole route of the test run was available in the GPS system (signifier), the AV system would be able to drive the same route (meaning relating to functionality): *"I don't know why I need to take over, if we program the route to take [referring to route on GPS]. If these sensors and everything are working correctly, couldn't the system just do that job?"* (P9).

Hence, incidental signifiers consisted of design elements which gave rise to an additional meaning, other than it was intended to signify; signifiers not belonging to the AV system itself; and environmental signifiers, which are beyond the designers' power to influence.

Relationship between signifiers and meanings and between signifiers themselves

According to the theoretical framework, meaning and signifiers are interrelated since signifiers communicate meaning. From the analysis of the study, it appears that meaning sometimes arose directly based on a single signifier, for example when participants interpreted an icon in a display; but also based on several signifiers simultaneously in parallel, for instance when environmental signifiers – which were almost always used in parallel with artefactual signifiers – and signifiers originating in the in-vehicle interfaces together resulted in the development of meaning relating to functionality. As an example, a statement from a participant illustrates how the speedometer, vehicle behaviour (artefactual signifiers) and other road users (environmental signifiers), in parallel, became signifiers: "*So my pilot assist is sensing 55 but it's not getting to 55, I think it's because if I do 55 I won't maintain the distance to the car in front so it's preventing me from doing it, which is pretty cool. And now that car is braking a little bit and, oh I'm braking a little bit. Now*

they are braking a lot, now I'm breaking a lot" (P8). Meaning did not only seem to arise based on several signifiers in parallel but also sequentially, where one signifier directed the participants' attention to another, developing new meaning or prompted the participant to act. For example, a seat belt tug during takeovers* signified action and was commonly interpreted sequentially, directing attention to other signifiers in the in-vehicle display. A participant explained it as: *"I was alerted by the slight tug of the seat belt, which I noticed first, then I noticed it in the instrument panel, right? Told me to take over"* (P14). Thus, meaning appears to have arisen based on single signifiers and several in parallel and sequentially by directing attention immediately or by changing participants' focus of attention.

In some of these situations when several signifiers were interpreted simultaneously, the cause of the AV behaviour was misinterpreted since participants attributed the cause of the vehicle's action to the 'wrong'** signifier. For example, one participant interpreted lateral movement of the vehicle as an intentional lane change when actually the system was inactive due to insufficient lane markings and therefore drifted. This interpretation was a consequence of environmental signifiers being used, instead of the signifiers in the in-vehicle display (which intended to signify that the system was not active), to make sense of the situation: *"I think that perhaps because the traffic was flowing better in that lane and the lane was clear that it decided to take a different .. take a better route … it went that way, but it didn't go all the way over to the next lane. And then from the rear I could see a car coming up in that lane. So, I'm assuming that the system was smart enough to detect all of those things, and make a casual move"* (P5). The participant also did not notice the absence of lane markings that could have signified the meaning of the vehicle behaviour, more accurate to the actual situation. However, sometimes when participants did interpret design elements such as icons in the in-vehicle displays, as intended by the designers, the functionality they already believed that the system had – their conceptual model – sometimes created confusion. For example, one participant stated that *"I know that it is [driving] but I don't know if it tells me that it is and when I should take the wheel because it has hands on it, right? But it also feels like it is in control right now"* (P13), being confused over why to put their hands on the steering wheel (meaning) when the system had the functionality to drive (conceptual model), indicating a relationship between the conceptual models and meanings. Thus, misinterpretations of the AV occurred both due to attribution of the cause to the 'wrong' signifier and due to conflicts between interpretation of design elements and earlier developed meaning.

Moreover, the context, except when providing environmental signifiers (as described in Study 1) also seems to have affected participants' ability to perceive signifiers provided by the in-vehicle interfaces. Even though intentionally designed signifiers for how to activate and deactivate the automated system were provided by the in-vehicle interfaces, the signifiers were almost only used by participants to interpret how to deactivate the system, and not how to activate it. This is likely to do with the fact that participants were in control of the driving and focused their

* Haptic signal designed to indicate that a takeover was needed.

** 'Wrong' here refers to a signifier that to the user is considered as signifying a meaning that explains the situation but does not explain the actual situation.

attention on the road, not noticing the cue in the display signifying how to activate the system. Thus, the use context seems to have influenced the participants' ability to perceive signifiers by affecting their attention.

Users' conceptual model

In addition to the previously described signifiers, findings indicate that the user's conceptual models were mostly influenced by the instructions given to participants before the test run and general assumptions* regarding the AV system; but also by previous experiences with other technical systems as well as naming of the AV systems; and meanings arising from social interactions or media. For example, one participant explained how the meaning relating to the functionality of the AV was influenced by expectations of the AV technology due to experience with other technologies: *"I wonder if it'll take other routes for traffic too … just because technology is very advanced now and I don't think it would be too hard to maybe incorporate that into the car, because our phones know it so... I don't know. I think cars are just becoming as smart as our phones"* (P16), expecting that the AV was more advanced than it was because they experienced smartphones as very advanced.

Furthermore, conceptual models were often used in combination with different signifiers in order to make sense of the AV and understand how to operate it. For instance, instructions and earlier experiences affected expectations that in combination with environmental and artefactual signifiers influenced the process of making sense. This was illustrated by a participant who interpreted the functionality of the ADAS based on the conceptual model, as well as artefactual and environmental signifiers: *"Well, it's at the top number, but it's not accelerating. I thought that was a part of cruise control [referring to the ADAS using the wrong name]. Like only when I put my foot on the accelerator ... Maybe it doesn't want me too close to the car in front?"* (P16), expecting the ADAS to maintain a set speed (conceptual model) but the vehicle's own deceleration (artefactual signifier) when approaching other road users (environmental signifier) modified their understanding of the functionality.

In other situations, the statements indicated that noticed signifiers could override 'correct' expectations about the AVs functionality and actions that the user was supposed to perform, in other words disregarding instructions due to interpretations of design elements. For example, one participant stated that *"I just forgot about that part [having to push buttons to deactivate system], because it said, 'take over driving now' and I just started driving now. So my first reaction was to start driving and I forgot, you know, how to turn off [the ADS]..."* (P11), resulting in the participant temporarily failing to deactivate the system, since even knowing how to deactivate the system, the cue signified a meaning that resulted in an inappropriate action.

Thus, conceptual models – an important factor when users make sense of the AV – were often used together with different signifiers and were seemingly partly constructed by instructions, word of mouth and earlier experiences with similar technologies.

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* Assumptions that are not apparently influenced by the instructions, information from media and so on, or earlier experiences with similar artefacts.

Action-meaning circularity

According to the theoretical framework, users actively affect the process of making sense through an action-meaning circularity. This was evident in the findings where meanings often arose after an action by the participant. The actions that the participant performed were directly prompted by signifiers during use, for instance elements in in-vehicle displays, or executions of their conceptual models, that is to say the participant acted based on previous understanding or assumptions about the system, which depending on signifiers originating from in-vehicle interfaces or environment could lead to new meanings being developed. For example, one participant expected the AV to be able to adjust the speed according to the speed limits, but after adjusting the speed and interpreting the signifier from the in-vehicle interface, modified the meaning related to the AV: *"Well, it doesn't know the speed limit, huh? [referring to the readout on the speedometer going above the road's speed limit] So, when I was clicking it up a bunch of times and then I clicked it down because it... it doesn't know the speed limit of the road, I have to pay attention to that... So we work together"* (P9).

Summary

In summary, meaning regarding how the AV relates to the user and context seems to affect participants' interpretation of the AV itself and its functionality, and vice versa. Both intentionally designed and incidental signifiers were identified, where the incidental signifiers consisted of design elements which gave rise to an additional meaning other than it was intended to signify; signifiers not belonging to the AV system itself; and environmental signifiers. Meaning appears to have arisen based on single signifiers, several in parallel and sequentially. The users' conceptual models were often used together with signifiers and were seemingly partly constructed by instructions, word of mouth and earlier experiences with similar technologies. Moreover, misinterpretations of the AV occurred both due to attribution of the cause of a behaviour to the wrong signifier and due to conflicts between interpretation of design elements and earlier developed meaning.

4.3. Study 3 – Conditional automation

The description of Study 3 is a summary of the study and the analysis based on the descriptive analysis that complements the analysis described in papers labelled E:

- Paper E - Johansson, M., Ekman, F., Karlsson, M., Strömberg, H., & Jonsson J. (2022). ADAS at work: assessing professional bus drivers' experience and acceptance of a narrow navigation system. *Cogn Tech Work (2022)*. https://doi.org/10.1007/s10111-022-00704-4

4.3.1. Method

The third study was conducted to investigate how drivers understand an ADS that can assist bus drivers when docking at bus stops. The ADS could perform the lateral and longitudinal DDTs that are to be performed just before and when *docking at bus stops* (see Figure 8). While the ADS could perform the full DDT during dockings, a partial *Wizard-of-Oz approach* was used, where a test leader inside the

Figure 8
Test route in Study 3.

bus had to prepare activation of the ADS at some distance prior to the bus stop, by initiating the system. When the test leader had initiated the process, it was possible for the participant to activate the ADS by keeping an activation button, located to the right of the dashboard, pressed down for half a second. When activated, the driver was still responsible for the driving task and was told to monitor the system and always be ready to intervene if the ADS failed.

The study was conducted on *public roads* with regular traffic located in an industrial area in Gothenburg, Sweden. The route that the participants drove was 2.7 km long and included five bus stops of different character, ranging from regular bus stops to roadside parking spaces. After receiving verbal instructions about safety aspects and system functionality and being allowed a practice session*, each participant drove the route six times in total: first, one lap manually to become familiar with the route and the different bus stops and then five laps while using the ADS to familiarise with the system. During the first two laps, participants were helped by a test leader to position the bus and what speed to have when activating the system.

Ten participants took part in the study, nine male and one female. All participants were *professional bus drivers* with between 1 and 41 years of driving experience (M = 14.1, SD = 14.4) and their age ranged from 32 to 71 years (M = 52.3, SD = 11.9). All participants had little to no experience with automated systems in buses.

Data was collected *before and after* the test runs using *qualitative data collection* methods in the form of semi-structured interviews and during test runs by collecting video data. The interview before the test was held in order to understand participants' attitudes and expectations and after the test to gain a deeper understanding about the participants' acceptance and understanding of the system. The recordings of the interviews were transcribed and later analysed. *Video data* was collected in order to investigate behavioural indications of meaning such as meaning relating to user actions.

4.3.2. Findings

The findings describe meanings regarding the AV itself and its relation to the user; relations between meanings; the influence of signifiers and conceptual models; and the effect of the context on users' attention.

Meanings and interactions across levels and dimensions

Several types of meanings were discerned from the participants' referrals, both interpretations of the AV itself and how it relates to the context and user.

Similar to the sensorial meanings, i.e., Level 1 meaning, identified in Study 1, participants often described the AV driving behaviour as for example 'harsh', 'soft' or 'jerky'. These meanings were mostly identified in statements concerning the hand-over procedure but sometimes the entire docking procedure. Also, like the findings from Study 2, several types of meanings about the interplay, i.e., Level 2 meaning, were identified, both regarding what the AV is and how it relates to the context. The meanings regarding what the AV is included:

* During the practice session, participants got to activate the system, override the steering and deactivate the system.

- Meanings relating to system role were high level interpretations of what the system is and its role, often interpreting the AV system as either assistive or autonomous: *"If someone comes running, I know that the [AV] system is a back-up, so that nothing will happen. It's a form of collaboration"* (P2).
- Meanings relating to functionality described how participants believed the system worked and what actions the AV could perform: "*He [the AV] steers by himself, he drives by himself, and stops by himself"* (P5)
- Meanings relating to system state were interpretations mainly about the ADS being in an active state or not: *"the blue light indicated that the [AV] system was active when it was lit"* (P2)

and the meanings regarding the AV's relation to the user and context included:

- Meanings relating to driver role consisted of interpretations of the role participants had while the AV system was activated, such as having to observe or being ready to intervene. One participant explained the role as: *"Instead of thinking about the driving, I can instead observe the passengers and see if someone needs help or if I have to lower the bus"* (P10), being an observer rather than driver.
- Meanings relating to use domain were interpretations of when and where AV system should be used: *"You know approximately where you can and cannot use the [AV] system. I think that is something you learn rather quickly"* (P6).
- Meanings relating to user actions described actions participants believed they needed to perform in order to operate the AV, often relating to how to activate and deactivate the system but also other related operations such as signaling when turning in to bus stops: *"I still need to signal and if something happens, I need to brake"* (P4)

Thus, participants' interpretations of the ADS concerned what kind of system it was and its functionality as well as what their own role as users was and how and where to use the system.

Relationships between meanings were also identified, similar to the ones identified in Studies 1 and 2, both between the two dimensions of meaning and between meanings within the same dimensions. In their simplest form the relationships concerned how meaning relating to functionality affected meaning relating to user actions. One participant explained: *"I am thinking if someone runs out in front of the bus, will the bus stop by itself or do I need to brake?"* (P4). A more complex example of the relationships is how participants, even after training as well as verbal instructions explicitly stating that the participant was responsible, nonetheless interpreted the system role mainly in two distinctly different ways, which seemingly affected how they believed that they were meant to act (further explained in Paper E): some believed it was a supporting or assistive system, while others perceived it as a fully autonomous function. The participants who interpreted the ADS as a *fully autonomous* function did so because they perceived that the ADS had the functionality to dock the bus by itself. The participants believed this meant that the ADS could conduct the task of driving without any human involvement

whatsoever and that the driver therefore only needed to hand over control, affecting the meaning relating to the driver role. In contrast, the participants who interpreted the system's role as being *assistive* believed that the ADS only took over some parts of the driving task. As a consequence, this meant that they could better observe the traffic environment for any possible upcoming risks (meaning relating to user actions). The interpretation of a more shared control sometimes made it difficult for participants to understand who was in charge of driving, even though they had received instructions before the drive. Thus, relationships between meanings relating to the system role, functionality, user role, and user actions were identified.

Combined use of artefactual and environmental signifiers

Also in this study, influences on meaning from both intentionally designed signifiers and incidental signifiers were identified. The ADS had two intentionally designed signifiers: a blue LED light intended to indicate if the system is active or not; and an icon intended to indicate if the bus was within a geofencing zone [*] or not. The blue LED light was the signifier most commonly mentioned and was mentioned as important by most participants to signify if the ADS was active or not. To many participants, the blue light when turned off also signified that the ADS had completed the docking and that they could continue driving themselves. Whereas the blue light was mostly used as feedback, the icon indicating the geofencing zone was instead used as feedforward information, signifying when the system was soon ready to be activated.

Other commonly used signifiers originated from the driving behaviour, as noted in both Study 1 and Study 2. Some participants mentioned that the vehicle motion indicated when the system was activated, referring to a little jerk in the driving behaviour when activating the system. The decreased velocity (artefactual signifier) when entering a geofencing zone was also used as feedforward information, similar to the previously mentioned geofencing icon, to signify that the system could soon be activated (meaning relating to system state): "*I suspected that I could push the button [to activate the ADS] when it [the bus] decelerated to 20km/h [due to entering a geofencing zone]*" (P1). Multiple signifiers originating from different information channels were sometimes used simultaneously to interpret the AV. For example, the blue light and the driving behaviour simultaneously signified that the ADS was active. One participant explained how the light was first used, but with more experience with the ADS vehicle behaviour was increasingly used to infer when the system was activated, indicating a process where the signifiers that the participants used to interpret a certain meaning could change during use, even originating from a different information channel.

Additionally, when using the system, most participants interpreted that the blue light on the dashboard signified whether or not the ADS was active. However, a few participants also used an incidental signifier in the form of an unrelated icon to infer if the system was active or not. Thus, as in Study 2, the participants used not only information communicated by the ADS but also by other systems in the bus to interpret the AV. This indicates that they saw the bus as one system

* A geofencing system adjusted the maximum speed of the bus to 20 km/h inside five zones near the respective bus stops in order to have as smooth transitions as possible.

and not several separate sub-systems and would probably use all the signifiers available (to them) to interpret the behaviour and functionality of the AV. Hence, the intentionally designed and incidental signifiers described in the theoretical framework seem to have been used in conjunction by participants to make sense of the AV.

Interaction between conceptual model and signifiers

Users' conceptual models seem to a great extent to have been influenced by the instructions given prior to the test run, probably due to the more extensive training compared to earlier studies, with verbal information and practical training in an enclosed area and on the test route. Participants described that the information from the instructions provided reference points, which established an approximate use domain, that is to say where the system could be activated. This was further refined by using objects in the environment as environmental signifiers, indicating where the ADS could be used, for instance identifying a tree on the specific route after which they could activate the system. One participant even suggested installing intentionally designed signifiers – orange poles – at bus stops, to signify the use domain. The environmental signifiers together with a decrease in speed (when entering geofencing zones) – an artefactual signifier – indicated to the participants that the ADS was ready to be activated. Although the intentionally designed signifiers originating from the vehicle behaviour and environmental signifiers were most often considered as sufficient, the participants felt it was crucial to have a signifier originating from the in-vehicle interface. Thus, the findings indicated a process where first the participants used their conceptual model and environmental signifiers to anticipate where the ADS could be activated (use domain), followed by signifiers originating from the driving behaviour and, due to the test setup, the test leader which signified that the ADS was available for activation.

Similarly, during the hand-over sequence participants knew from prior training approximately where to position the bus and what the speed for hand-over should be. Nevertheless, they still had problems finding the 'perfect' speed and position, since no feedforward information was provided in the in-vehicle interface. Signifiers regarding this were also commonly requested by participants, with one for example stating that they *"would have needed some assistance that you are on the right track and are travelling at the correct speed… and that the system informs you that you are in a zone and the system is ready to use"* (P9), suggesting design elements signifying meaning relating to system status. Participants could only afterwards interpret the correctness of positioning and speed based on driving behaviour, where a perceived harsh behaviour signified to the participants 'wrong' positioning and/or speed and perceived smooth behaviour signified 'good' positioning and speed. A few participants intentionally used this feedback through a trial and error-procedure to find good placement during hand-overs, in which they tested different speeds and positions and assessed the result based on feedback interpreted from the driving behaviour. Thus, similar to Study 2, participants interpreted the ADS's use domain through an active process, in which actions were intentionally performed to make sense of the AV system.

Use and work context

Finally, as in Study 2, the process of making sense was also seemingly affected by how the ADS was used since it affected where the participants focused their attention. When the ADS was active, participants often scanned the bus's surroundings to detect potential risks which resulted in some participants having difficulty noticing the blue light whose purpose was to signify that the ADS was active and in control of the driving task. Hence, participants did not notice the intentionally designed signifier, since the use context made them observe what was happening outside. In contrast, some participants instead focused a lot of attention on the light when the ADS was active, mostly before coming to a halt at bus stops, something about which one participant expressed concerns: "*Then I only focused on the blue button and that is not good, because too much [focus on the blue light turning on when ADS active] and you lose focus on the road*" (P9). This was also evident in the video data, where some participants spent more and more time looking at the dashboard. This probably has to do with the work context as a result of their role as bus drivers, where it was important to be effective in order to follow the schedule, and participants got stressed by what they perceived as a slow docking process. Hence, even if the use and work context in this case did not directly affect the process of making sense, it seems like it influenced participants' ability to perceive signifiers and objects in the environment and in turn probably their understanding.

Summary

In summary, participants' interpretations of the AV concerned what kind of system it was and its functionality as well as what their own role as users was and how and where to use the system, between which relationships were identified. The same information and training procedure led to two distinctly different interpretations, which appeared to affect how participants believed they were meant to act. Furthermore, intentionally designed and incidental signifiers seem to have been used in conjunction by participants to make sense of the AV, and participants interpreted the ADS through an active action-meaning process in which actions were intentionally performed to make sense of the AV system. Lastly, even if the use and work context in this case did not directly affect the process of making sense, it seems like it influenced participants' ability to perceive signifiers and objects in the environment and in turn probably their understanding.

05
ANSWERING RESEARCH QUESTIONS

This chapter gathers the insights from the three empirical studies presented in the previous chapter to answer the research questions posed in the thesis. Based on the outcome of the cross-study analysis performed on the initial and descriptive analyses of the empirical studies, the chapter first presents the answers to the three supplementary research questions: (How) do these four factors influence how users make sense when using an AV? (RQ1a), Are there other and/or additional factors? (RQ1b) and How do the factors interact in the process of making sense of AVs? (RQ2). These insights are structured in two parts that present the factors influencing the way users made sense of AVs and how these interacted, in which the insights are related back to the theoretical framework that was used to interpret the findings of the empirical studies.

Furthermore, the chapter presents the outcome of the synthesis of how the factors and relationships relate to each other, in order to answer the overarching research question: How do users make sense of AVs during use? The synthesis is presented as a model for understanding and studying users' process of making sense of AVs.

5.1. Factors influencing how users make sense of AVs

Indications of all four main factors that influence the users' process of making sense of artefacts presented in the theoretical framework were identified in the empirical studies: *(i) meanings associated with the AV or AV system; (ii) signifiers noticed; (iii) users' conceptual models; and (iv) the context in which the AV is used*. No additional factors were identified but within the factors new insights were reached, elaborating existing factors and expanding theory.

5.1.1. Meaning

As presupposed, the most central of the factors was meaning, since meanings associated with the AV are the outcome of the process of making sense itself and was influenced by the three other factors. During use of the AVs, participants' interpretations of the AV were multifaceted and related to a diverse range of aspects regarding the AV itself and how and where it was meant to be used. In part, these meanings differed between studies, as regards both which types of meanings were identified and to what they specifically related. However, even if they were diverse,

the meanings also shared similarities and it was possible to discern categories of meanings. Meanings on all three levels, presented in the theoretical framework, could be identified in the studies. Figure 9 illustrates a categorisation that was created of the meanings that were identified in the three different studies. The figure differentiates between the two dimensions of meanings, regarding the AV itself and its relation to the context (illustrated by the left- and right-side areas of Figure 9).

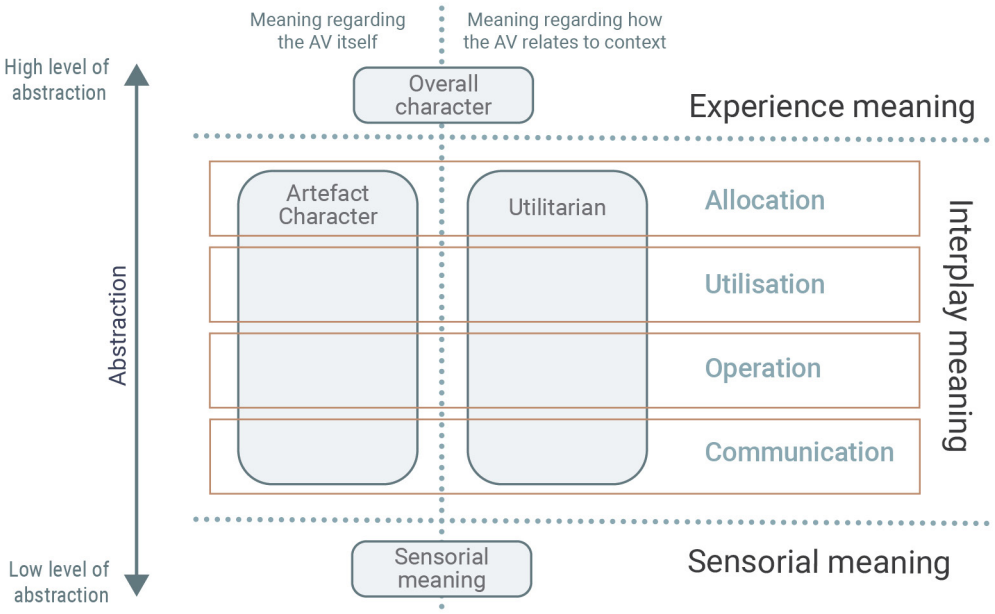


Figure 9 Categorisation of identified meanings.

- The first level (at the bottom), ***sensorial meaning***, includes direct interpretations of the sensorial impressions. These meanings were identified in all three studies but primarily in Study 1 and often related to the AV's driving behaviour, which could for example be interpreted as smooth, harsh or jerky.
- The second level (in the middle), ***interplay meaning***, was identified in all three studies, and included the largest amount and most diverse range of meanings. Due to the amount and diversity of the interplay meanings identified, the earlier categorisations were further ordered into four new sub-categories of meanings, where each new sub-category covers both dimensions of meaning (meanings regarding the AV itself being referred to as character meaning and meanings regarding how the AV relates to context being referred to as utilitarian meaning):
  - ***Meaning relating to allocation*** involved interpretations of what t*he role of the AV* (e.g. the AV system was an assistive system) *and user* was (e.g. being a navigator), and how the overall control was distributed between them.
  - ***Meaning relating to utilisation*** was interpretations of the *functionality* that the AV was believed to have in order to perform the driving task, e.g. being able to detect traffic lights, and if it was *aware* of the environment and itself in relation to it. These meanings also concerned the *use domain* where the participants believed the AV was meant to be used, including physical places, traffic conditions, and velocity.

- ***Meaning relating to operation*** concerned interpretations of what *operational actions the AV* could perform and what *actions the participants* themselves needed to perform in order to operate the AV, e.g. accelerate, brake, or steer.
- ***Meaning relating to communication*** often concerned the *current state* of the AV system, including interpretations of whether the system was active or not, and the current availability of the system.

- The third level (at the top), ***experience meaning***, was interpretations that related to overall experiences of the AV or experiences resulting from using it. For example, in Study 1 the AV was interpreted as having the overall character of being capable or considerate.

These meanings seem to differ in abstraction and in temporality, illustrated by the arrow to the left in Figure 9, both between meanings on different levels and within Level 2, Interplay. The lower-level meanings, for example, relate to the system status or more directly to the sensorial impression, often through short-term single operational actions from the AV, while the highest-level meanings, for instance, relate to the system and driver role or a more general experiential meanings often based on more long-term situations such as a whole test run or an overall AV behaviour. These abstraction and temporal dimensions were evident in meanings both regarding the AV itself (to the left) and its relation to the context and user (to the right).

Thus, during use of the AV, participants' interpretations of the AV were multifaceted and related to a range of aspects regarding the AV and its relation to the context. It was possible to describe the different meanings that arose in the three levels of meaning, presented in the theoretical framework and, due to the complex and collaborative nature of the AV, meanings on the second level were further organised into four new categories. Meanings on the different levels as well as within levels, at least Level 2, also seem to have differed in abstraction and temporality.

Even though the meanings that arises are true to the participants, they do not necessarily need to correspond, as seen many times in the empirical studies, to the actual functionality of the AV or the, by designers, intended meaning. Mismatches between users' meaning and intended one were identified in meanings that specific design element was intended to signify, but also higher-level meanings, such as meaning relating to allocation, e.g., if it is an assistive or autonomous system. Furthermore, even if meaning is subjective and many times differed between participants, meanings that arose were sometimes also more general and were associated with the AV by most participants. This suggests that single or several design elements in combination may signify meaning that is more general and arises for most users when using the AV.

One way that the meanings seem to differ between studies is in personification, i.e., participants using human similes and human-related terms to interpret and describe the AV. This was identified mainly in Study 1, in which participants experienced what was for them a very advanced AV that could conduct the whole driving task without the involvement of the user. Even if the statements in the other studies show that many participants experienced the AVs as highly advanced

(sometimes more than they actually were) and as having a high level of agency, able to take complicated decisions on their own, referring to the AV in human terms or comparing it to humans was rare in Studies 2 and 3. This indicates that more human-like meanings arose, and probably conceptual models of human drivers were used, when the AV was perceived as very advanced, such as when it could perform the entire driving task.

5.1.2. Signifiers

The second factor, signifiers, which affected the development of meaning, originated from a wide variety of information channels. The theoretical framework does not differentiate between where signifiers originate from but in the findings from the studies two different types of signifiers were often discerned. One was signifiers originating from the AV per se, referred to as *artefactual signifiers*. Many of these originated from several different in-vehicle interfaces, such as icons in displays, auditory cues, and haptic feedback in the seat belt or the driving behaviour of the AV, which was commonly mentioned in all three studies. The second was signifiers originating from the environment, referred to as *environmental signifiers*. The environmental signifiers often originated from other road users and the road itself and were frequently interpreted in combination with other artefactual signifiers. Sometimes, but not to the same extent, other signifiers were also used to make sense of the AV, such as the form of the AV or sounds not directly related to the in-vehicle interfaces.

The artefactual signifiers were often intentionally designed, such as icons, lights and text, even though they were not always interpreted as intended by designers, providing feedback and feedforward information to the users. At other times they were incidental, as differentiated in the theoretical framework. In the studies, three types of incidental signifiers were identified, expanding the notion of *incidental signifiers:* (i) *environmental signifiers*, which were the most common; (ii) *signifiers used to interpret the AV but that did not belong to the AV system*, for example icons not belonging to the automated system that signified to the participants when the system could be activated in Study 3; and (iii) *signifiers that signified additional meaning than that intended by the designer.* For example, in Study 2, a video application icon in the display did not only signify that it was possible to watch videos but was also interpreted to mean that the participant was no longer responsible for the driving task. Table 5 shows a characterisation of the different types of signifiers, as identified in the empirical studies.

Table 5
Characterisation of the signifiers, as identified in the empirical studies.

	Artefactual signifiers	Environmental signifiers
Intentionally designed	Icons in displays, auditory cues, and haptic feedback in the seat belt.	(none)
Incidental	Driving behaviour, signifiers not belonging to the AV system and signifiers that signified additional meaning.	Traffic and other road users.

5.1.3. Conceptual models

The third factor, conceptual models, consisted of participants' expectations and assumptions about the specific AV to be used and also to a high degree their understanding of AVs and technology in general and similar experiences. One such example in Study 1 indicated that participants used conceptual models of human drivers to interpret the behaviour of the AV and make sense of it. Hence, the user's conceptual model included a mix of meanings and assumptions that were related to the specific AV, AVs and technology in general, and human drivers (seen in the centre of Figure 10).

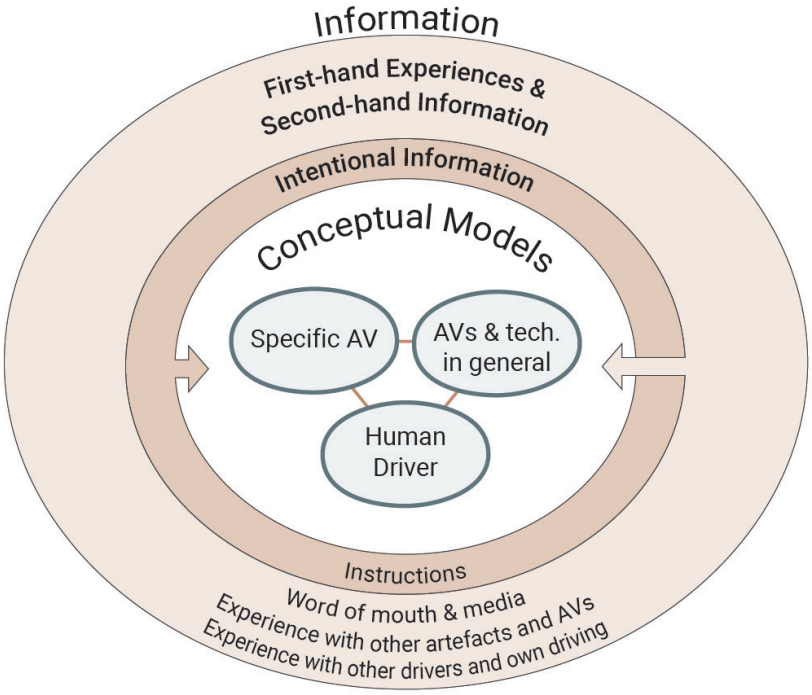


Figure 10
Representation of conceptual models used to interpret the AV and the information that constructed them (layers surrounding the conceptual models).

Furthermore, the users' conceptual models were seemingly constructed based on:

- *Instructions received before test runs,* including naming not intentionally meant to influence participants' interpretations, which were often used by participants to understand the AV's functionality, use domain, and which actions the participants were meant to perform to operate the AV.
- *Past experiences with similar AV systems and other technical artefacts*, which created expectations about the functionality of the AV, sometimes causing the participants to overestimate the functionality of the AV, as noted in Study 2.
- *Similar experiences*, that is to say driving themselves or being the passenger in a vehicle, as seen in Studies 1 and 3.
- *Word of mouth and news media,* as discerned in all studies, often referring to the perceived functionality of a specific AV or AVs in general that they themselves had never experienced.

This information was received during two different periods of time, where the instructions constitute more *recent information that was intentionally provided about the specific AVs* in the studies and the other information participants received

over a longer period of time, which included information that users encountered through first-hand experiences and information they received from other people and read or saw in news media. The extent of the influence of the different types of information on users' conceptual model and how or if that changed during use is not possible to discern from the data.

Hence, the users' conceptual model included a mix of meanings and assumptions that are related to the *specific AV, AVs and technology in general, and human drivers*. Conceptual models, unsurprisingly, did not always correspond to the actual design and were sometimes conflicting. These conceptual models seem to be constructed on information created intentionally for the purpose of instructing, that is to say instructions, but also assumptions and beliefs based on first-hand experience and second-hand sources, which are illustrated as layers surrounding and influencing the conceptual models.

5.1.4. Context

Regarding the fourth factor, the context, the three different aspects of the context that were proposed in the theoretical framework were identified: *(i) the driving environment, (ii) temporality of the use; and (iii) the use*. The driving environment was the physical surroundings in which the AV was used. This affected the meaning that arose by providing surrounding conditions that the AV is interpreted to belong to or not and the meaning the AV is believed to have in the specific environment, as well as parts of the environment becoming environmental signifiers, as earlier described, which often in combination with artefactual signifiers affected the interpretation of the AV. According to the theoretical framework, meaning changes over time and even though participants experienced the AVs for a short period of time in the studies, some temporal effects were identified. For instance, the signifiers that were used to signify a certain meaning could change over time and certain design elements signified different meanings over time with more experience with the AV, showing the effect temporality had on signifiers used and meanings that arose. Furthermore, the use influenced the way users made sense of the AV both by affecting artefactual signifiers and by affecting the focus of participants' attention. For example, when participants were conducting the driving task themselves, they

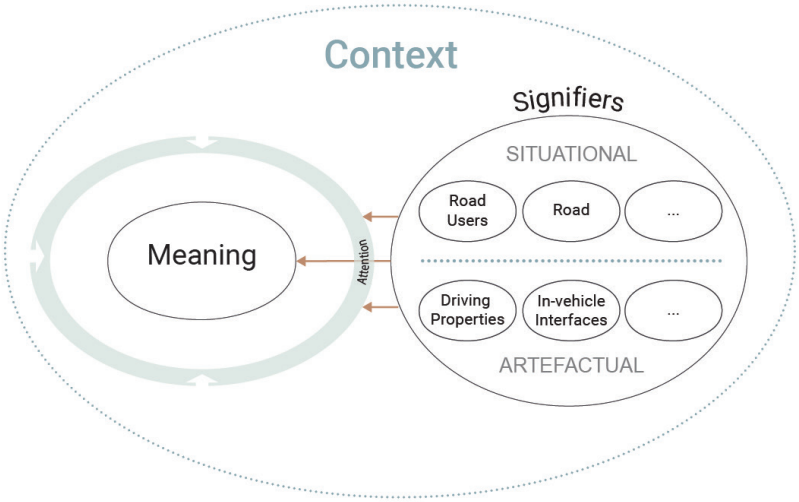


Figure 11
The effect of context functioning as a filter affecting signifiers noticed.

sometimes did not perceive the intentionally designed signifiers about how to activate the automated system or current system status on the dashboard, since they were focusing on the road (Studies 2 and 3). They did however notice the information more when the automated system controlled the driving, even if the information was the same, since they then did not have to focus on the road to the same extent. Similar effects were observed when the participants used the AV systems – they sometimes did not use the available information or notice the intentionally designed signifiers. The use did not directly influence the participants' understanding but seemingly worked as a filter that affected which signifiers were noticed, as depicted by the arrows going from signifiers to meaning in Figure 11.

5.1.5. Summary of factors

A summary of the different factors identified in the empirical studies and their character is illustrated in Figure 12.

The factors identified in the respective empirical study are summarized in Table 6.

Table 6
Summary of the identified factors in the three empirical studies.

Factors	Study 1	Study 2	Study 3
Meaning	Sensorial meanings, interplay meanings, and experience meanings.	Two dimensions of meaning, regarding the AV itself and its relation to the context.	Sensorial meanings and two dimensions of interplay meaning, regarding the AV itself and its relation the context.
Signifiers	Artefactual signifiers - Mainly driving behaviour. Environmental signifiers – situations and other road users.	Artefactual signifiers – Mainly in-vehicle interfaces and driving behaviour. Environmental signifiers – road and other road users. Incidental signifiers: design elements giving rise to additional meaning; signifiers not belonging to the AV system itself; and environmental signifiers.	Artefactual signifiers – LED lights and icons, as well as driving behaviour. Signifiers was perceived as part of one system and not several sub-systems.
Conceptual model	Conceptual model of AVs and human drivers constructed based on previous experiences of similar artefacts and similar experiences.	Conceptual model seemingly influenced by instructions but also by previous experience with other technical artefacts, naming of the AV, and social interactions and media.	Conceptual model seemingly influenced by instructions.
Context		The environment influencing participants' ability to perceive signifiers.	Use and work context affecting participants' ability to perceive signifiers.

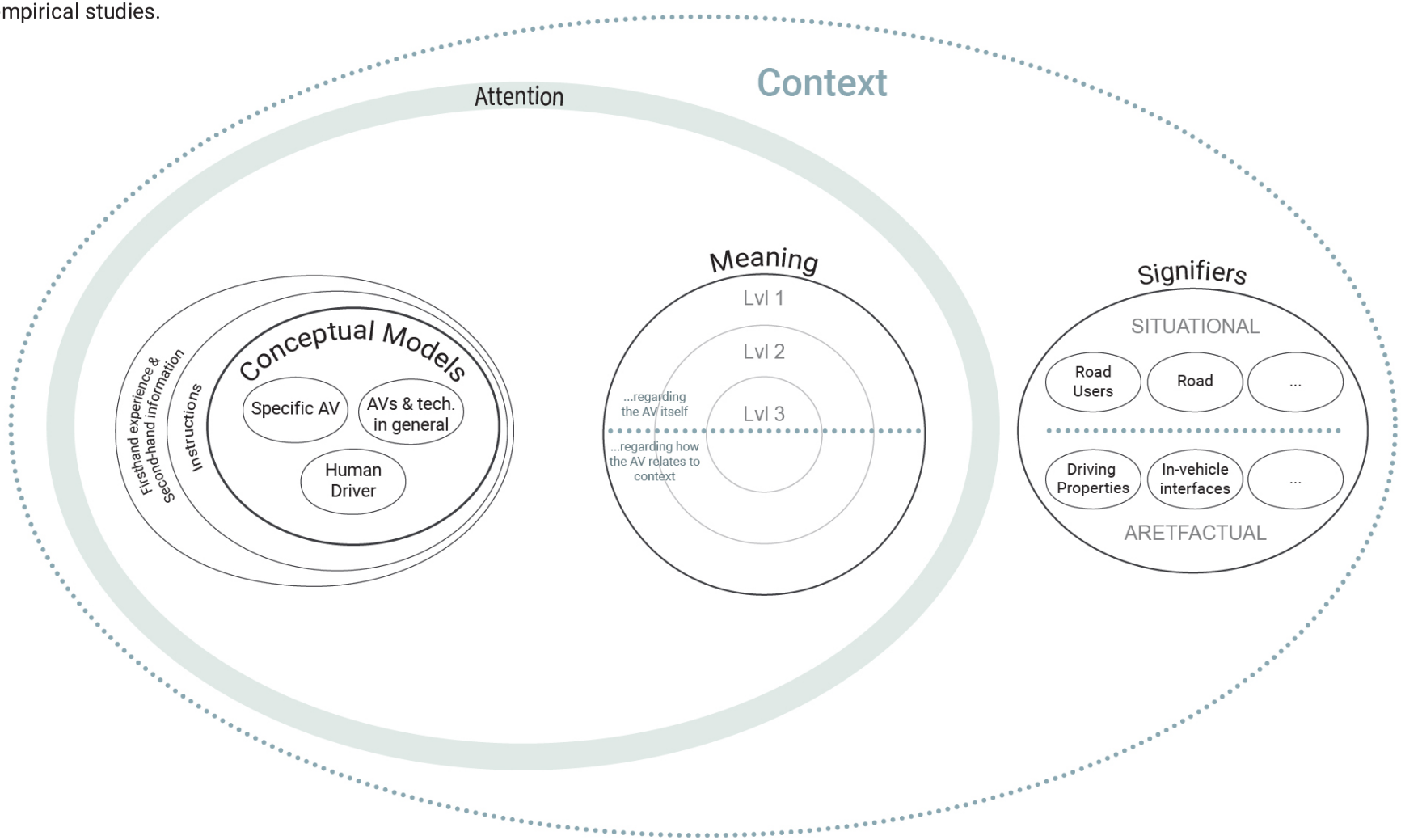
5.2. Relationships between factors in the process of making sense of AVs

The identified factors seem to interact with each other in several different ways in the process of making sense, as expected and suggested by the theoretical framework. However, the insights from the empirical studies illustrate previously described relationships using AVs as the artefact of investigation and also identified relationships that were not so prevalent previously.

5.2.1. Meanings influencing and affecting each other

As mentioned earlier, meaning is a central factor in how users make sense since it is affected by all three other factors, but it was also clear that different meanings were influenced by and affected each other, where meaning arose based on other meanings, creating a chain of interpretation, most evident in Study 1. This process probably *started both from low-level meanings*, where a sensorial impression was experienced that led to an interpretation resulting in higher-level meaning arising, comparable to the meaning attribution process that is described in the theoretical framework; and *from higher-level*

Figure 12
Factors identified in the empirical studies.



meanings, for example in the form of expectations about the AVs capability which led to interpretations about lower-level meanings. Furthermore, not only do different levels of meanings seem to influence each other, as previously described, they also affected the different dimensions of meanings, i.e., meanings regarding the AV itself and its relation to the context and user. Both Studies 2 and 3 indicated that the meanings that arose relating to the AV's role and functionality, i.e., character meaning, affected the meanings relating to the driver's role and user actions, i.e., utilitarian meaning, and vice versa. Hence, meanings regarding the AV itself may shape or limit the perceived action space, i.e., what actions the users believe they can perform. This in turn not only shapes how users believe they should act in order to operate the AV but also what actions are possible, thereby probably affecting where they will look for signifiers.

Thus, the different levels and dimensions of meaning seem to have affected each other in a *bidirectional manner*, indicated by the horizontal and vertical arrows in Figure 13, which created chains of interpretation, where meanings are formed based on other meanings.

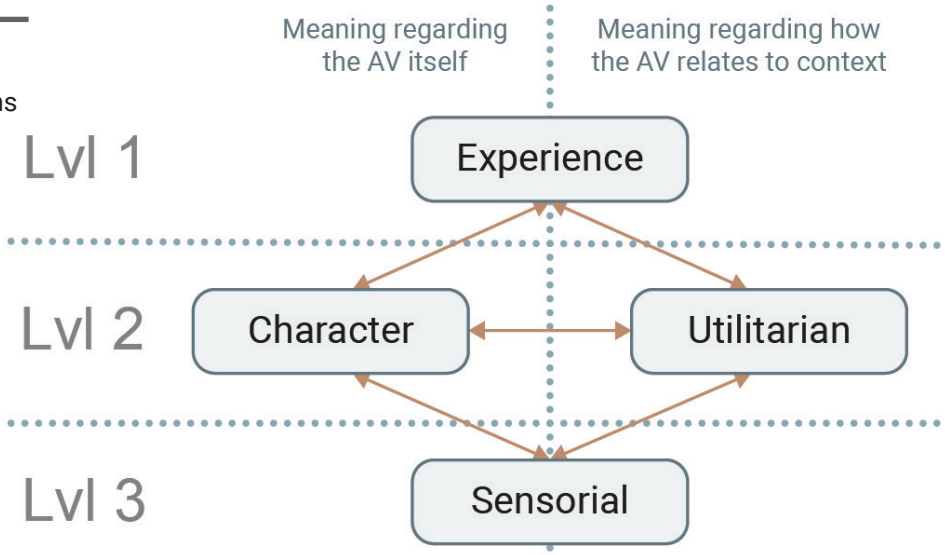


Figure 13
Interaction between levels and dimensions of meaning.

5.2.2. Signifiers influence on meaning

The signifiers gave rise to meaning by influencing the development of meaning *directly, in parallel or sequentially* (see Figure 14). Many of the statements in the studies revealed a direct influence of signifiers on the process of making sense. In addition to the direct influence of a signifier described in the theoretical framework of the thesis and identified in the studies, development of meanings was affected by combinations of signifiers originating from the same or different information channels. These combinations often occurred in parallel, where several signifiers were simultaneously interpreted to mean something about the AV. Study 2 showed that the environmental signifiers were often used in combination with other artefactual signifiers. However, the combination of signifiers also occurred in sequence, one signifier directing attention to another signifier. For example, as in Study 2, a haptic signal in the seat belt signified that an action was needed, directing attention toward another signifier. The signifiers were sometimes intentionally designed to just alert the participants but at other times they may have been a result of participants not being able to interpret any meaning.

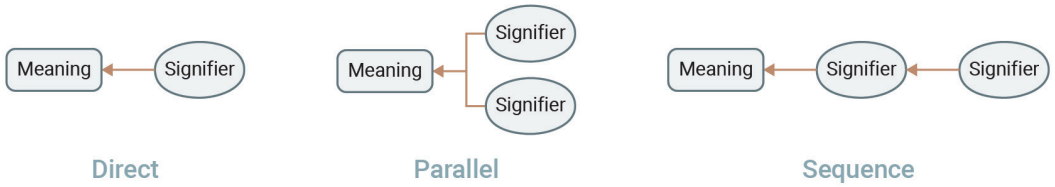


Figure 14
The three different identified ways signifiers led to meaning rising.

5.2.3. Influence of users' conceptual models on meaning

In addition, users' conceptual models influenced meaning in a way where expectations and assumptions about AV functionality and how to operate the AV, primarily noted in Studies 2 and 3, influenced the meaning that was associated with the AV. Participants were able to operate the AVs due to instructions given before using them and believed due to earlier experiences and information that the AVs could perform actions that they could or could not. Furthermore, Study 1 indicated that the same driving behaviour evoked different meanings relating to the overall character of the AV, due to different conceptual models of what a "good" driver is. This also seems to have affected the positive and negative connotations of the meanings associated with the AV.

5.2.4. Combined influence of signifiers and conceptual models

It is likely that the influence of signifiers and the conceptual model does not occur as an isolated factor but rather in combination. The findings of the empirical studies often indicated that meaning arose based on *combinations of both the users' conceptual model and signifiers*. In Study 2, it was noted that users' expectations on the one hand, and artefactual and environmental signifiers on the other, in combination influenced the development of new meaning or modified existing meaning. The combination of the conceptual model and signifiers also seemingly influenced the process of making sense over a longer period of time, as noted in Study 3. Participants used the instructions given beforehand to form an estimation of the use domain which was then refined by environmental and artefactual signifiers.

Furthermore, sometimes participants disregarded either the conceptual model or intentionally designed signifiers, one of them being more prevalent than the other. For example, in Study 2, it was noted that even if some participants knew how to deactivate the AV system, they disregarded this and acted based on meaning influenced by artefactual signifiers.

Finally, in Studies 2 and 3, it was evident that participants were not only passive receivers of information in the process of making sense of the AV, but *actively affected the information received* and thereby the meaning that arose, forming an action-meaning circularity as explained in the theoretical framework. Participants performed actions based on meaning that was often influenced by signifiers, such as icons, sounds and text messages that signified when and how to act, but also meaning influenced by their conceptual model, where expectations of how the AV functioned or was supposed to be operated were acted upon and based on signifiers perceived, where meaning arose affirming or contradicting the expectations. The

actions were performed both in an undeliberate way, as part of the task of driving or using the automated system, and also in a more intentional exploration. This was for example evident in the trial-and-error behaviour that occurred in Study 3, where participants intentionally tried different actions in different situations so as to interpret the functionality and use domain of the AV.

5.2.5. Summary of relationships between factors

A summary of the different relationships between factors that were identified in the empirical studies is illustrated in Figure 15.

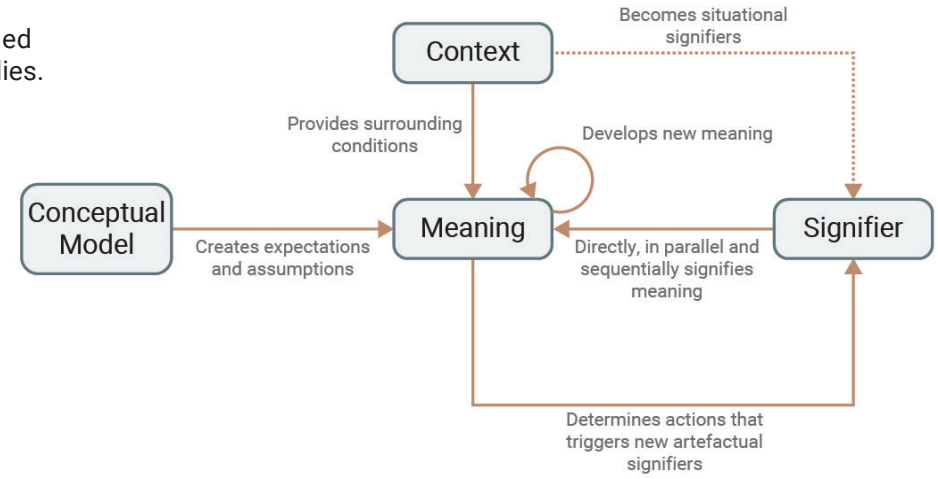


Figure 15
Factors and their relationships identified in the empirical studies.

The relationships between factors identified in the respective empirical study are summarized in Table 7.

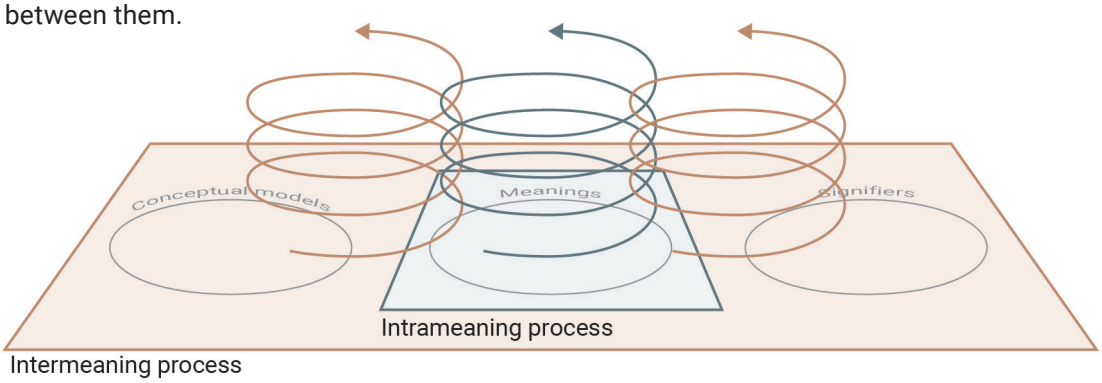
Interactions	Study 1	Study 2	Study 3
Between meanings	Different levels of meaning affecting each other.	The two dimensions of meaning, regarding the AV itself and its relation to context affecting each other.	The two dimensions of meanings and meanings within the same dimension affecting each other.
Between meanings and signifiers	Certain configurations of AV driving behaviour evoking similar meanings.	Meaning arising based on single signifiers and several in parallel and sequentially. Misinterpretations occurring due to attributing cause to 'wrong' signifier.	Several signifiers from different information channels simultaneously influencing meaning.
Between conceptual model and meaning	Expectations of what AV behaviour is. Meanings having positive or negative connotations, being affected by earlier experiences.	Expectations and assumptions about AV functionality and how to operate the AV.	Expectations and assumptions about AV functionality and how to operate the AV.
Between conceptual model and signifiers		Conceptual models being used in combination with signifiers. Signifiers overriding expectations about AV. Meaning arising due to participants' actions, being executions assumptions about the AV or signifiers	Conceptual model providing reference points which is refined by environmental and artefactual signifiers. Intentionally using actions in a trial-and-error procedure to make sense.

Table 7 Summary of interactions between identified factors in the three empirical studies.

5.3. PoMSAV - Process of Making Sense of AVs

This section presents the outcome of the synthesis of the descriptive analysis of three empirical studies, in order to answer the overarching research question of the thesis: How do users make sense of AVs during use? The synthesis organises the identified factors and their relationships into a holistic framework which is represented by a model referred to as the Process of Making Sense of AVs or PoMSAV model, meant for practitioners and researchers for studying and understanding the phenomenon. The sub-chapter is organised in accordance with the model which entails a two-part meaning making process, intrameaning and intermeaning process, which influence each other and interact to form over time an increasingly coherent understanding of the AV in a process of making sense (a schematic representation of the two-part process is presented in Figure 16).

Figure 16
Schematic representation of the two-part process that the PoMSAV model entails. The arrows illustrates new meaning being created in the interaction between factors in each part of the process and between them.



5.3.1. Intrameaning process

The outcome of the cross-study analysis indicates that it was possible to organise the meanings associated with the AVs into several levels that seemingly differed in abstraction and temporality. These meanings influenced and were affected by each other, where meanings were formed based on other meanings, creating a chain of interpretation. This process of meaning forming new meaning without the influence of extenal stimuli could be described as an **intrameaning process of making sense of the AV.** The findings from the empirical studies suggest that this process could start both from lower-level meaning – where for example sensorial meanings lead to an interpretation of higher level-meanings – and higher-level developed for example through preconceptions, may result in a trickledown effect, developing meaning on a lower level.

Furthermore, the intrameaning process did not only involve a chain of interpretations where different levels of meanings influenced each other, but also the two dimensions of meanings suggested in the theoretical framework: what the AV was considered to be or how it functioned influencing how and where participants believed they could use the AV.

5.3.2. Intermeaning process

The intrameaning process is likely to be initiated either by users' conceptual models, derived from earlier meanings and assumptions, or sensorial impressions, in the form of signifiers originating in the AV or environment. In addition, the meaning that arises in the intrameaning process will most likely affect the continuous formation of users' conceptual model and the signifiers perceived, by affecting users' actions and attention. This process, where sensorial impressions and users' conceptual models develop meaning which in turn updates the conceptual models and also affects actions that result in new sensorial impression, can be considered an **intermeaning process of making sense of the AV.** This implies that the two processes are mutually dependent on each other, since the intermeaning process affects the initiation of the intrameaning process, and the outcome of the intrameaning process will affect users' development of their conceptual model as well as the interpretation of signifiers.

The influence of signifiers and users' actions

The intermeaning process of making sense consists of a continuous direct influence of signifiers that affect the development of meanings. In this regard, just as the meanings that arose in the empirical studies were diverse, so too were the signifiers that influenced them. The AVs were interpreted in a process where the parts of the AV and the environment became signifiers, in combination, occurring in sequence or in parallel, influencing the development of meaning. The signifiers perceived were in turn affected by the participants through action-meaning circularity. This process seems to have occurred in a more undeliberate way where participants, as part of the task of driving or using the AV, but also in a more deliberate exploration, where participants intentionally tried different actions in different situations in order to interpret the AV by revealing new signifiers.

Furthermore, the context in which the AV is used also affects the role the AV is perceived to have in the specific context. In addition to providing a frame against which the AV is compared and providing environmental signifiers which are co-interpreted with artefactual signifiers to make sense of the AV, the context also seems to affect what signifiers that are notices. The use sometimes resulted in participants not noticing the available information and perceiving the intentionally designed signifiers, because they focused their attention somewhere else. The attention does not directly influence the intermeaning process of making sense but seemingly worked as a filter that affected which signifiers are noticed.

Thus, one part of the intermeaning process of making sense involves a continuous influence of sensorial impressions based on artefactual signifiers originating from the AV, and environmental signifiers originating from the environment. In this process users actively affect the information received and thereby the meaning that arises, sometimes in a more deliberate way, which may need support for users to develop an appropriate understanding. The users' ability to assimilate information and notice-intended signifiers in this process appears to be influenced by the signifiers of the artefact and the meaning that arises, and how the artefact is used, thus in turn influencing the users' process of making sense of the AV.

The construction of users' conceptual model and its subsequent influence

In the empirical studies it was evident that participants were influenced by their conceptual models which were seemingly constructed based on information received before the actual use and consisted of knowledge that concerned the specific AV, AVs and technology in general, and human drivers. Part of the knowledge regarding the specific AV to be used was received through the intentional instructions and training sessions. However, even if more extensive instructions seem to improve users' understanding of and performance with the AV, the instructions that were received are not always assimilated into the conceptual model, as indicated by some participants not being able to properly use the AV systems after receiving instructions and the fact that participants had distinctly different views of the automated system even if the same information was received. Except instructions, participants' conceptual models were probably also formed over a longer period of time, through their own first-hand experiences and second-hand sources, such as news media or word of mouth.

Thus, the intermeaning process of making sense also involves a continuous

influence of users' conceptual models that provides expected meanings, which in turn is updated and developed through prolonged use of the AV, creating a bidirectional relationship between the meaning that arises and the users' conceptual model. As a consequence, the process of forming the conceptual model affects the subsequent use of the AV, both due to the knowledge formed through deliberate instructions and through more long-term first-hand experiences and second-hand sources.

Summary and exemplification of the PoMSAV model

This section presents a summary the PoMSAV model and provides an exemplification of users' process of making sense of AVs over time.

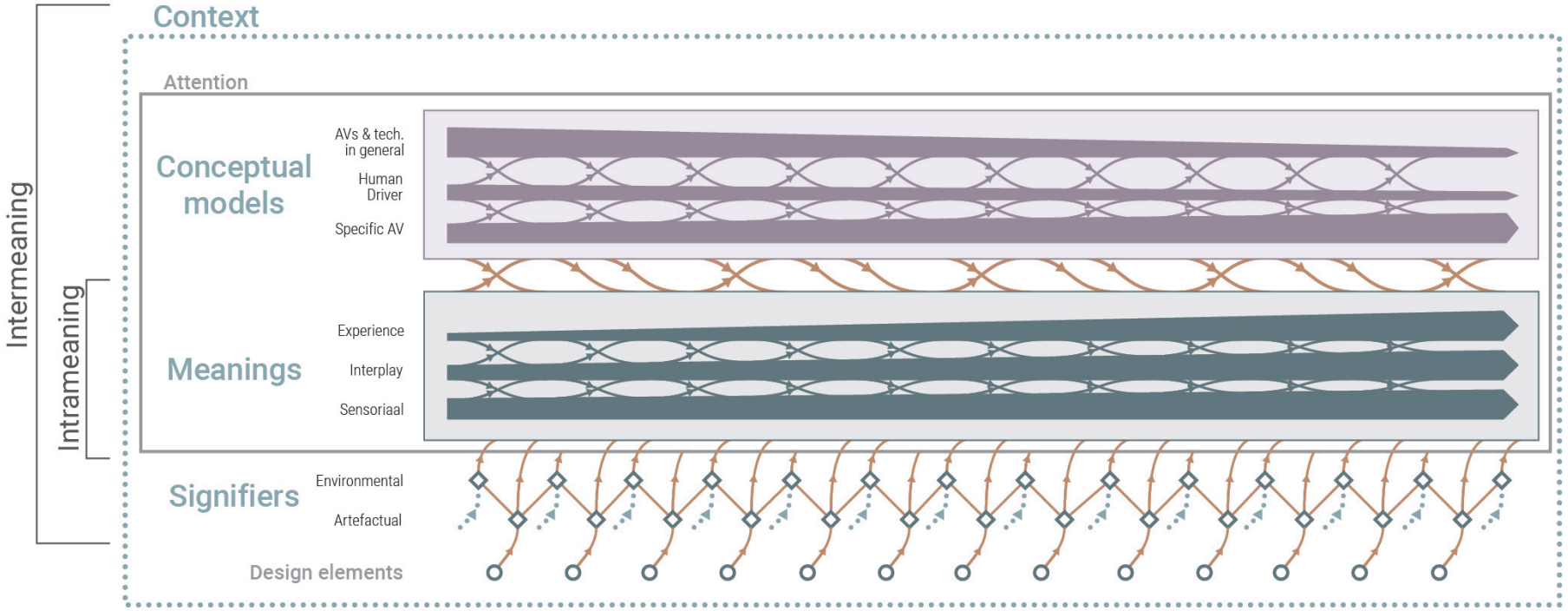
In summary, users' understanding of the AV was multifaceted with meanings residing on three levels of meaning, illustrated in the centre of the model in Figure 17. These meanings seemingly arose through two different processes, showing the complex nature of the process of making sense. First, an intermeaning process, where integration of the participants' conceptual models, artefactual signifiers (originating from design elements) and environmental signifiers (originating from the environment) develop meaning and the meanings that arise during use update the conceptual models (shown by the bidirectional arrows between meanings and conceptual model). In the intermeaning process of making sense, users were an active part of the process, through the actions they perform in order to operate the system, which in turn made them notice new signifiers that influence the development of meaning, creating a meaning-action circularity.

Second, there was also an intrameaning process where meanings, at different abstraction levels, developed new meanings and where the development is suggested to go in both directions initiated from either sensorial influence, or expectations from the conceptual model (shown by the bi-directional arrows between the levels).

Moreover, users' attention and in turn their ability to assimilate information and to notice intended signifiers appear to be influenced by the signifiers of the artefact and meaning that arises. The attention functions as a filter that indirectly influences users' process of making sense of the artefact.

To exemplify the temporal dimension, in the beginning of the use of the AV, the user will most likely have a rather incomplete conceptual model of the specific AV, depending on the amount and quality of instructions and training. As a consequence, the user will also have to rely on conceptual models of other, probably less advanced, AV systems they have previously experienced and information they received from other people or read, for example, on an Internet forum. In this first use phase, the user tries to identify the type of AV, where, for example, meaning relating to the role of the system and user is largely affected by the expectations and assumptions from the conceptual models. The user then continues to explore what the AV itself is and how it relates to the context and user, when using the AV. This, more or less deliberate, exploration is supported through a combination of expected meanings, artefactual signifiers originating from intentionally designed in-vehicle interfaces and environmental signifiers. New meaning is inferred based on the meaning that arises in the process, which assists the user in being able to use the AV more appropriately, as more meanings relating to actions and utilisation arise and initial meanings are modified. During this phase, the user experiences the AV in different contexts and interprets where the AV is meant to be used and how,

Figure 17
Overview and exemplification of the PoMSAV-model. Arrows indicate the influence of different factors and elements, and the thickness of the types of meanings and conceptual models illustrates how developed the level of meaning is and the amount of influence the conceptual models have.



developing meanings relating to the use domain. Over time and after prolonged use of the AV, the user's conceptual model regarding the specific AV is updated and becomes more comprehensive; and as a more coherent understanding is reached their attention moves more away from exploration toward what can be achieved with the AV and more experience meaning is developed.

06
IMPLICATIONS FOR DESIGN OF AVS

Even if it is not possible to design users' understanding it is possible to design for understanding. A structured and deliberate process when designing will most likely facilitate users' development of an appropriate understanding of the AV, thereby also enabling users to act in an appropriate way when using the AV.

This chapter presents the thesis's implications for design of AVs by showing how the previously described insights could be utilised in strategic work and early in the design process as well as when evaluating prototypes. The implications are presented in relation to design phases and considerations that should be taken into account when designing. The implications should be regarded more as support and inspiration rather than clear design guidelines that can be directly utilised when designing an AV. The chapter presents ten design considerations when trying to communicate the intended meaning of the AV and which are structured in accordance with three phases: deciding on the message; choosing the carrier; and contextualising the design. These phases and considerations do not replace developers' existing design processes but work as a complement, adding a new perspective and mindset, that can be utilized as part of the design process.

6.1. Deciding on the message

The first design phase concerns the intended meaning that developers want to communicate through the design. Users' understanding of AVs are complex. The empirical studies showed that meanings regarding the AV and its relation to the user are multifaceted and of diverse character concerning meaning relating to allocation, utilisation, operation, and communication (see Chapter 5.1.1 Meaning for a comprehensive description of identified meanings). Furthermore, since meanings affected the development of new meaning, indicating a relationship that suggests that even if it is not evident which meaning affects appropriate use the most, *(i) all levels and types of meanings need to be considered when designing the AV.* The different levels and types of meanings can be regarded as a framework consisting of aspects to consider when designing, as a support when exploring the design space and continously evaluating the design. To this framework designers can assign meanings that they want to communicate. This can later also be used when investigating users' understanding of the AV, to organise and structure empirical

data, in order to compare intended meaning to meaning that arose when users used the AV. The intended meaning that is going to be communicated should be guided by the possible technical functions of the AV system, the relationship that one wants to create between the user and AV, and the intended character and use of the AV.

Furthermore, the identified meanings relate to both the AV itself and its relation to the context and the user, between which incoherencies may emerge. For instance, users seem to understand what role and operational actions the AV has and is able to perform, which consequently affects the role and actions they themselves believe they need to perform when using the AV. If the meanings relating to these different dimensions are incoherent this may lead to confusion and incorrect use. In the studies, it was evident that when the AV assisted or took over parts of the driving, it sometimes created confusion about the users' role and the actions they were supposed to perform; for example, when the ADAS assisted in the steering (Study 2) and the ADAS in Study 3 controlled many, but not all, of the operational actions. Thus, shared responsibility and control may be difficult for users to understand and may cause conflicting meanings. The issue of conflicting meanings and confusion is probably more likely to arise when the users are faced with having two similar systems in the vehicle, especially if the two systems perform similar operational actions, such as performing longitudinal and lateral control as noted in Study 2. Therefore, it is important to *(ii) foster a clear understanding of allocation of role and division of operational actions and avoid the occurrence of conflicting meaning.*

The next question is: when a set of meanings is decided upon, how should these be communicated in order for the user to interpret them as intended? This will be discussed in the next section.

6.2. Choosing signifiers

The second phase concerns how to communicate the intended meaning and what signifiers to use. Initially, the meanings that are intended to be associated with the AV need to be decided, beneficially relating to as many, if not all, of the aspects as possible, followed by how these intended meanings should be communicated through intentionally designed signifiers. These signifiers may be used by the users in combination with each other, both in parallel and sequentially, as found in the empirical studies. This emphasises the importance of them being interpreted to mean the same thing, not creating conflicting meanings or misleading participants in the transition from one signifier to another. It is also important to identify incidental signifiers that may be used to make sense of the AV, in order to be able to change the design of the element or physically constrain it. Thus, *(iii) it is important to consider how to signify the intended meaning, and it is equally important that different signifiers are interpreted consistently by users*. The signifiers therefore need to be evaluated together and not just individually, since the meaning that one signifies can influence how the other is interpreted.

Moreover, it is evident from the empirical studies that users are influenced by signifiers that relate to several different information channels, not only the visual displays and auditory signals which are usually regarded as the AV's user interface. Even if the in-vehicle displays were used to interpret the AV, users' process of making sense was also greatly influenced by the vehicle behaviour and by other in-vehicle

interfaces, such as haptics in the seat belt or the movement of the steering wheel. For example, despite the fact that the AV driving behaviour was a common influence in the development of meaning, the driving behaviour is often not intentionally designed to signify meaning regarding the AV. This makes it an important, but underutilised, information source to consider when designing for users' understanding, as regards both how driving behaviour can be utilised to provide signifiers and how it may affect other information channels. It is therefore important to *(iv) have a broader view of what the HMI is in order to consider and explore more different information channels*. When deciding on which specific design elements to assign to signify a certain meaning in the previously designed framework, the information channels can be seen as resources from which one can choose. The information channels that were seemingly used by the participants in the empirical studies to make sense of the AVs included: in-vehicle interfaces with design elements such as text, icons and animations in displays, verbal and auditorial signals, haptic feedback in seat belts and steering wheel; AV driving behaviour relating to driving properties such as lateral and longitudinal acceleration and deceleration as well as positioning and distance to other objects.

Furthermore, users were not only influenced by signifiers which belonged to the AV system itself but also other systems within the vehicle. This indicates that they understood the whole vehicle as a single system and not several separate sub-systems, using all the signifiers available to them to interpret the behaviour and functionality of the AV. Therefore, it is important to *(v) regard the whole vehicle (both AV system and other systems) as one system when designing the HMI, so that different signifiers do not mislead or contradict each other.* This may be even more important as use of the AV systems becomes even more complex and probably includes multiple artefacts, not all of which are part of the vehicle itself. Already today, other external artefacts are integrated into the use of the vehicle. For instance, smartphones are nomadic devices, not primarily belonging to the vehicle, that are used to control certain in-vehicle functionality prior to its use, such as pre-heating the car, or to integrate functionality from the smartphone into the vehicle when using it, such as playing music from the phone. It is likely that this development of integrating more artefacts will continue. It is therefore important to *(vi) consider how external artefacts can be utilised to design more understandable AVs and how they may possibly affect the process of making sense*.

However, meaning does not only arise based on information from different information channels during use but also before using the AV. As seen in the studies, one influence on the conceptual model is information that is communicated through media and the vehicle manufacturing companies themselves, which may give rise to a conceptual model that does not correspond to the functionality of the AV. Other influences are the more deliberate instructions that are communicated but it was noted in the empirical studies that even with more comprehensive instructions and also training, not all participants understood the AV in the same way or acted as instructed. Moreover, even if an appropriate conceptual model is formed before use of the AV, it was evident in the studies that there were situations when signifiers made users disregard earlier information. Hence, it is not suitable to only rely on instructions to form an appropriate understanding of the AV. The AV behaviour and in-vehicle interfaces, need to complement the instructions in a

consequent way. Therefore, a combination of a well-designed HMI and some form of education is most likely necessary to help form an appropriate understanding of the AV. Thus, *(vii) the information that users are to receive before using the system, such as corporate communication and instructions, must be deliberately and carefully designed as well as be consistent with the meaning that is intended to be communicated through the HMI*. To achieve this, evaluating the meaning that arises from instructions and communication should preferably be compared with meanings arising from the HMI. This demands cooperation between different actors, since the information communicated through the different information channels, such as instruction materials and HMI, is often developed in different departments within or outside the company, making it complex and difficult to achieve unity, communicating the same meaning, between the different information channels.

6.3. Contextualising the design

This phase concerns the influence of the context. A central part of the context and an important factor in the meaning that arises is the environment within which the AV is used. The environment affects the actual behaviour of the AV but also affects the meaning associated with the AV by providing environmental signifiers and surrounding conditions against which the meaning is interpreted. Even if the environment and the environmental signifiers are out of the designer's realm of influence, the meaning that arises will still be affected by it. Therefore, it is crucial to *(viii) consider and investigate how users make sense of the specific AV in the environments where it is possible to assume that the users will use it*. This implies that the same signifier will not signify the same meaning in all environments but also that different signifiers may be warranted in different situations. For instance, the driving behaviour should possibly not be the same in all situations but instead differ depending on the environment.

Furthermore, meaning that arises when using the AV is also indirectly affected by where users' attention is focused, as seen in the studies. The use context, in other words how the AV was used, influenced users' attention and subsequently their ability to notice signifiers. For example, if users are in control of the DDT their attention is probably focused on the environment and they will be less likely to notice visual signifiers inside the vehicle. On the other hand, if the AV is performing the DDT, it may be easier for users to notice signifiers inside the vehicle. Hence, depending on the use context, different types of signifiers may be more viable to use. Therefore, when designing the AV, it is important to *(ix) consider how use will affect users' attention and consequently their ability to perceive the designed signifiers*. This affects what information channels to choose and where to position the design elements during different situations when participants are believed to use the AV system in a specific way.

Lastly, users' understanding is not static, but changes over time and will be affected by different signifiers and design elements may be interpreted to signify different meanings during different periods of use. As mentioned earlier, users will bring preconceptions into the use of the AV in form of their conceptual model, and their understanding will continue to develop during use as new meanings arise,

forming a pre-use and use phase that are important in users' process of making sense. However, even if not prevalent in the studies, a post-use phase will probably also be influential in users' process of making sense and a phase that may be utilised in order to influence users' understanding. Furthermore, with prolonged use and more experience with the system, where attention will, according to the theoretical framework, most likely shift towards what use of the AV will enable for the user and more experience meaning likely arising. This implies that it is important to *(x) consider all temporal dimensions: pre-use, use, post-use, and prolonged use*. It is important to consider the different temporal dimensions when designing the AV, in other words when different information should be communicated and how it is believed to be experienced over time. Having said that, it is also important to try to capture the temporal dimension during evaluation, investigating users' understanding during several phases and also over a longer period of time.

07
DISCUSSION

This chapter discusses the findings from the empirical studies, research approach used, contributions of the thesis, and future work and provides concluding remarks.

7.1. Research findings

7.1.1. The process of making sense of AVs

The aim of this thesis has been to develop knowledge which can facilitate the design of AVs that users understand by exploring how users make sense of AVs and the meaning that arises when using the AV. In order to investigate the subject, a human-centred design perspective with product semantics as the theoretical framework was applied. The thesis suggests a two-part process of making sense of the AV, with an intrameaning and an intermeaning process, which are dependent on each other. The intrameaning process, where new meaning is developed based on existing meaning, is seemingly initiated by either sensorial impression or the conceptual model. The influence of the conceptual model and sensorial impressions on meaning constitutes the intermeaning process, in which the conceptual model also may be updated by meaning that arises and sensorial impressions are affected by actions performed based on meaning that arise. The intrameaning process shares similarities with the process being described as a hermeneutic circle by Krippendorff, where perceived parts of the artefact and the artefact as a whole mutually affect each other (Krippendorff, 1989, 2006). The intrameaning process describes how meaning in turn affects the way meaning is developed, which implies that depending on the meaning already associated with the AV, this will affect any new meaning that arises. For this reason, the interpretation of the AV as a whole, the sum of already associated meanings, will affect new meanings that arise.

Meanings on all three levels, suggested in the theoretical framework, were identified in the empirical studies. Earlier research have described a multi-level process where sensorial impressions develop meaning on different levels starting from low-level meanings (E Kapkin, 2016), similar to what was identified in the empirical studies in the thesis. However, the thesis work expands the earlier described model by identifying a process between types of meanings within the levels and across two dimensions of meanings. It also suggests a process starting from higher-level meanings. This chain of interpretation that starts from higher-level meanings may be a result from users expecting a certain character of the AV, which is based

on earlier information from, for example, media or the company itself. Janlert and Stolterman (2017) suggest that the character may generate expectations on the artefact behaviour and capabilities. For example, an AV that is perceived as sporty or competent may give rise to lower-level meanings that are usually associated with those higher-level meanings. This proposed chain of interpretation starting from higher-level meanings is probably similar for most artefacts, even if not as complex has such a high level of agency as AVs, since users likely have expectations and assumptions about most artefacts, which may result in an intrameaning process of making sense starting from higher-level meanings. However, whereas a less complex artefact, such as a chair, is easier to makes sense of based on its visual appearance and clear affordances, for example, being sittable and liftable, in a more advanced and complex artefact, such as an AV, the functionality and affordances may be more concealed (Flach et al., 2017), requiring the use of the conceptual model, at least early on in the use.

The thesis also identified the use of signifiers originating in the environment, which is probably partly a result of users experiencing an artefact with high levels of agency. Many participants experienced the AVs as able to interpret and understand the environment around it and therefore signifiers that originated in the environment became important when interpreting the AV itself. This suggests an interpretation process where users interpret not only the AVs actions but also its intentions, as seen in meanings relating to the AV being to a lower or higher degree considerate (paper B), and how the AV interprets its surroundings. In contrast to other artefacts with lower levels of agency, where the feedback from the artefact may be more of a direct result of users' actions. This will likely be more prevalent when AVs become even more advanced and are able to monitor the user, also adding the AV's interpretation of the users themselves. Thus, the high levels of agency in the more advanced AVs seem to create an interpretation process also involving a perceived AV interpretation process, which may contribute to a process more like making sense of another human. For example, a more relational approach to trust has been proposed in the nearby area of trust in automation (Chiou & Lee, 2021). The interpretation of an AV interpretation process could partly be an explanation for the personification, of the most advanced AVs that participants experienced, that occurred in study 1. However, this is something that needs to be further explored.

7.1.2. About meanings and their influence

The thesis illustrates that users have a complex and multifaceted understanding of AVs, with several different types of meaning being identified in the empirical studies. Most probably, as a result of investigating a complex artefact with high levels of agency, interplay meanings were especially prevalent, where four sub-categories of meaning were identified and created. These four sub-categories that include meaning relating to Allocation, Utilisation, Operation, and Communication highlight the collaborative nature of AVs. These sub-categories are likely most distinguishable when using artefacts that involve collaboration between user and artefact and would probably not have been identified or needed to be taken into consideration when investigating a less complex artefact.

Earlier AV research has investigated or identified aspects of users' understanding,

that are possible to organize into many of the categories of meaning developed in the thesis, individually. Having said that, much of the existing research has focused on users' understanding of functionality and limitations (e.g. A. Boelhouwer et al., 2020; A. McDonald et al., 2018), that is to say meaning relating to the functionality of the AV. All the four sub-categories of interplay meaning have been considered in different studies, for example, non-availability information (Danner, Pfromm, Limbacher, & Bengler, 2020), i.e., meaning relating to utilisation; system state (Cho & Heo, 2020), i.e., meaning relating to communication; and allocation of control and responsibility (Flemisch et al., 2003; Strömberg, Ekman, Bligård, & Johansson, 2019), i.e., meaning relating to allocation. However, these earlier studies have often investigated and identified the influence of the different categories of meanings individually, while the thesis also illustrates how they affect and relate to each other. This provides insights into how understanding of more specific aspects of the AV, for example, actions taken by the AV, affect understanding of more abstract aspects of the AV such as, the role of the user or AV. It also provides insights into how users' understanding of the AV itself affects how they themselves believe they should act, and the experience of sensorial impressions affects this understanding. These insights generate further knowledge about how understanding of the AV is shaped during use and the factors that influence this understanding.

Furthermore, the two dimensions of meanings – meanings regarding the AV itself and its relation to the context – that are proposed in the theoretical framework were identified in the empirical studies. It is possible that these two dimensions of meanings correspond to the direct and indirect influence of understanding posited in the introduction. In other words, that users' understanding seems to directly affect their ability to use AVs (e.g. Beggiato & Krems, 2013; Pradhan et al., 2020; Rossi et al., 2020; Zhou et al., 2021) but also indirectly by mediating trust and acceptance (e.g. Hancock et al., 2020; Körber et al., 2018; Seppelt & Lee, 2019). Meanings regarding the AV's relation to the context, concerns meaning relating to the role of the AV, where to use it, and how to use it. If meanings in this dimension arise that do not match the meaning intended by the designers, it may result in users not being able to use the AV or that they use it an unintended way, for example in a situation or place where it was not designed to be used. This could lead to inappropriate and unsafe use. Meaning regarding the AV itself instead probably to a higher degree corresponds to the indirect influence of understanding. Meaning regarding the AV itself concerns meaning relating to the role of the AV, its functionality, and operational actions, which are aspects of the AV's character. In the empirical studies it was noted that participants interpreted the AV as being capable or professional, for example, and used similes when describing the AVs. In Paper D it was noted that users' trust was affected by more than the AV's perceived ability to perform the driving task and Ekman (2020) theorises that users' trust in an AV is formed by an overall impression of the AV. This suggests that meaning regarding the AV itself may affect the trust users have in the AV. For example, an AV that is interpreted as professional and as having control of the entire driving task is probably likely to be trusted, which may in turn affect how users act. Therefore, not only users' understanding of AV capabilities may influence users' trust and acceptance of AVs, but also character-like meaning associated with the vehicles.

Thus, both dimensions of meaning, which are often investigated separately, need

to be examined together to be able to design AVs that are safely used, and that users are willing to trust and accept, since they seemingly affect each other and correspond to the direct and indirect influence of users' understanding of use. Therefore, having a more holistic perspective and taking into consideration different levels and dimensions of meaning may assist in the strategic and early design phases. This approach may also help when investigating existing AVs or prototypes of AVs, by allowing for comprehensive mapping of intended meanings and identification of the location of inconsistencies and unintended meaning. It has also been suggested that correctness, completeness and content are dimensions of this understanding which are important to consider in order to achieve safe use of AVs (Morris et al., 2021; Sullivan, Flannagan, Pradhan, & Bao, 2016), implying that all types of meaning must be considered, to facilitate completeness, and evaluated, to facilitate intended content, of users' understanding.

7.1.3. Expanding the view of how to design for users' understanding of AVs

The insights from the thesis show that the users' process of making sense of the AV starts before its use, where earlier information influences the meaning that arises during use. Instructions were identified as important for users to be able to use the systems in the empirical studies, something that also received much attention in recent AV research and is regarded as crucial in order to achieve safe use of AVs (e.g. Pradhan, Sullivan, Schwarz, Feng, & Bao, 2019). However, even if more extensive instructions in the empirical studies seem to have improved users' understanding of the AV, instructions seem to not always have been assimilated into the users' conceptual models. Several earlier studies on instructions have argued that not only extensiveness but also that the type of instructions is important for the understanding of AVs (e.g. Edelmann, Stümper, Kronstorfer, & Petzoldt, 2020; Forster, Hergeth, Naujoks, Krems, & Keinath, 2019; Krampell et al., 2020). In addition, more implicit information, not necessarily intentionally meant to influence participants' interpretations, such as naming (Abraham, Seppelt, Mehler, & Reimer, 2017; Homans, Radlmayr, & Bengler, 2020; Teoh, 2020), tone and framing of the instructions (I. Harms, Teuchies, Boudry, & Van den Berghe, 2021; Singer, Jenness, Tefft, Benson, & Horrey, 2021) as well as news coverage and marketing from companies themselves (Dixon, 2020) seem to influence how users make sense of the AV, as also indicated in the empirical studies. This emphasises the importance of the explicit information communicated through well-designed instructions and implicit information, such as naming or corporate communication.

However, instructions and training on their own are not enough to achieve appropriate understanding. This was noted in the empirical studies, where sometimes participants disregarded the information or had not assimilated earlier information, as earlier discussed. Therefore, a combination of some form of education and a well-designed HMI that supports intuitive, relevant communication about the AV system during use (Mueller, Cicchino, Singer, & Jenness, 2020), is most likely necessary to help form an appropriate understanding of the AV, as also emphasised by Forster et al. (2020). The insights from the

thesis indicate that the participants used several types of artefactual signifiers originating from several different information channels, not only the in-vehicle displays that previously received a lot of attention. Many of the signifiers used by participants cannot be designed, like the environmental signifiers. However, some signifiers used can be designed but are currently not considered in the design process or at least not to the extent that may be required. An obvious example is the AV's driving behaviour, where the focus of design and investigation has often been on comfort (Bellem, Schönenberg, Krems, & Schrauf, 2016; Bellem, Thiel, Schrauf, & Krems, 2018; Hartwich, Beggiato, & Krems, 2018). However, the AV's driving behaviour has not to the same degree been regarded as an information channel that influences how users make sense of the AV, which was evident in the empirical studies. Therefore, more information channels should be taken into consideration when designing the AV, an aspect that has also been emphasised by (Carsten & Martens, 2019). Also, as a support for learning during use of the AV, researchers have, for example, proposed guided exploration of the system (Novakazi, Orlovska, Bligård, & Wickman, 2020) and an adaptive digital in-car tutor (Boelhouwer, van den Beukel, van der Voort, Verwey, & Martens, 2020), suggesting some form of guided process of making sense of the AV during use. Consequently, it is very important to understand and support the process of making sense during use of the AV.

Thus, the users' process of making sense of AVs is seemingly affected by the type of instructions given, explicit information, and information during the use, in form of the AV's user interface, which could be supported by a guided process of making sense of the AV. This emphasises the importance of broadening what is regarded as a user interface communicating meaning during use while at the same time taking into consideration communication from sources other than just the AV itself. Therefore, the view of how to design for users' understanding of AVs needs to be expanded to include well-designed instructions, communication and user interfaces that should all be developed in a consistent manner.

7.2. Research approach

7.2.1. My own process of making sense

Writing this thesis has involved what can be seen as a process where I made sense of how the participants made sense of AVs. Such a process may be biased due to the understanding and preconceptions of the researcher conducting the research (Revell & Stanton, 2012). Therefore, several steps have been taken in the thesis work to overcome or reveal possible biases. In the initial analyses presented in the appended papers, the analyses were performed by several researchers. In the thesis, discussions with supervisors have been used to verbalise and discuss thoughts and interpretations of data and theory, and clear descriptions of analysis methods and the use of quotes have been employed to ensure transparency in my own process of making sense. The use of the theoretical framework and a clear analysis process have also assisted in making the analysis process less biased by having a clear structure to follow.

7.2.2. Methodological influences

The methodology used in the empirical studies was an efficient way to create a setting that was perceived as natural by the users, making it possible to study how users' make sense of the AV during normal everyday use, in contrast to earlier research on critical and risky situations (Forster, Hergeth, Naujoks, Krems, et al., 2019; Gaspar, Carney, Shull, & Horrey, 2020). This has enabled extraction of a large amount of rich data (cf. Given, 2008) while the different types of AV systems investigated in the studies have facilitated exploration of a wide range of meanings that can arise when interacting with a system as complex as AVs. This included meanings on different levels regarding what the AV is and how it relates to the context in which it is used or supposed to be used, illustrating the complexity of the users' process of making sense of AVs. Due to this complexity, a combination of data collection methods may be needed, as the methods used in the studies extracted information regarding different aspects of the theoretical framework. The think-aloud protocol applied during use of the AVs was very useful in eliciting data that illustrated the process by which users made sense of the AV. However, users' process of making sense will be affected when they start to verbalize their thoughts, since the verbalization itself requires thinking, and, at least in the way these studies were conducted, a test leader probes with questions when needed. The method may also affect the users' attention and in turn how they act. Therefore, a trade-off emerges between the possibility of extracting the users' thought processes and ensuring that the experience feels as natural as possible. The decision on methods needs to be guided by the aim of the study and with due regard for whether or not other connected aims exist. In the empirical studies conducted in the thesis work, the insight gained from using the method outweighs the effects on the process of making sense and attention, since that rich data would have been hard to elicit in other ways and the interest of the research was not on objective performance of the users.

7.2.3. Ethical and methodological considerations of the WOz approach

Regarding the WOz approach, used in all three studies, earlier researchers in human-robot interaction have raised concerns regarding how the approach is used (Riek, 2012). One concern that is raised regards how the approach is implemented, where Fraser and Gilbert (1991) propose that it must be possible to specify behaviour of and simulate the future system, and to make the simulation convincing. In the empirical studies conducted in the thesis work, the 'wizard' had approximately one day of training including multiple drives along the test route, and in Study 2 used ACC, to be able to simulate as consistent behaviour as possible. The AV driving behaviours had been specified before each of the studies to be considered as 'safe' driving behaviours and in Study 1 as distinctly different, but both still 'safe'. Even if the driving behaviours may have differed slightly between participants, the findings show that the different driving behaviours were experienced similarly, since similar meanings were associated to the same AV driving behaviour. It is also recommended to include a scenario that put constraints on the study but where participants are still able to act in several ways to reach the set goal (Dahlbäck, Jönsson, & Ahrenberg, 1993; Riek, 2012). Except for Study 1, where participants were not able to control

the AV, the other two studies included a set route that the participants had to follow but they were free to choose if and how to use the AV systems when driving on that route. Another concern relates to the ethics of misleading participants in the studies (Fraser & Gilbert, 1991), which is often the case in WOz studies since the whole or parts of the system are faked without the participants knowing this, as shown in two of the empirical studies in the thesis. In the studies, it was important that participants were not aware of the vehicle being controlled by a human operator, since this knowledge was deemed to excessively influence the outcome of the results. Therefore, the participants in Studies 1 and 2 were not informed in advance about the WOz approach, the 'wizard' being presented as a safety operator; only one of 40 participants suspected the vehicle was being controlled by the 'wizard'. However, for ethical concerns, all participants were afterwards briefed about the procedure and were able to ask questions, in order to not deceive them and so as to not impose false perceptions of the current state of technology.

7.2.4. Temporality of the empirical studies

Furthermore, even though the methodology used uncovered a lot of different meanings, not a lot of meaning on the highest level, i.e., experience meaning, was identified. Experience meanings were by far the least common, which is probably an effect of several reasons, one of which is related to the focus of the studies and analyses. They mainly focused on the interplay between human and AV during use, in order to be able to design more understandable AVs, in comparisons to, for example, studying the AV in a social context. For this reason, other methodology may be necessary in order to elicit more meaning relating to the experience with the AV and more underlying influences of users' assumptions and preconceptions of the AV. Another likely reason is the amount of time which the users experienced the AVs. The period of time that users experienced the AVs in the studies varied between approximately 30 and 90 minutes, which may be too short for the users to develop a more substantial amount of experience meaning. This is relevant since higher level meanings are believed to arise after extended experience with the artefact (Kapkin, 2016). Therefore, longer periods of use than those experienced in the empirical studies and longitudinal studies may be warranted to fully understand the users' process of making sense during use. A good example of a more longitudinal study design can be seen in (Lindgren, Fors, Pink, & Osz, 2020).

7.2.5. The use of the theoretical framework

The theoretical framework was useful to apply to complex artefacts such as the ones that were studied in the thesis – namely AVs. All four factors in the theoretical framework were identified in the empirical studies but no additional factors were found, probably a result of the factors being rather comprehensive. With the factors being so overarching, this can at the same time be seen as a weakness of using the theoretical approach since it becomes too general. In the thesis, it was therefore necessary to include additional categorisations and sub-factors. Furthermore, using the theoretical framework was valuable for structuring the findings and providing a holistic and human-centred overview of users' development of meaning. This framework has been useful since it takes equal account of user, artefact and context

and encompasses both users' understanding of the character of the artefact and context, such as what it is and what functionality it has, and how and where to use it, for instance user role and what actions are needed to use it. As previously discussed, the framework has also made it possible to identify interactions between meanings themselves as well as between meanings and signifiers, illustrating an intra- and intermeaning process. The framework also helped illustrate the diverse character of users' understanding of AVs, where several different meanings can arise during use of the same AV. So rather than being a binary conclusion, that is to say understanding or not understanding, users' understanding is more complex and needs to be considered in terms of correctness, completeness and content (Morris et al., 2021; Sullivan, Flannagan, Pradhan, & Bao, 2016).

To use the theoretical framework has provided a focus and enabled a structured investigation but there are aspects that the theoretical framework has not related to. Other theories and frameworks have considered other factor in order to understand the interplay between users' and artefacts. Earlier research by Flach et al. (2017) have suggested that to better understand users' sensemaking and to predict behaviour, three dimensions needs to be considered: the possible actions (Affordings), information grounded in the interface (Specifying), and value and quality of outcome of possible actions (Satisfying). This thesis has considered the perceived possible actions of users; firstly, through the meanings, taking into consideration the AV's relation to the context and user, and secondly as information regarding these possible actions through the identification of multiple artefactual and environmental signifiers. However, users' intentions to act on a specific meaning among several others have not been considered to a great extent. Users' goals and intentions are suggested to influence the development of meaning and it has been noted in the empirical studies that users' goals had some influence on the meaning that arose, but this dimension needs to be considered to a greater extent, and is a good complement to the existing theoretical framework, to be able to fully predict the use of AVs and aid in their design.

7.3. Contributions of the thesis

7.3.1. Contribution to the area of research on users' understanding of AVs

The work presented in the thesis contributes to the area of research into users' understanding of AVs by describing the complex interplay of how users make sense of AVs. A model is presented to describe the process of users making sense of AVs, based on three empirical studies, and the thesis also illustrates several identified issues which can occur when making sense of the AV during use. Furthermore, the thesis also contributes by prescribing design considerations divided into three phases that proposes how the findings could be utilised in the process of designing AVs, providing the foundation for a more structured tool to be developed. As part of these design considerations the thesis develops a framework consisting of types of meanings that are important to consider in the strategic work and early in the designing of the AV as well as to follow up when evaluating prototypes. This framework concerns both meaning regarding the AV itself and its relation to the context, which, as earlier discussed may be important to facilitate safe use and

acceptance in the AV. It also describes how different signifiers and information channels could be used to communicate the by designers intended meaning and how the context can be taken into consideration.

7.3.2. Contribution to the area of product semantics

The work also contributes to the area of product semantics. Much of the earlier product semantic research is highly theoretical and the empirical studies conducted have mostly focused on more of the character meaning, for example investigating if artefacts are being perceived as elegant or modern. Very few studies have investigated meaning in use and especially not in combination with meaning regarding the artefact itself, as done in this thesis. Moreover, earlier studies have often only concerned the visual perceived form of the artefacts and not considered other sensorial impressions. Against this background, this thesis contributes to the area of product semantics by providing further insights into users' development of meaning and how they make sense of artefacts, describing an intrameaning and an intermeaning part of the process of making sense based on three empirical studies. The work also contributes by exploring a type of artefact – AVs – that is complex, collaborative, has a high level of agency and the user is enclosed in, in contrast to artefacts usually studied which are often less advanced and observed from the outside. This resulted in new insights regarding the factors influencing how users make sense of AVs during use, described in the theoretical framework, elaborating existing factors and expanding theory. The findings of the empirical studies identified several types of meaning regarding what the artefact is and how it relates to the context, especially interplay meaning, which most likely is a result of the artefact being complex and is used collaboratively to perform the task of driving. The findings also describe how these meanings also apparently interact with each other and the influence of signifiers, including the use of signifiers originating in the environment, referring to them as environmental signifiers and separating them from artefactual signifiers, as earlier discussed.

As mentioned previously, the contributions to the work presented in this thesis stem from empirical studies of a complex artefact, namely AVs. The original theoretical framework could probably be applied to other artefacts. The same is for the two-part intrameaning and intermeaning process which is also probably transferable to other artefacts. However, the previously discussed additions of the sub-categories of interplay meaning that the work presents are probably more useful when working with more complex and collaborative artefacts with higher levels of agency.

7.3.3. Future work

The work presented in the thesis has only considered how users make sense of the AV when using it or have had use experience. Having said that, the importance of the meaning that is developed before using the system was apparent in work on the thesis, for example via corporate communication or instructions. Therefore, future work should further investigate the differences and interplay between the information that shapes the conceptual model and the meaning that is associated with the AV during use.

Furthermore, since the length of the empirical studies presented in the thesis may have been too short to fully capture meanings on the highest level, future work should

perform longer studies preferably of a longitudinal character. In doing so it is also possible to investigate how the meaning associated with the AV changes over time with prolonged use and together these insights can generate a more comprehensive understanding about the dynamics of the process of making sense of AVs.

Moreover, the work in the thesis is exploratory in nature and there is a need to investigate in greater detail the dynamics of the process of making sense, possibly in more controlled studies. The empirical studies did not explicitly focus on communication from designer to user, even though the thesis proposed several design considerations. These design considerations have a methodological character and should be further developed into a tool which could more effectively be used in the design process of AVs. This could enable empirical testing of the model and the considerations by using them in the design process and investigating their usefulness when designing and their ability to improve users' understanding of AVs.

7.4. Summary

By exploring how users make sense of AVs during use, and by applying a product semantics framework as a theoretical foundation, this thesis provides insights into the complex interplay between users' conceptual model, signifiers and the context it is used in. The findings show the complexity of users' understanding of AVs, identifying several different meanings of different character, which are suggested to reside on three levels: (i) sensorial meanings, (ii) interplay meanings, and (iii) experience meanings, and regards the AV itself as well as how it relates to the context it is used in. The thesis suggests that the meanings are developed through a two-part process of making sense of AVs, consisting of an intrameaning process, where meanings that arise develops new meaning; and an intermeaning process, where the meanings that arise is influenced by users' conceptual models of AVs, human drivers and other artefacts, and/or signifiers originating from the artefact or environment. The process is illustrated as a model that describes the interrelations between the user, artefact, and environment in which it operates.

Based on the findings, design considerations that can support the design process and analysis of AVs are proposed in three phases: deciding on the message, choosing signifiers, and contextualizing the design. The design considerations emphasize the need for a structured process when deciding the meaning that should be communicated but also, most importantly, to investigate how these intended meanings correspond to the meanings that users associate with the AV during use, in the context it is intended to be used. The insights from the three user studies included in the thesis also highlight the need to broaden the perspective on the human-machine interaction as well as develop the information provided e.g. by different communication materials, instructions and the AV itself in a consistent and coherent way.

Finally, the thesis contributes to the area of users' understanding of AVs by describing the complex interplay between factors in the process of making sense of AVs and also by identifying several types of meaning that may arise in the usage of AVs. The thesis also contributes to the field of product semantics through the practical application of product semantic theories, especially on a type of artefact on which the theories have not been used, an artefact which has high level of agency, is complex and collaborative, and incapsulates the user.

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PAPER A

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

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PAPER B

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PAPER C

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PAPER D

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PAPER E

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