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# Human factors in developing automated vehicles: A requirements engineering perspective☆

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ABSTRACT

Automated Vehicle (AV) technology has evolved significantly both in complexity and impact and is expected to ultimately change urban transportation. Due to this evolution, the development of AVs challenges the current state of automotive engineering practice, as automotive companies increasingly include agile ways of working in their plan-driven systems engineering—or even transition completely to scaled-agile approaches. However, it is unclear how knowledge about human factors (HF) and technological knowledge related to the development of AVs can be brought together in a way that effectively supports today's rapid release cycles and agile development approaches. Based on semi-structured interviews with ten experts from industry and two experts from academia, this qualitative, exploratory case study investigates the relationship between HF and AV development. The study reveals relevant properties of agile system development and HF, as well as the implications of these properties for integrating agile work, HF, and requirements engineering. According to the findings, which were evaluated in a workshop with experts from academia and industry, a culture that values HF knowledge in engineering is key. These results promise to improve the integration of HF knowledge into agile development as well as to facilitate HF research impact and time to market.



## 1. Introduction

The term automated vehicles (AVs) refers to an emerging technology that increasingly automates driving tasks and decision-making in transportation (Erdal, 2018). The society of automotive engineers (SAE) has defined six levels of automation (0–5) (sae.org, 2021), starting from *no automation* at Level 0. Many automation features of Levels 1 and 2 (providing one or more automated driving assistance systems (ADAS) to the driver of the car) are already available to consumers. Level 3 features such as lane changing (Yu et al., 2018), steering control, and car parking (Wu et al., 2019) are becoming more common. Level 4 is known as high automation, and there are very few companies that have deployed Level 4 vehicles in real traffic (Waymo (Schwall et al., 2020) is one example). However, several companies are promising Level 4 deployment (Anderson, 2020), and prototypes of Level 5 vehicles (full automation that does not require human intervention and can perform driving under all circumstances) are under development.

Thus, the number of vehicles with medium to high levels of automation are increasing; according to Litman, half of all new vehicles will be autonomous (which the author defines as automation Levels 4 and 5) by 2045 (Litman, 2021). As the number of AVs is increasing, so does the number of reported failures. Although fatal crashes of Teslas have been well publicized, Banks et al. (2018), Deaths (2020), Anon (2019), failures of AV technology are not limited to a single brand; for example, a pedestrian was killed by an Uber self-driving car in 2018 (Kohli and Chadha, 2019).

These examples, as well as more recent ones reported in scientific journals (Morando et al., 2021; Inagaki and Itoh, 2013) and the media (Anon, 2021a,b), show how human over-trust in and over-reliance on automated systems can cause fatal failures of AV. Clearly, even if an engineered, automated solution works perfectly in theory, human factors (HF) must be accounted for to ensure perfect functionality on the roads. As a research field, HF considers humans' physical, physiological, social, and cognitive capabilities and limitations while designing a system (Human Factors and Ergonomics Society, 2021). Expanding on this characterization, several definitions of HF are available, depending upon the context (Human Factors and Ergonomics Society, 2021). As part of our study, we extended one of these definitions to enable us to be more precise about HF in relation to AV (see Section 4.1).

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Several HF researchers have emphasized the need to consider HF knowledge during AV development (Hancock, 2014, 2017; Lee, 2008; Navarro, 2019). For example, Hancock states that attention must be paid to the proper design of new vehicle automation technologies and warns that with the breakneck speed at which automated and autonomous systems are developing, HF perspectives might be overlooked (Hancock, 2017). According to Lee, HF aspects must be considered in order to increase the safety, trust, and acceptance of automated technology, as well as to avoid its misuse and disuse (Lee, 2008). Currently, companies are trying out different ways to manage the integration of HF knowledge into their research and development (R&D).

In addition to the changes urged by HF researchers, agile development approaches to system engineering are also being introduced to AV R&D organizations (Kasauli et al., 2020). While initially agile approaches were focused on small software development teams (Beck, 1999; Meyer, 2014; Kahkonen, 2004), their success has led to their adoption in the development of large-scale (Dikert et al., 2016; Lagerberg et al., 2013; Salo and Abrahamsson, 2008) and mechatronic systems (Gren and Lenberg, 2020), where non-agile, plan-driven, and stage-gate-based processes have been the norm (Pernstål et al., 2012). While in practice, the integration of agile practices into large-scale systems engineering may look like a hybrid approach (Klünder et al., 2017), our case companies report themselves that they are transitioning or have transitioned to large scale-agile frameworks, such as SAFe (Knaster and Leffingwell, 2017a).

The agile ways of working adopted by these companies are primarily based on the scaled agile framework (SAFe) (Knaster and Leffingwell, 2017a), which promises to provide "proven, integrated principles, practices, and competencies for achieving business agility using Lean, Agile, and DevOps". SAFe suggests distinguishing a number of abstraction levels, including the lowest level teams, a middle layer where different *solution trains* (a group of teams working on a coherent part of the product) are managed, and a portfolio level on top. Due to their iterative nature, agile approaches are suitable for building systems whose requirements may change; further, experience from early versions of a system can impact later versions (Beck, 1999; Meyer, 2014; Gren and Lenberg, 2020). Thus, in theory, agile approaches are well suited to the introduction of stakeholder concerns (such as those provided through HF knowledge) in automation development: Agile often reveals previously unforeseen requirements for a system under development, such as considerations of HF.

To integrate human factors during system development (in general, not specific to agile), researchers advocate incorporating human factors knowledge already into the early stages of development (Calp and Akcayol, 2019; Chua and Feigh, 2011; Håkansson and Bjarnason, 2020). Traditionally, such information is usually included in system requirements, which are defined up front and serve as the basis for any subsequent development work. The process of eliciting, analyzing, describing, and validating requirements is called requirements engineering (RE) (Wiegers and Beatty, 2013). To date, it has been particularly challenging to apply RE to the agile development of systems at scale (Meyer, 2014; Kasauli et al., 2021). Meyer highlights the rejection of upfront analysis as particularly problematic (Meyer, 2014), but other challenges exist, particularly with managing and communicating requirements-related knowledge at scale (Kasauli et al., 2021).

The literature (Hancock, 2014, 2017; Lee, 2008; Navarro, 2019; Beauchamp, 1986) leaves no doubt about the importance of considering HF in AV development. For example, an AV at Level 3 still requires humans to be able to take over control of the vehicle. Especially when it comes to switching control between the human and vehicle, human factors such as reaction time, comfort, fatigue, and understandability must be considered as requirements (Gold et al., 2017). Yet, particularly in the light of well-known challenges for RE in scaled agile system development, it is unclear how to ensure their consideration. There is a lack of empirical research on how to integrate HF aspects of vehicle automation development and communicate such requirements to AV engineers[1] In this study, we distinguish between HF experts and AV engineers[2] in order to clarify how HF experts are currently communicating with AV developers and identify any communication gap, particularly during agile development. This is a relevant research gap with practical implications: Automotive companies are moving towards scaled-agile system development. It is unclear how to introduce HF requirements into agile system development, which is the traditional way of managing knowledge in the development lifecycle. Thus, it is unclear how to ensure that HF knowledge should best be integrated into agile system development, and practitioners struggle with a lack of clear guidelines.

We investigate this research gap in this exploratory qualitative study. Within the general research goal of determining how HF aspects of AV development can be integrated in agile AV development, *this study specifically aims to investigate how HF knowledge as requirements can be integrated in the development process and communicated to AV developers in the context of large-scale agile AV development.* The research goal is operationalized by addressing the following research questions (RQs):

**RQ1:** How do HF experts and AV engineers characterize HF in relation to AV development?

RQ1 is motivated by the broad spectrum of definitions offered by literature. In order to understand how HF aspects can be communicated, we first need to establish a working definition of HF in terms of AV development. We then explore the relevant properties of HF and agile work in RQ2 to lay the foundation to reach our research aim.

**RQ2:** Which properties of HF and agile ways of working impact AV development?

In RQ3, we are particularly interested in implications for agile ways of working, HF work, and managing requirements in AV development:

**RQ3:** What are important implications when aiming to better integrate HF into AV development?

This work answers these research questions by qualitatively analyzing interviews with ten experts (HF experts and AV engineers who work in the automotive industry), complemented by two additional interviews with academic leaders in the field of human factors. Our results indicate that an important property of scaled agile is its way of working, which advocates responsiveness to change by shifting responsibility from managers who

[1] We recognize that many HF experts can also be considered engineers in terms of AV development (the domain of HF engineering).

[2] Note that in this work, HF experts are individuals in an organization that typically have formal training in Human Factors (e.g., often with a background in psychology, behavioral or cognitive sciences) and who have a role in the organization where he or she on a daily basis works with HF aspects (i.e., works with HF related topics; for details of what is meant by that, see the definition of Human Factors in Section 2.1. Further, in this work, an AV engineer is typically a software, electrical, or mechanical engineer, whose work is to develop the AV from a technical perspective, and that does not have an HF background. More precisely, when referring to AV engineers in this paper, we specifically exclude HF engineers (Wickens et al., 2003), i.e., professionals that have a background both in HF and engineering, who, for the purpose of this study are categorized as HF Expert.

plan at the system level to autonomous teams that make local decisions. To support such local decisions, it follows that HF knowledge should be available to the agile teams to raise awareness, enable asking relevant questions, and guide them in the right direction. It also follows that agile AV teams should be able to produce HF knowledge on demand, e.g., by conducting HF experiments within their team's iterative work; further, RE should provide methods for effectively managing the knowledge gained from the experiments. We validated these findings in a workshop setting using a survey questionnaire, as well as in discussions with 28 expert participants from industry and practice. The evaluation study confirms that our findings are very relevant to the industry.

The paper is divided into seven sections. This introduction, Section 1, is followed by Section 2, which provides the background and reviews related work; Section 3 discusses the research methodology. The main findings are presented in Section 4. Section 5 presents the outcome of the survey performed to evaluate the findings of this study. In Section 6, we discuss our findings. Finally, Section 7 concludes the paper.

## 2. Background and related work

The research presented in this paper is interdisciplinary, targeting both systems and software engineers as well as HF experts. Therefore, this section provides the background on which the argument of the exploratory qualitative analysis is built. This background may seem obvious and basic in parts. However, since the targeted readers belong to many disciplines, some basics need to be explained for completeness: many HF experts are not familiar with the agile way of working or RE, and many AV engineers are not familiar with the domain of HF.

### *2.1. Human factors in automated vehicle development*

Human factors are an integral part of the development of road transport (Wickens et al., 2003). However, as the definitions of HF are many and diverse (Licht et al., 1991; Human Factors and Ergonomics Society, 2021), there may be a problem when people with different definitions are communicating requirements and knowledge (Licht et al., 1991). Taking a scientific perspective of the definition of human factors,

*The Journal of the Human Factors and Ergonomics Society* describes the science of human factors as pursuing "fundamental knowledge of human capabilities and limitations—and the basic understanding of cognitive, physical, behavioral, physiological, social, developmental, affective, and motivational aspects of human performance" as a means "to yield design principles; enhance training, selection, and communication; and ultimately improve human-system interfaces and sociotechnical systems that lead to safer and more effective outcomes".[3] Although this definition may seem clear and concise, individuals may have different views of what HF entails (Licht et al., 1991), and their views may impact how they consider HF in their profession. Thus it is important, when studying how HF is considered in the workplace, to investigate what their views of HF actually are. This may be particularly important when the subjects in a study have very different backgrounds, such as when studying the role of HF in the development of automated vehicles (as in the current study); HF experts, as well as a range of different engineers, are involved (Wickens et al., 2003). As a consequence, developing a precise definition related to a specific topic (here AV design) is warranted.

3 https://journals.sagepub.com/aims-scope/HFS

Finally, to help readers that are not HF experts get a better grasp of HF, some examples in the field of AV development are listed below. As the HF domain is very broad, also this list is highly diverse and only represent a small fraction of all HF aspects considered in AV design. Its aim is only to provide some insight into AV HF considerations. HF knowledge helps to answer questions on how to design and develop…:

- AVs that are predictable and safe for other road-users
- AVs that users trust (to a reasonable degree)
- AVs that are transparent with their capabilities, avoiding over-reliance
- AVs that drivers like
- human–machine interfaces (HMI) for AV users (e.g., touch screens for adjusting settings) that are safe, user-centered and in-line with the company branding.
- HMIs for other road users (external HMIs) to, for example, communicate state and intent
- AV motions that the users like (e.g., to make them feel comfortable with the AV speed and acceleration, as well as relative speeds and ranges to other road users and infrastructure features)
- AVs that ensure intended effects of the AV functions are reached by considering user's and surrounding road users intent and actions
- AVs' auditory, visual, and haptic information exchange with their users (e.g. as information and warnings) including braking, active vehicle steering and acceleration through actuators
- models of human behavior to use in virtual simulations to assess AV safety

Human factors for AV development include all considerations of the human in the AV design. It does not include the development of hardware and software in general, but many tasks that typically are considered "hard core engineering", such as path planning, has clear HF aspects in them (see list above). Consequently there may be HF requirements on the sensing or actuator system and other AV engineering that may have HF implications (e.g., sensing and actuation needs to provide the path planners the means to navigate in a way that is acceptable to the AV users).

#### *2.1.1. Human factors and its role in AV development*

In AV development, HF relates to aspects of both software development and physical AV design. Examples of HF aspects in AV development are many. Note that a common misconception by many non-HF experts is that HF is simply a list of factors, while it is actually a range of aspects that affect humans, or that humans affect (see, e.g., the definition by the Journal of Human Factors). Physical aspects range from seating ergonomics (as AVs are impacting vehicle interiors (Salter et al., 2019)) to the physical design and placement of human–machine interfaces (HMIs). Typically, humans are directly affected by software aspects of HF, including: how and when the (software-based) HMIs display information (Carsten and Martens, 2019), how external road users are to be communicated with (Ackermann et al., 2019a; Faas et al., 2020), how the vehicle stays in the lane (Xu et al., 2017; Miller and Boyle, 2019), how it keeps its distance from a lead vehicle (De Winter et al., 2014; Reagan et al., 2017; Morando et al., 2016), how it overtakes other road users (Abe et al., 2017; Kovaceva et al., 2019), how humans and AVs communicate (Ackermann et al., 2019b), and how AVs can avoid driver over-reliance on the AV performance and ensure that the trust in the AV is properly calibrated (Mirnig et al., 2016; Kraus et al., 2020). These examples highlight the extent to which successful engineering depends on HF knowledge. Yet it remains an open question how engineers gain awareness of HF in their daily work and design decisions.

#### 2.1.2. What HF issues impact AV development?

Kyriankidis et al. highlight that as AV development in the industry keeps moving forward at a fast pace, the gap between research in academia and R&D in the industry continues to grow (Kyriakidis et al., 2019b). They stress the importance of more research on the interconnection of AVs with other road users, human trust in and acceptance of AVs, and how much (and which) information drivers will get and should be getting from AVs. The authors also discuss the need for more experiments to study how humans interact and control transitions between the driver and the AV. Similarly, Noy et al. (2018) argue that the benefits of AVs (such as safety) can only be achieved if they are designed according to standards of human–system integration. The importance of integrating HF into the design and evaluation processes of autonomous vehicles to increase their safety and trust is also highlighted in this position paper (CARTRE, 2018) and in the book by Wickens et al. (2003).

The work by Saffarian et al. (2012) lists six specific issues regarding HF in AV development: overreliance, behavioral adaptation, erratic mental workload, skill degradation, reduced situation awareness, and inadequate mental models of automation functions. The authors proposed a solution for these issues specific to CACC (Cooperative Adaptive Cruise Control), as well a proposing a mechanism of interaction between humans and CACC. However, the solution simply proposed a few different modes to keep the driver in the loop and facilitate cooperation between driver and vehicle.

Chen et al. (2018) describe the importance of transparency between intelligent systems (e.g., robots or AVs) and humans. The authors developed a Situation awareness-based Agent Transparency (SAT) model to ensure an appropriate interplay between AVs and humans. Their study mainly targets human drivers' need for transparency of AV functionality in order to promote better understanding, trust, and interaction.

For each individual HF issue encountered during the AV development process, involved engineers may lack the experience or competence to include the appropriate HF aspects. However, no one can know everything. Communication about HF among stakeholders is therefore crucial. The AV development process must include many stakeholders from different domains, making it interdisciplinary.

### 2.2. AV development: Processes, approaches, recent developments

In the automotive sector, the R&D required to create cars and trucks and offer related services is a complex affair, involving many disciplines such as mechanics, electrical hardware, and (increasingly) software. Whereas electronics and software in cars were originally introduced simply to optimize engine control, their development now drives 80% to 90% of the innovation in the automotive industry.[4] This subsection provides an overview of AV development in the context of requirements engineering (RE).

#### 2.2.1. Requirements engineering

International standardization and certification bodies provide valuable insights into the fundamental concepts of requirements engineering. The IEEE defines a requirement as either (i) a condition or capability needed by a user to solve a problem or achieve an objective; (ii) a condition or capability that a system or component must meet to satisfy a contract, standard, specification, or other formally imposed documents; or (iii) a documented representation of a condition or capability as in (i) or (ii) (IEEE, 1990). The International Requirements Engineering Board (IREB) describes requirements as representations of the needs and desires of customers and users for new things to be built or old things to be upgraded (International Requirements Engineering Board, 2020). Accordingly, requirements can be of three types: functional (a result or behavior to be provided by a function), quality (a quality concern not covered by functional requirements, such as performance, availability, security, or reliability), and constraint (a further limitation on valid solutions beyond what is necessary to fulfill functional and quality requirements). IREB characterizes Requirements Engineering as specifying and managing "requirements for systems such that the systems implemented and deployed satisfy their stakeholders' desires and needs" (International Requirements Engineering Board, 2020).

Activities of RE typically include elicitation, analysis, specification, validation, and management of requirements (Nuseibeh and Easterbrook, 2000). In addition, requirement prioritization becomes a key RE activity in agile development, supporting elicitation and analysis by identifying the requirements with the highest stakeholder value (Heikkilä et al., 2017). Research emphasizes the interdisciplinary aspects of requirements engineering (Nuseibeh and Easterbrook, 2000); however, we are not aware of any works that explore how HF research can be integrated into requirements engineering activities for agile system development at scale.

#### 2.2.2. Development practices

Traditionally, the automotive environment has been characterized by long lead times (Berger and Eklund, 2015) and stable, sequential engineering practices (Pernstål et al., 2012). Eklund et al. (2014) argue that the industry is currently transitioning from plan-driven, stage-gate processes (Pernstål et al., 2012) to more value-driven, continuous approaches (Knauss et al., 2016; Fagerholm et al., 2017a) (often referred to as agile methods (Meyer, 2014) or agile transformation (Paasivaara et al., 2018)). Gren and Lenberg argue that the main motivation for such a transformation is to be able to respond to changing requirements (Gren and Lenberg, 2020).

Agile methods have traditionally been proposed for small teams (six to eight developers) (Beck, 1999; Schwaber and Beedle, 2001; Meyer, 2014). The core values of agile methods as described in the agile manifesto Beck et al. (2001) are: Focusing on individuals and interactions to develop working software in close collaboration with customers with an emphasis on embracing change while de-emphasizing processes, tools, extensive documentation, contract negotiation, and following plans. In fact, agile methods have been presented as the antithesis of previous plan-driven approaches. In its original form, an agile team would take notes about customer needs in the form of user stories on small index cards. Often, these are described as boilerplate statements: "As a <role> I want <feature> so that < value >" (Leffingwell, 2010). The much more detailed requirements of plan-driven approaches are omitted; instead, agile methods push for a continuous dialogue with customer representatives or product owners and comprehensive sets of tests, which are ideally automated (Meyer, 2014). On the other hand, agile methods have been criticized for limiting requirements engineering to functional requirements described through (exemplary) scenarios and discouraging upfront planning (Meyer, 2014).

#### 2.2.3. Development approaches at scale

Automotive R&D work is typically a collaboration between an OEM (Original Equipment Manufacturer) and suppliers in several tiers. The OEM owns the vehicle brand and orders mechanical, electrical, and software components from suppliers. Thus, the ability to specify requirements for the vehicle and break them down into component specifications is a core competency for an OEM.

[4] According to industry experts: https://tinyurl.com/y9jnoupd.

In order to improve their responsiveness to changing requirements, OEMs have started to bring more development in-house and to identify new collaboration models with suppliers (Hohl et al., 2016; Van Der Valk et al., 2018). As a result, OEMs struggle to maintain effective ways of structuring, documenting, and managing requirements for increasingly complex systems (Liebel et al., 2019; Kasauli et al., 2020). While software teams may have quickly learned to adopt agile methods, company-wide adoption is usually slow, mostly due to skepticism (Lindvall et al., 2004). Thus, new ways of managing requirements must be conceived for OEMs and their supplier value chains (Kasauli et al., 2021).

Moreover, for complex products such as cars, it is important to scale agile methods beyond individual teams, since if the overall plan for the complete vehicle cannot be changed there is limited value in an individual team's ability to respond to change (Gren and Lenberg, 2020). SAFe is the most commonly used framework for scaling agile (Knaster and Leffingwell, 2017b), especially in the automotive domain Kasauli et al. (2021). SAFe describes a requirements information model that groups several user stories into epics. Epics can then describe mid-to-long-term goals for groups of teams. The model also describes non-functional requirements as a way to present quality requirements as constraints for user stories and epics (Leffingwell, 2010).

Previous works have described inadequacies in the SAFe framework (Kasauli et al., 2021) and its requirements information model (Wohlrab et al., 2020). Of particular relevance to this paper is the fact that scaled-agile methods struggle to provide alignment among many software teams (Kasauli et al., 2021; Wohlrab et al., 2020); we need to consider the effects of scaling agility beyond individual software teams since questions about agile ways of working must be part of our exploration of HF. For example, for a given automated driving function, several teams must align on how to address HF. For brevity, hereafter we refer to *scaled agile* or *large scale agile* simply as *agile*.

### *2.3. Related work: communicating human factors knowledge and requirements to AV engineers*

Interdisciplinary communication is often difficult. However, many fields such as aviation, transportation, and medicine, acknowledging the importance of HF knowledge, have worked to integrate HF design principles and techniques into the design and development of products and systems. Vincent et al. (2014) suggested that the communication gap between HF knowledge experts and other developers is due to a lack of common ground; they proposed the use of mediating representations of boundary objects (Star and Griesemer, 1989) for effective communication. Bruseberg (Bruseberg, 2008) introduced a novel methodology that feeds HF knowledge into an architectural framework. However, the author mainly discusses HF from a cognitive perspective. Alternatively, Chua and Feigh (2011) suggest including HF in an early design stage. While HF can provide significant input to improve the communication between HF experts and system engineers, it is unclear exactly how to include HF knowledge in these stages of development. Other authors (Bodenhamer, 2012; Ramos et al., 2012; Orellana and Madni, 2014; Watson et al., 2017) advocate including HF in system design via SysML, using activity, block, and sequence diagrams.

van Maanen et al. (2005) have discussed how HF can be integrated with AI for better human–machine cooperation (HMC). Whereas current customization is limited to static interfaces, improved HMC could provide customized support to users. However, knowledge about both HF and artificial intelligence (AI) and how to integrate them is lacking. To bridge this knowledge gap, van Maanen et al. (2005) have proposed a methodology based on interdisciplinary cognitive engineering (CE+). In CE+, HF experts provide the relevant information (such as the support concepts and rules) and strategies for the specification and evaluation of HMC. The authors concluded that HF and AI must be integrated into the early stages of the development process. In fact, the User Centered Ecological Interface Design (UCEID) (Revell et al., 2018) method proposes a combination of techniques (e.g., data collection and task and cognitive task analysis) to include HF considerations in the early stages of the overall system design processes. The main finding of UCEID is that it is important to meet the dual requirements of demographically diverse clients and technology delivery. It remains unclear how these requirements can be integrated into the (agile) development cycle; however, considering the importance of the issues mentioned above, a way must be found to design AVs with HF in mind (Merat and Lee, 2012; Kyriakidis et al., 2019a).

Adopting this design practice proves to be challenging, not the least because of the adoption of agile development (Mehrfard et al., 2010). Processes have become more iterative, putting more emphasis on a continuous understanding of requirements. It is unclear how the above-mentioned methodologies would work for the communication of HF knowledge in today's large-scale agile AV development. For example, Kashfi shows how difficult it is to align user-centered design and UX in agile development (Kashfi, 2018).

In summary, although communicating HF knowledge to engineering teams is challenging, research provides ample motivation to explore how this challenge can be overcome in practice. To our knowledge, no systematic approach exists that make sure that HF are adequately represented in agile system development.

## 3. Research method

Our exploration of the role of HF in developing automated vehicles is widely based on the epistemological stance of critical realism (Lawani, 2020), a research philosophy that distinguishes between the 'real' world and the 'observable' world. With respect to this study, we made this distinction by observing and analyzing expert opinions about how HF aspects are addressed in engineering, rather than assuming that we can analyze those aspects directly. Critical realism relies on a common ontology or sociological theory, which we provide through our detailed assumptions about the role of HF, RE, and agile methods based on related work in Section 2. In our study design, however, we were also inspired by the school of pragmatism, focusing on particular causalities of pragmatic relevance (i.e., the implications that follow from particular properties of agile AV development and HF). As discussed by Lawani (2020), pragmatism and critical realism are often associated with each since both advocate the use of mixed methods and on understanding (causal) relationships that are thought to be not directly observable. In fact, we added continuously to our knowledge as we learned new items that did not previously fit into our mental model. Given this mix of epistemological stances, we decided that an exploratory, qualitative inquiry was the most appropriate to address our research questions (Creswell and Creswell, 2017).

Our case consists of a number of automotive companies, including manufacturers and suppliers, collaborating not only within the value chains needed for building automated vehicles but also beyond, to build and maintain excellence in the field. We relied on semi-structured interviews with experts to provide the primary data, since we were specifically interested in applying the personal views of experts in the field (who collaborate within and across value chains and concrete products) to chart the landscape of HF in relation to AV development.

In this section, we describe the collection and analysis of the data.

**Table 1**
Interviewees' roles and work experience (Experience level: Low = 0–5 years, Medium = 5–10 years, High = More than 10 years).

| ID | Role | Experience Level |
|---|---|---|
| S1 | HF Expert (Specialist) | High |
| S2 | HF Expert (Strategy, Specialist & Research) | High |
| S3 | AV Engineer (Strategy & Architecture) | High |
| S4 | AV Engineer (Requirements & Research) | Medium |
| S5 | HF Expert (Management & Research) | High |
| S6 | HF Expert (Specialist) | High |
| S7 | HF Expert (Specialist & Design) | High |
| S8 | AV Engineer (Safety & Research ) | Low |
| S9 | AV Engineer (Strategy & Specialist) | High |
| S10 | HF/AV Engineer | High |
| *Special | Interviews | |
| S11 | HF Expert (Specialist) | High |
| S12 | HF Expert (Specialist) | High |

### 3.1. Data collection

Our strategy for recruiting interviewees for our study (Palinkas et al., 2015) relied primarily on convenience sampling. That is, we aimed to identify interviewees who possess the relevant expertise and were willing to participate. Our results confirm that such experts are rare among companies, and that it is important to protect their time. In recruiting interviewees, we relied both on the personal and professional networks of the authors, built through years of research with participating companies, and on recommendations from the interviewees themselves. We aimed for a mix of similarity and variation in our sampling in order to cover different perspectives (HF vs. engineering and OEM vs. supplier) in sufficient depth.

As a result of these efforts, we interviewed ten experts from five Swedish companies: four from Volvo Cars, two from Volvo Trucks, two from Zenuity, one from Veoneer, and one from Autoliv. In addition, we conducted two more complementary interviews with international academic leaders in the field (S11 and S12), to get additional perspectives on the definition of HF and emerging themes. All of the industry interviewees have been working with AV companies for years, often more than ten (see Table 1). The experience level of the participants is classified as *low* if they have less than five years of experience, *medium* if they have between five to ten years, and *high* if they have more than ten years. Experience level is the sum of all jobs for each participant, which can span one company or more. However, from talking to them, we can infer that, even though they changed companies, their roles and companies were similar in the same domain, and their experience is well in line with both the needs for their individual job roles and this interview study.

In Table 1, S11 and S12 are separated from the other participants because these interviews were conducted in a slightly different style, and the preliminary results from the other interviewees were kept in mind.

We relied on semi-structured interviews because they are especially suitable for exploratory studies (Creswell and Creswell, 2017): depending on the course of the interview, questions can be adjusted to mitigate the risk of asking the wrong questions, and follow-up questions can be created to satisfy emergent information needs. This approach allowed the participants to articulate their individual and valuable views, concerns, and expectations. Consequently, interviews tended to resemble guided discussions and were engaging both for interviewees and interviewers.

Each interview took between 60 and 80 min. In most interviews, all three authors were present; at least two authors were present in every interview, which allowed us to keep extensive, often verbatim, notes. The second author took notes, and the first author conducted the interview. The second and third authors have extensive experience in the automotive industry, having been involved in various research projects over the years. The second author has particular expertise with RE and Agile and the third author has formal training as an engineer, but has worked between HF and engineering for many years. Given their multidisciplinary background, they was there to ask follow-up questions and provide clarification.

Notes ranged from 700 to 1750 words and contained, on average, 1325 words. We did not record the interviews. We did, however, show our notes to the interviewee during the interview. While we were interested in the perspectives of experts on the role of HF knowledge in AV development, the discussion could have touched on examples of perceived or real shortcomings in processes, which would be very sensitive information. It was thus deemed better not to record the interviews; after a sensitive discussion, any such content was eliminated from the meeting notes or, if necessary, more suitable examples/formulations were substituted. Rutakumwa et al. argue similarly to us that the context can have a negative impact on the quality of answers when recording (Rutakumwa et al., 2020). They also indicated that there is not necessarily a negative impact on the quality of the transcript in relation to its role in the thematic analysis (Rutakumwa et al., 2020).

Before the interviews, we prepared a guide[5] to help us cover the same topics in each interview. Each interview included the nine open-ended questions and detailed follow-up questions contained in the guide. We designed the interview guide with the intention of getting an HF perspective on the design and development of AV technology. The questions in the interview guide are based on our literature review and experience. This includes assumptions of research gaps, as apparent in question three. Studies such Hancock (2019), Wickens et al. (2003), Navarro (2019) clearly indicate that problems of HF are not properly addressed. With respect to our experience, the authors are currently involved in a project (SHAPE-IT, 2023) with many senior human factors experts. Discussions with those experts clearly indicate substantial gaps in the integration of HF in AV development. Although some of the questions posed during the semi-structured may have influenced the interviewers, this is a common risk with this interview format since it involves open-ended conversations. To mitigate this risk, we tried to include three interviewers to capture the conversation and minimize any potential biases that could have arisen during the interviews. Consequently, we believe that the level of risk posed by these potential biases is negligible.

The map between the interview guide questions and the research questions is shown in Table 2.

### 3.2. Data analysis

In order to analyze the data obtained from the interviews, we relied on the common set of principles (Noble and Smith, 2014) used for qualitative analysis of interview data. Specifically, these principles include: transcribing the interviews, familiarizing ourselves with the data to attain a deep understanding of the phenomena being investigated, coding, generating initial themes, and finalizing the themes and overarching concepts.

[5] We provide the interview guide as well as an overview of our themes in relation to codes and example quotes as data set at Zenodo, DOI: 10.5281/zenodo.5562487.

**Table 2**
Interview questions, mapped to the research questions.

| Interview questions | Research question(s) |
|---|---|
| 1. Background of interviewee (Demographic Data)<br>• What is your role?<br>• What is your experience in that role?<br>• What is your experience with HF/Requirements?<br>Reminder: We will take notes during the interview, which we will send later for confirmation. | Demographics |
| 2. How would you characterize what HF is and how it relates to requirements for AV development (or AI-based systems)? | RQ1 |
| 3. In your experience, how does engineering work with or without HF? What is missing? | RQ2 |
| 4. How does HF knowledge come to engineers? | RQ3 |
| 5. What are the main challenges in conveying requirements from HF to engineers that design automated vehicles (or from engineers to HF experts)?<br>• Follow-up: what about conveying knowledge from HF/behavior as input into the AI-based AV-design process?<br>• Think about comfort zones as an example, safety aspects, software requirements aspects (e.g., AI based control of the vehicle) compared to traditional physical "user experiences" of AV. | RQ2 & RQ3 |
| 6. What scenarios related to AV in urban environment are the most difficult (and/or important) to convey requirements to AV-engineers? | Not used |
| 7. Do you have recommendations on how to optimize communication between human factors experts and engineers of AI-based AVs? Any guidelines for incorporating human factors into AI-based AV design guidelines? | RQ2 & RQ3 |
| 8. How should the process (or: way of working) for system design look like? Particularly in agile development how we do that? | RQ3 |
| 9. Thanks you for the interview, next steps.<br>• Whom else should we interview?<br>• Anything we forgot to ask? | All |

The extensive interview notes were a good starting point for further analysis. To familiarize ourselves with the data, we read the interview notes thoroughly while creating memos describing those ideas that the notes inspired (Birks et al., 2008). Then we highlighted parts of the text related to our research interest and assigned them labels (so-called "codes"). In parallel, we continued to create and discuss memos to capture any noteworthy aspects as they surfaced. For these activities, we relied on both generic word processors (MS Word) and specialized qualitative analysis tools (NVivo[6]). Through these steps, we identified the main ideas as well as common perspectives.

After formalizing and coding the data, we further classified all the relevant codes into candidate themes. For example, the following quotes were coded as "validation test" and "test dilemma", respectively.

> *"Perhaps put more emphasis on validation tests, that is, not only automated tests but also test the quality in use."* — S4 - AV Engineer

> *"I have seen people spend three person-years on things they have never tested with real humans. Then they claim they have never had time to do so."* — S2 - HF expert

By analyzing and categorizing these and other relevant quotes, we came up with a theme called "Testing".

The themes and codes were then re-analyzed to check if there was any missing or extra theme with respect to our interview notes or any mismatch in the code classifications. In this way, we refined the set of themes until all authors agreed that it provided complete coverage of all aspects of the data, without redundancy, on a meaningful level of abstraction.

Finally, we renamed our themes to better align with research questions. Section 4 describes the outcomes of our data analysis

## 4. Findings

This section presents our findings, with each subsection addressing one RQ. We start by defining HF in AV development, based on our interviews and the literature (RQ1). The second research question focuses on the properties of HF and agile ways of working (RQ2). These properties raise important questions (discussed in our interviews) about the interplay of both disciplines. Then, we present the implications that emerged from these discussions in three themes related to research question RQ3: implications for agile ways of working, implications for HF work, and implications for managing requirements.

For each theme, we start our report of results with a box that shows in which interviews we have identified related codes. Table A.3 presents a comprehensive list of all the themes covered in this paper, along with their corresponding codes. Additionally, we provide an overview of our themes and codes per interview as an external resource, here.

### 4.1. Human factors in relation to AV development (RQ1)

HF Definition based on codes from interviews with: S1-3, S5-6, S11-12

In order to explore the systematic capturing and managing of human factors in AV development, it is important to share a common understanding of the key concepts. Therefore, our first question aimed to understand each interviewee's perspective on human factors and their relation to AV development. Our interviews show a broad and diverse usage of the term 'human factors', which is also reflected in the literature.

For example, the following quote shows a rather broad definition of the term, assigning responsibility for considering human factors to the complete development cycle:

> *"How to safely develop an AD function (without killing humans in the process) so that in case of a crash, people will say that the car was behaving reasonably."* — S1 - HF Expert

In other examples, interviewees had a more technical, outcome-oriented view of the term and how it feeds into other engineering processes:

6 https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home

*"Learning the user preferences, should it be race driving, comfort, safety, or speed."* — S3 - AV Engineer

*" HF was 2WW system ergonomics, then CS brought up HMI. Those have merged since. You have physical interfaces, but also services, but also how users are adopting new functions and whether or not they continue using. HF and HMI are intertwined. Ergonomics is included and overlaps with the cognitive side, e.g., external communication with other road users. Understanding the warnings and so on."* — S6 - HF Expert

Human factors knowledge, such as preferences about the level of comfort, safety, and speed, is instrumental for the development of AV. The role of HF in providing input to design and development is also reflected in another interviewee's quote:

*"Understanding the interactions between people and all other elements within a system, and designing in light of this understanding."* — S5 - HF Expert

However, considering HF requires more than one-way communication with engineers. As the following quote reveals, HF sets limitations on both engineers and users.

*"How to communicate the limitations of behavior so that people understand what they are allowed to do and what they are not allowed to do... [This is easy to do with] HF related to safety. [With other] HF [e.g., those] related to a sense of calm or serenity that is a bit more difficult."* — S2 - HF Expert

Given the broad use of the term 'human factors', we aimed to integrate different interpretations from practitioners' perspectives into a definition of human factors in AV development.

As part of this process, we relied on the two international experts to provide more insight. They confirmed that a working definition is indeed needed and might need to be compiled from various sources and then matched with comments from our other interviewees:

*"So one definition is from the Journal of human factors, which is about knowledge of human capabilities and limitations. I think that would be good, but there is one on this other page... The goal to design safe, comfortable, effective [systems for] human use is almost describing what you are trying to achieve, so I am just wondering whether you could start by saying this is what we believe HF is and then add more with your work."* — S12 - HF Expert

In addition, our international experts confirmed that a good working definition must be related to the engineering cycle

*"Understand, create and evaluate cycle. HF plays a role in each component & understand is about identifying requirements, human capabilities, limits, needs & describing those in ways that influence the design."* — S11 - HF Expert

*"AV has physical considerations regarding how you get in a vehicle, make the seats big enough to accommodate the people, there are certain design issues. But it also that people trust the AV to be safe, how do they perceive the important risk, do they feel comfortable with the algorithms, do the algorithms behave as expected, does it enhance end goals: pleasure, satisfaction, aesthetics? "* — S11 - HF Expert

This is a cross-cutting theme that is also visible in the other subjects' quotes above.

In summary, we note that multiple definitions of HF exist, even on the homepages of key journals of the field (e.g., The Journal of the Human Factors and Ergonomics Society, 2020), depending on the specific research context. In our research context, it is crucial to link HF to AV design and development, as well as the development cycle. As suggested (by S12 above, for example), we start from a generic established definition of HF (taken from The Journal of the Human Factors and Ergonomics Society, 2020), and relate it to the development cycle. Fig. 1 represents our working definition graphically: added aspects are shown in green, and the most important aspects from our interviews are underlined (both in the Figure and in the quotes above).

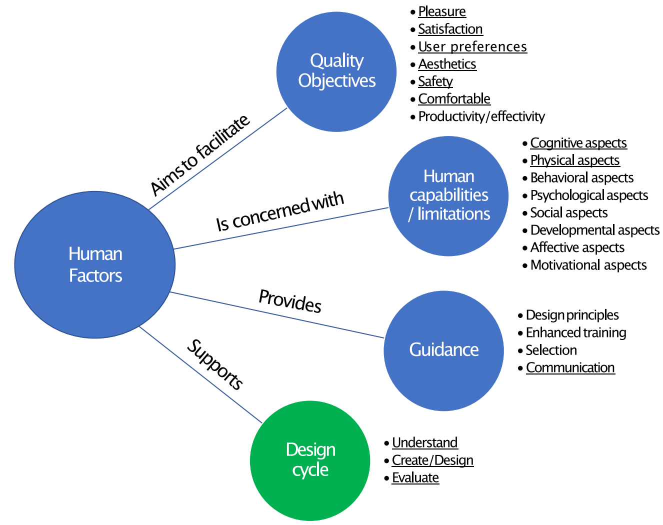



**Fig. 1.** A mind-map of aspects that define Human Factors in the context of the design and development of automated vehicles.

**Definition.** The field of *Human Factors in AV Development* aims to inform AV development by providing fundamental knowledge about human capabilities and limitations throughout the design cycle so the product will meet specific quality objectives.

Based on our interviews, we can highlight some critical aspects of this definition that shape the relationship between human factors and agile AV development. Firstly, it is important to relate human factors to *AV development and its product quality objectives*. These objectives usually include an AV design result that is pleasurable, satisfactory, user-preferred, comfortable, aesthetic, effective, and safe for stakeholder interaction (Wickens et al., 2003).

Another component of the definition, *human capabilities and limitations*—which include cognitive, physical, behavioral, psychological, social, affective, and motivational aspects, is the core concern of human factors experts (The Journal of the Human Factors and Ergonomics Society, 2020). It is critical to effectively manage these capabilities and limitations during AV development. Therefore, it is a crucial role of HF in AV development to provide *fundamental knowledge* about human capabilities and limitations and their relation to quality objectives for AV design. Typically, this knowledge is provided in the form of design principles, training, selection, and communication. In this paper, we will focus on the implications of knowledge transfer in the context of agile AV development.

This fundamental knowledge is needed throughout the *design cycle of AVs*. While various design cycles have been proposed, we refer to the phases that Jacobson et al. found to be essential when building software-intense systems (Jacobson et al., 2012): understanding the requirements; shaping, implementing, testing, and evaluating the AV system; and putting the AV system to use. Note that in modern AV development, these phases are iterative and incremental. Relating HF to AV development throughout the design cycle is of paramount importance for discussing the relationship between HF and AV development. Yet, it is missing from many established definitions of HF and therefore highlighted in green in Fig. 1.

Thus, to answer RQ1, we noted that AV development is suffering from the lack of a working definition of HF. From our interviews with industry HF experts, we extracted the core aspects that such a working definition should have and triangulated it with definitions found in the literature. We further validated

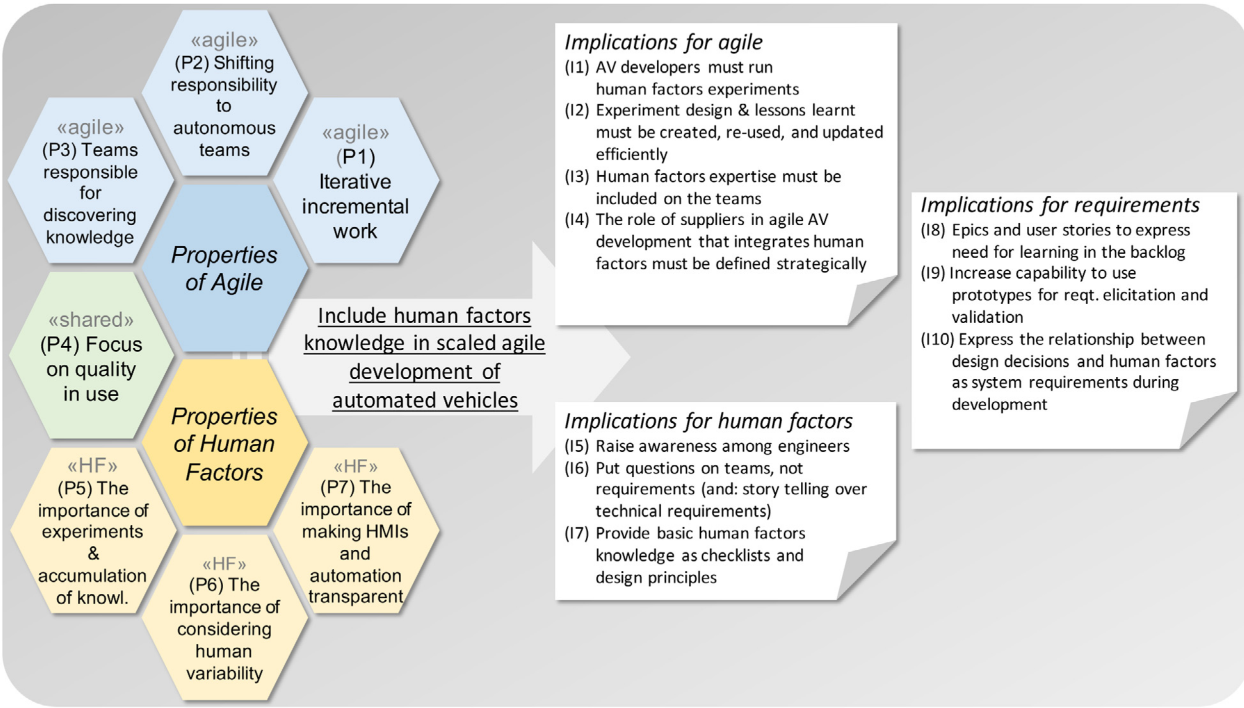



**Fig. 2.** Taking a requirements engineering perspective, our qualitative study on Human Factors for Automated Vehicles revealed themes relating to properties of human factors and agile system development, as well as implications for human factors and agile system development and requirements.

our suggested definition with interviewees S11 and S12. Thus we have established a common language for addressing RQ2 and RQ3.

### *4.2. Properties of human factors and agile (RQ2)*

In order to lay the foundation for improving the way that HF knowledge and development work are integrated into agile AV development, we first focus on the properties of HF and agile ways of working. We provide an overview of our findings for RQ2 in the left part of Fig. 2.

#### *4.2.1. Properties of agile.*

When we started our investigation, we were aware of the role of agile in transforming companies and the challenges this puts on requirements. Initially, we mainly included questions about agility to investigate its influence. However, all interviewees highlighted certain properties of agile that are important when considering the interplay of HF and AV development. In order to mirror the emphasis that our interviewees put on agile methods, we begin by describing the properties of agile that influence the management of HF knowledge most. The following themes emerged from the data analysis of these properties (shown as P1–P4 in Fig. 2).

*(P1) iterative incremental work.*

P1 based on codes from interviews with: S2, S4, S5, S6, S7

Agile promotes *iterative incremental work*, to help organizations deliver fast and often as well as increase their responsiveness to changing requirements. For example, Subject 4 mentions that a property of agile work is an incomplete specification early on, combined with iterative work:

> *"[...] But we are working in an agile way, so the specification is not complete in the beginning, but we iterate, and changes might come later. "* — S4 - AV Engineer

Subject 2 suggests that this has completely changed how HF are communicated to development teams:

> *"We had requirements, but that has changed with the agile transformation. We now see it mainly as knowledge transfer, how to move HF knowledge to the teams. The game has completely changed. It is much more a social kind of setting."* — S2 - AV Expert

Our interviewees mainly expressed this as a positive change, as expressed by Subject 5:

> *"At least not in the very old way, where high-level aspects are very much disconnected. Waterfall will not be the solution. But better integration and iterative work sound very promising."* — S5 - HF Expert

Yet, it is important to complement the perspective of teams with a full system view and make sure that HF (for example) fit into the big picture, as Subject 7 mentions:

> *"Agile teams tend to get small bits of tasks and work with these for a short period and then leave it because it is not in the backlog anymore. If it was only for the teams to develop, then nobody would take full system view. What kind of language do we use, when to use knobs, touch screens,...,if it was only up to the teams, you would not have that holistic picture. That is our most important part right now."* — S7 - HF Expert

*(P2) shifting responsibility to autonomous teams.*

P2 based on codes from interviews with: S3, S6, S7

Agile methods aim to achieve fast, incremental delivery and responsiveness to change by *shifting responsibility to autonomous teams*. These teams can then make local decisions quickly. As a result, agile teams dislike static, detailed requirements, which limit the team's autonomy and, therefore, its effectiveness. This property of agile is mentioned by Subject 3 (for example):

*"[...] they are then responsible for the topic. T-shaped teams."* — S3 - AV Engineer

This property of agile teams has advantages and disadvantages. Subject 6, for example, highlights the transparency that this approach generates.

*"I like the way we work now with agile trains. Things are very visible; you see all the stories created by the different teams, and you have clear goals. It is in the method that you promote what each team is doing."* — S6 - HF Expert

However, Subject 7 repeats their concern about the potentially missing system level view as a result of increased team responsibilities.

*"Ideas come up internally that developers and hardware designers should know their requirements by themselves. I feel like that is difficult."* — S7 - HF Expert

*(P3) teams responsible for discovering knowledge.*

P3 based on codes from interviews with: S1, S3, S6, S7, S9

Instead of receiving detailed requirements, agile teams prefer being *responsible for discovering knowledge* themselves, relying on face-to-face communication rather than on extensive documentation.

This preference is implied by a number of our interviewees. Subject 7, for example, explains how the role of HF experts has changed:

*"[...] It is less about handing over requirements, and instead being there for discussion or to evaluate the concepts."* — S7 - HF Expert

The responsibility of agile teams to discover knowledge is also evident from how S9 describes the need for agile teams to seek expertise:

*"Then, as an engineer, you should have enough awareness to know when to seek out that expertise. But it is, of course, only one competence area of many."* — S9 - AV Engineer

Similarly, Subject 1 shares their view on how to guide agile teams to discover knowledge about the right concepts, not by defining requirements but by relating high-level stories that then can be explored:

*"[...] Do the guerilla requirements. Do not write requirements, but tell interesting stories based on empirical data, getting the right concepts into the brains of engineers (where it then stays because they are so bad at forgetting things)."* — S1 - HF Expert

*(P4) focus on quality in use.*

P4 (agile) based on codes from interviews with: S3, S4, S6, S10

One of the differences highlighted by our interviewees between agile and traditional approaches is the different concept of quality. The quality of software-based systems is commonly divided into internal quality (structural properties such as maintainability of the software) and external quality (the fulfillment of user requirements—i.e., providing the desired functionality) (Freeman and Pryce, 2009). In contrast, agile approaches suggest that requirements rapidly change and those provided initially may not describe the users' needs by the time the product is finished. Therefore, according to agile approaches, it is not sufficient to fulfill (potentially outdated) requirements to obtain user satisfaction; it is necessary to address the users' actual needs and focus on *quality in use*. Agile practices with this focus include, for example, the on-site customer (Beck, 1999) and sprint demos (Schwaber and Beedle, 2001).

Thus, agile teams take responsibility for regularly demonstrating a working product, putting it to use in the intended context, and enabling feedback by end users and customers.

A good description of this property was given by Subject 3:

*"[...]Working agile means being able to test what you are doing and improve the quality continuously."* — S3 - AV engineer

It is, however, important to not rely solely on automated tests. Subject 4 highlights the need to push for acceptance tests.

*"[...] Put more emphasis on validation tests, that is, not only automated tests but also test the quality in use."* — S4 - AV Engineer

This is generally a good fit for HF, as our interviewees mentioned—for example:

*"Understanding that problem is crucial, as well as getting experience about what users like. How do people want to be addressed?"* — S10 - HF/AV Engineer

*"[...] If you have a nice mindset and an open point of view, the iterations, increments, and multi-disciplinary work will fix many of these things. User-centered design."* — S6 - HF Expert

There are, however, a number of conceptual mismatches between the HF and agile AV development domains. Examples include agile focusing on delivering a working product and rejecting big up-front analysis and secondary documents (for example, requirements, architectures, or HF studies)—and even removing those documents after implementation is complete (Meyer, 2014). These practices may lead a team to decide on a particular design based on requirements and HF studies, and to maintain only the actual work product. In future iterations, therefore, the rationale for a design decision is no longer available, potentially leading to duplicate or sub-optimal work (since previous requirements and HF knowledge cannot evolve).

#### 4.2.2. Properties of human factors.

In order to represent the relevant properties of human factors, the following themes were derived from certain characteristics referred to by the interviewees.

*(P4) focus on quality in use.*

P4 (HF) based on codes from interviews with: S2, S9, S10

HF experts also focus on *quality in use*, since they are concerned with deriving knowledge from human interactions with the system (here: the AV). Clearly, with that focus, the internal, structural properties of the software are of little relevance. Even external quality does not sufficiently describe a system's quality from a human factors perspective: A system that fulfills all requirements on paper but is not pleasurable, satisfactory, or safe to use in the real world will fail to win over an end user. As a result, with agile, HF experts and AV engineers are much closer to each other than they were in traditional development approaches (which broke HF quality considerations down into internal and external quality indicators for implementation). This concordance is implied by the following response from S9:

*"[...]Not sure we are good with agile yet, but ideally, through improved testing, we should get even more improvements. As long as you can include an HF expert, then all should be fine in the larger picture."* — S9 - AV Engineer

Incremental, agile work can actually be ideal for addressing HF. For example, S2 points out that it allows the quick generation of feedback and an understanding of HF in relation to the system under construction.

> *"[…] Could be really interesting to see how an HF requirement changes with time. How and why does it change? You change it because of some feedback. Why did it not work? Because of this test. Then assess the quality of the test (formal or just friends trying it out). Then also heuristic evaluations, defining usability errors. For those, you do not need a lot of subjects. This is not a statistical approach; it can generate a lot of problems at a low cost. But are these the right problems? The key problem is that HF experiments are expensive."* — S2 - HF Expert

*(P5) the importance of experiments.*

P5 based on codes from interviews with: S2-4, S7, S9, S11

HF experts highlight the importance of experiments and testing the system. In agile development particularly, iterative work demands continuous testing, both to avoid regression problems and to address changing requirements.

HF experts aim to perform experiments with the system under assessment using human subjects who are not on the engineering team developing the product. Thus, HF experts might test how humans react in specific situations, how they get distracted, how they feel about the system, and how the system affects their behavior (e.g., over-reliance), while considering human variability. S2, for example, relates the importance of experiments to the need to identify assumptions:

> *"You need to identify assumptions. …Start from someone's idea and explore it (from engineering), or you can take your own knowledge (HF) and bring it in. And then you create the experiment and the conditions."* — S2- HF Expert

Again, the shift to agile work has significantly changed the work with experiments. As S3 points out, it requires continuously finding ways to test assumptions.

> *"[…] Before it was easier: Just ask this department to come up with requirements from HF perspective, then push it into the development teams. Then, have test methods in place. What we have done…working agile means to be able to test what you are doing and improve the quality continuously. That also well matches with HF."* — S3 - AV Engineer

Even though it might have been *easier* before, as S3 points out, referring to none-agile ways of working, our interviewees confirm that agility promises to be more effective, as stated by S7:

> *"Agile promotes these things; you need to demo regularly. [but are there enough HF people?]."* — S7 - HF Expert

Other interviewees reason that short, quick experiments with quick feedback cycles should be preferred. The short feedback cycle would help to identify challenges and notify the organization while the topic is still hot. This could enable bringing in the right expertise (e.g., HF or control theory) at the right time, and consequently make the team "fluid and agile".

Perhaps experiments to check assumptions could become a continuous source of input to agile development, since assumptions will always come up. S4, for example, speculates about a shared service to provide support for such continuous experimenting:

> *"You could treat this as a shared service for everyone, support to set up such experiments. It should be quick and easy. It is also related to dealing with assumptions in a more structured way than we currently do."* — S4 - AV Engineer

*(P6) the importance of considering human variability.*

P6 based on codes from interviews with: S1, S4-5, S8, S12

HF play an important role in ensuring that the developed systems are suitable for all humans (with different user characteristics such as age, culture, experience, and visual and cognitive capabilities). Depending on their backgrounds, humans have different capabilities, limitations, and behavior, as for example stated by S4:

> *"Requirements are very different depending on the country and customer company. How does culture change how people think about HF?"* — S4 - AV Engineer

HF knowledge can help design the system to improve its performance, while considering human variability makes the system usable for a diverse set of users. For example, S5 confirms:

> *"Yes. Humans are complex, with strengths and weaknesses that are very different from artificial systems, there is a lot of variability in the performance of a human."* — S5 - HF Expert

This leads to a high level of complexity that must be managed during AV development.

> *"In many cases, the empirical data set is very complex."* — S1 - HF Expert

Bringing the complexity of human aspects into the development of AV also poses technical challenges to engineering, as S8 suggests:

> *"We need the car to handle random walks with these parameters or with those parameters. Can we even model all human traffic in this way?"* — S8 - AV Engineer

The challenge of modeling complex human traffic behavior could also be seen as an argument for the iterative development of AV systems and HF experiments: it would not only allow the incremental verification of assumptions that are relevant for the current development, but it would also allow the accumulation of knowledge about the bigger picture.

*(P7) the importance of making HMIs and automation transparent.*

P7 based on codes from interviews with: S4, S7, S10-11

It is critical for users of vehicle automation to have a proper understanding of the system's capabilities and limitations (i.e., the decisions the AV makes must be understandable and the user must understand what the system's limits are) in order to respond correctly and avoid misuse or disuse of the system. Yet not all users read the manual or attend training. Therefore, the system's capabilities and limitations must be completely transparent, through HMIs and kinematic cues; the AV's capabilities and limitations should be obvious as a result of proper HF design. S10, for example, frames important HF questions around this theme:

> *"Who even checks the manual? Will you even be able to find the button that activates an assisting system? With new functionality in a car, how do you introduce it to users?"* — S10 - HF/AV Engineer

If a feature is not transparent to users, they might deactivate it (potentially reducing their safety, but even more problematically, resulting in over-reliance and over-trust).

*"Try to find ways so that users do not switch off active safety systems. It is about the methods, how you use them, and their purpose, HF and RE."* — S4 - AV Engineer

It is through the effective interplay of systems and users that the overall safety goals are reached. Making sure that typical users sufficiently understand new features is, therefore, an integral HF part of developing AV.

*"[…]There are certain design issues there, but there is also [the fact that] that people trust the AV to be safe; how they perceive the risk is important. Do they feel comfortable with the algorithms? Do the algorithms behave as expected? Does it operate reliably?"* — S11 - HF Expert

Aligning trust and understanding between users and automated systems is of critical importance—but also hard to do. HF expertise is needed, which could, as S7 points out, be obtained from experts on the team or from the results of surveys (or other sources):

*" …8/10 people can make sense of the new function in the first attempt. We need either to be there with our expertise or bring in the end users, e.g., in a clinic or survey, have test drivers."* — S7 - HF Expert

### *4.3. Implications (RQ3)*

This section presents the implications that emerged from interview notes on the three themes related to research question RQ3 (shown as I1–I10 in Fig. 2). Each theme (implications for agile ways of working, implications for HF work, and implications for managing requirements) is presented in a separate subsection.

#### *4.3.1. Implications for agile*

Given the set of properties of agile and HF discussed above, there are certain implications for any organization that aims to take HF knowledge explicitly into consideration during agile AV development. These implications are not currently provided by agile methods, nor are they easily achieved. This section, therefore, highlights the need to adjust agile ways of working and presents, where available, potential approaches indicated by interviewees.

*(I1) AV developers must run human factors experiments.*

I1 based on codes from interviews with: S2, S5, S7-8, S12

*"[…]Holistic view, ideas come up internally that developers and h/w designers should know requirements by themselves. I feel like that is difficult."* — S7 - HF Expert

*"[…] it is less about handing over requirements, and instead being there for discussion or to evaluate the concepts."* — S7 - HF Expert

Thus, when integrating HF knowledge into agile AV development, it follows that agile teams must be able to run HF experiments themselves. This ability is the first implication for agile that we derived from our interview data. For example, S8 clearly states that the engineers are ultimately responsible for the implementation of a function:

*"[…] Engineers should make sure that those (requirements) are implemented and tested."* — S8 - AV Engineer

This generally includes extensive testing. However, as S12 points out, tests that only focus on technical aspects and ignore HF will not fully cover the actual needs.

*"You know engineers will test and retest and retest, but not really with a human in mind…"* — S12 - HF Expert

Agile teams know best what specific knowledge is needed at any given time. Yet, those teams usually lack the HF expertise and knowledge, which must then be provided in a different way (see Implication I3).

*"For an engineer without HF training, the fundamental thing in HF is to test your assumptions. How do you communicate to engineers that to get HF knowledge, you need to test it with human subjects? Experiments."* — S2 - HF Expert

*"[…]I do realize that the teams need such HF knowledge."* — S5 - HF Expert

Our interview data indicates that a core challenge is that agile frameworks do not offer dedicated support for teams to run HF experiments. Due to the large number of autonomous agile teams and the wide variety of situations in which HF considerations may have to be made, there are often no dedicated HF resources available to take on the role of designing and running HF experiments for the team.

Based on *(P2) shifting responsibility to autonomous teams*, *(P3) teams are responsible for discovering knowledge* and *(P5) the importance of experiments*, we conclude from our data that *AV developers must run human factors experiments.*

*(I2) experiment design & lessons learnt must be created, re-used, and updated efficiently.*

I2 based on codes from interviews with: S2, S8-9

If agile teams are to take responsibility for running HF experiments (Implication I1), the teams should also be responsible for decisions about which *experiment design & lessons learnt must be created, re-used, updated efficiently*. S8, for example, suggests the need to aim for re-use.

*"[…] We must have a generic model for such experiments, that can be reused in different products."* — S8 - AV Engineer

In particular, the re-use and updating of designs and lessons require additional attention in agile ways of working. Agile setups must support a single team as it creates HF experiment designs and generates results, which are then re-used by other teams. If a particular change to the system invalidates the results of a study (e.g., by changing how a user interacts with the system), the team must understand the change and, for example, run a new, updated experiment. In short, teams must be able to judge the validity of experimental designs and results and re-run the experiments if needed, as mentioned by S9:

*"Create new knowledge on demand but also use the accumulated knowledge from previous projects. Several levels of tests, even with customers."* — S9 - AV Engineer

AV development therefore must integrate discovery and reuse of HF knowledge into agile methods, where the focus is on maintaining tests and deploying working versions of the product iteratively. S2 provides thoughts on how this could work in principle:

*"With the agile approach, you continuously test. It allows you to fake a finished product. Then you can put an experienced user in the car and see how they react. You can go in both directions: Start from someone's idea and explore it (from engineering), or you can take your own knowledge (HF) and bring it in. And then, you create the experiment and the conditions and then update it."* — S2 - HF Expert

Our second implication therefore follows from our data, specifically considering *(P1) iterative incremental work, (P4) focus on quality in use,* and *(P5) the importance of experiments.*

*(I3) human factors expertise must be included on the teams.*

I3 based on codes from interviews with: S1-2, S6-9

Agile teams should have the expertise that allows them to take ownership and responsibility for identifying HF needs and relevant HF knowledge. Interviewees suggested *including HF expertise in the agile teams* (for example, in the form of T-shaped teams), with each team member having a certain area of expertise.

> *"Not sure we are good with agile yet, but ideally, through improved testing, we should get even more improvements. As long as you can include an HF expert, then all should be fine in the larger picture."* — S9 - AV Engineer

In the experience of our participants, while there is a lack of availability of HF expertise in most companies, there are, different ways of ensuring teams have the necessary expertise.

S8, for example, wonders whether HF experts should be involved in creating abstract, reusable models, or instead be part of the teams which are deriving operational requirements.

> *"[…]But this requires a good model of the HF. We must have a generic model for such experiments that can be reused in different products, or do we need to create those models within the operational requirements specification? In that case, HF experts must be included in the teams."* — S8 - AV Engineer

Similar considerations were also discussed with S6. In typical scaled-agile frameworks, such as SAFe, HF experts could be assigned as a shared resource or within a particular release train. S6 suggests that as a shared resource, HF experts would lack visibility and would thus not be able to have an impact on agile design decisions.

> *"I like the way we work now with agile trains. Things are very visible; you see all the stories created in the different teams, you have clear goals... The problem is, if you are not on the train, you are not able to promote yourself. If you are a shared resource team, you have less visibility. So it will be better to be on the train."* — S6 - HF Expert

For the same reasons, S1 also considers adding HF experts to the release trains; but in line with S8 above, advances the alternative consideration of having HF experts as part of the individual development teams within an agile release train.

> *"You cannot be everywhere. But having your requirements and hand them over and then wait, that is not going to work. Being a part of the team or an agile train to some extent is the way forward."* — S1 - HF Expert

S7 indicates a clear preference that the HF expert should be involved with the teams directly.

> *"[…]The way you communicate your requirements is within the teams. You need to be there. If you are not in the teams, it will be a challenge."* — S7 - HF Expert

In summary, our interviewees indicated that successful AV development relies on HF experts who can guide developers with respect to how to set up an experiment, run it, and interpret its results—as well as judge its credibility (and identify when a change invalidates previous experiment results, requiring another experiment iteration).

While there are clear advantages to including HF experts directly in agile work (i.e., within the teams or in larger release trains that combine a number of teams working on a specific product area), there are also challenges with this setup: for example, lacking HF experts as S2 indicated.

> *"But we are lacking HF people."* — S2 - HF Expert

*I3* is established based on *(P2) shifting responsibility to autonomous teams, (P3) teams responsible for discovering knowledge, (P5) the importance of experiments* and *(P6) the importance of considering human variability*.

*(I4) the role of suppliers in agile AV development that integrates human factors must be defined strategically.*

I4 based on codes from interviews with: S3-6, S10

Given the lack of HF expertise, one has to identify a strategy that ensures that HF are taken into account in agile AV development. Our participants pointed out that the strategy may consist of getting support in certain specialized areas from outside the team or release train, or even from suppliers with expertise in the area. As the automotive value chain is increasingly transformed into agile ways of working and continuous integration and delivery, new collaborative models are emerging that integrate suppliers tightly into incremental work for specific purposes. In fact, large suppliers already do a substantial amount of research on HF related to their current and future product portfolios as, for example, mentioned by S6.

> *"Currently, we are working more on component level. This is even more challenging since it depends on system level engineering decisions, so you should ideally work with an OEM to define the particular requirements for the component and its context."* — S6 - HF Expert

A particular impediment is the access of suppliers to users of a specific AV, which limits the supplier to relying on their more general expertise and specific requirements from the manufacturer, as discussed by S4.

> *"Yes, but we do not often have access to the users, we get the requirements from the OEM, and we rely on them to tell us what is really needed. So perhaps, it is good that things are then indeed separate (HF, RE)."* — S4 - AV Engineer

Still, we conclude from the overall interview data that the role of suppliers is significant for two reasons: (a) they often possess HF expertise that could be valuable to their customers and (b) as agile development includes increasingly large parts of the value chain, our previous reasoning about the need for HF expertise in agile teams also holds for suppliers.

Our final implication for agile is, therefore, to *systematically decide whether and how to include (or get engaged as) a supplier* in the agile development of AVs, including the supplier's HF expertise in the teams when collaboratively designing, developing, and integrating AV components. It is based on *(P2) shifting responsibility to autonomous teams, (P6) the importance of considering human variability* and *(P7) the importance of making HMIs and automation transparent.*

**Summary and important questions.** The four implications for agile lead to the following important questions for future research in agile AV development:

1. How can developers be encouraged to run HF experiments?
2. How can we efficiently create, re-use, and update HF experiment designs and lessons learnt?
3. How can HF expertise be included in agile teams, given that few experts are available?
4. How can suppliers be involved strategically in working with human factors?

#### *4.3.2. Implications for HF*

*(I5) raise awareness among AV developers.*

I5 based on codes from interviews with: S5-7, S9

Through our interviews, we learned the need to *raise awareness among engineers* about HF and the implications for the final product of not including HF in the development process.

> *"It is a lot about marketing yourselves internally. For example, we are part of PI planning for different trains, talk to the teams, explain what we need at which point."* — S7 - HF Expert

Although conducting extensive experiments and communicating their results are part of agile development, engineers often do not have enough time to acquire the needed information (e.g., due to short, agile development cycles). Moreover, engineering companies may have engineering cultures; generally, engineers prefer gathering information through data rather than HF, which may be considered less important than simply getting the technology working. This culture is implied in the following quote from S5:

> *"[...]Sometimes, engineering sometimes just seems to think that HF is about putting nice wallpaper on the wall. They do not understand how early [how fundamentally] HF needs to be taken into account."* — S5 - HF Expert

S6 points out that for managers, it is often easier to bring a particular expert onto a team than to work on changing the mindset of the engineering department (although it is much less effective):

> *"They like to bring in a UX engineer rather than work on the mindset. "* — S6- HF Expert

A shift of the overall company mindset would be needed so that HF knowledge can be integrated into the AV development more effectively, as S9 hopes for:

> *"[...] Then, as an engineer, you should have enough awareness to know when to seek out that expertise."* — S9 - AV Engineer

*I5* is based on *(P2) shifting responsibility to autonomous teams, (P5) the importance of experiments, (P6) the importance of considering human variability* and *(P7) the importance of making HMIs and automation transparent.*

*(I6) provide teams with questions, not requirements.*

I6 based on codes from interviews with: S2-4, S7, S11

As AV engineers adapt to work in an agile way, communication about HF and its incorporation in the development process must be adjusted as well. One of our interviewees formulated this implication clearly:

> *"Put questions on teams, not requirements."* — S3 - AV Engineer

Agile teams do not like detailed requirements, which are often too detailed and too static, interfering with their autonomy as they seek appropriate solutions and adjust to change as indicated by for example, S2.

> *"We had requirements, but that has changed with the agile transformation. We now see it mainly as knowledge transfer, how to move HF knowledge to the teams. The game has completely changed. It is much more a social kind of setting."* — S2 - HF Expert

It might be better, therefore, to raise important questions and allow the agile team to find answers that fit their current state of development as stated by S7.

> *"[...] it is less about handing over requirements, and instead being there for discussion or to evaluate the concepts."* — S7 - HF Expert

A complementary approach (to raising questions for the team) relies on storytelling. By using stories that highlight the critical concepts while considering questions that point to the critical information needed, agile teams are enabled to take responsibility for HF knowledge. This empowerment is the consequence of *(P3) teams responsible for discovering knowledge*, and *(I3) human factors expertise must be included on the team.*

*(I7) provide basic HF knowledge as checklists and design principles.*

I7 based on codes from interviews with: S1, S6-7, S12

A key impediment to providing HF expertise to agile teams is the availability of experts, as mentioned by S7:

> *" We have tried different things. We had one HMI expert in each team, but that did not scale, we do not have enough experts to have one in each team for 100%. Maybe HF experts should provide checklists to engineers."* — S7 - HF Expert

We, therefore, add implication *(I7)*: HF experts should *provide basic HF knowledge as checklists and design principles* to development teams. S1, for example, points out that HF experts should work on a higher abstraction level to increase their reach. They should provide guidelines and other reusable knowledge, rather than specific, system-related requirements:

> *"From an HF perspective, it is important to prioritize the human experience. Better to talk about guidelines than about requirements."* — S1 - HF Expert

The availability of such reusable guidelines would be an asset, as S5 confirms:

> *"Ideally, one would need some guidelines, to coordinate between application projects that must be communicated. Those guidelines can be in PowerPoint or other company standards."* — S5 - HF Expert

According to S12, this could be done via checklists:

> *"I think we need to make engineers aware of the typical HF limitations and capabilities...You know, how is the mental model affected, or, you know, what is the relationship between the system and our mental model, or fatigue, distraction, situation awareness, workload, all of this everyday stuff that we as people suffer from when it comes to interacting with systems. So, you know, it is almost like a checklist...I guess we need to have a certain checklist."* — S12 - HF Expert

Several of our interviewees agreed that this could lead to a better utilization of the available HF experts' skills. This implication is supported by *(I1) AV developers must run human factors experiments, (I3) human factors expertise must be included on the teams, (P5) the importance of experiments, (P6) the importance of considering human variability*, and *(P7)the importance of making HMIs and automation transparent.*

**Summary and important questions.** The implications for HF indicate a strategic, rather than operational, role for HF experts. Instead of designing and running experiments themselves, these experts are increasingly mentoring and supporting agile teams. This raises important questions:

1. How can awareness of HF be raised in agile AV development?
2. How can agile teams be enabled to effectively create and maintain HF knowledge?
3. Which guidelines and design principles can provide basic HF knowledge to agile teams?

#### 4.3.3. Implications for requirements engineering

*(I8) use epics and user stories to express a need for learning requirements in the backlog.*

I8 based on codes from interviews with: S1, S3, S6

Agile methods provide only a limited view of requirements, focusing mainly on epics and user stories in various backlogs. This shortcoming introduces new challenges for decomposing high-level concerns into different backlog items and distributing them over the different release trains and value streams, as S3 pointed out.

> *"Base product stream, the AD product stream. SAFe will affect the effort to find the right solution very much. Epic on high level, how to divide it into different backlog items. Need to learn it."* — S3 - AV Engineer

While interviewees mention that there is still a lot to learn, advantages and best practices slowly become manifest, as mentioned by S6:

> *" Things are very visible, you see all the stories created in the different teams, you have clear goals... We should likely start documenting them as part of epics in JIRA. We have HF streams, active safety streams, .... The work is cross-functional, so I am both in HF and active safety streams. The recommendations/ functions should be written in a user-friendly way and which value it provides to customer and user."* — S6 - HF Expert

This, in particular, affects strategies to get cross-cutting and interrelated requirements such as those related to HF into the system, as the following practice from S1 suggests:

> *"[...] Do the guerilla requirements. Do not write requirements, but tell interesting stories based on empirical data, getting the right concepts into the brains of engineers (where it then stays because they are so bad at forgetting things)."* — S1 - HF Expert

In the experience of our interviewees, for RE experts in the automotive domain, the change in focus from providing a comprehensive requirements document to managing continuous learning with respect to certain goals is challenging. From our interviews, we conclude that an RE expert should enable teams to approach and document this learning systematically, instead of writing requirements for them. This implication is based on *(P1) iterative incremental work* and *(P4) focus on quality in use.*

*(I9) increase capability to use prototypes for requirements elicitation and validation.*

I9 based on codes from interviews with: S2, S4, S10-11

Prototyping was suggested by S4 when discussing requirements engineering:

> *"Prototyping for requirements engineering, so one can find specific details about a problem, and use them to discover new requirements."* — S4 - AV Engineer

This is not only a good way for agile teams to discover requirements, but also a necessary way for HF experts to uncover new HF knowledge, as S2 suggests:

> *"Then I like to ask them to help me build a prototype, a Wizard of Oz car. Then I can test it. Because prototyping is a good way for requirements elicitation and validation."* — S2 - HF Expert

Consequently, prototypes are key for aligning HF experts and agile teams as well as facilitating synergies as indicated by S11.

> *"Prototype adds a set of requirements, but also how the requirements are manifest in terms of interaction or physical design. Then HF experts get involved in evaluating that in usability testing and heuristics evaluation."* — S11 - HF Expert

The infrastructure for constructing prototypes has become quite sophisticated, as mentioned by S10—allowing a huge variety of tests to be run and collecting large amounts of data.

> *"What do we need for hardware to succeed in ADAS or AD platform(first question from the system team)? We have this box full of things we can measure in our prototype.–> Which of these tools do we need... It is fun to work with everything. But we need to find the key sensor outputs for good collaboration. If we have new sensor inputs, how can we put a value on those for a collaboration? How can we structure that kind of work?"* — S10 - AV Engineer

We summarize our interview data in this theme as an implication for RE to *increase the capability to use prototypes for requirements elicitation and validation*, based on the identified needs and HF checklists within agile teams. This implication resonates well with *(P3) teams responsible for discovering knowledge* and *(P5) the importance of experiments*, and might offer good support for *(I2) experiment design & lessons learnt must be created, re-used, and updated efficiently*. This is also in line with *(P6) the importance of considering human variability*, as prototype validation must take into account the range of human variability.

*(I10) express the relationship between design decisions and human factors as system requirements during development.*

I10 based on codes from interviews with: S3, S5, S9, S10

While it makes sense to describe stakeholder requirements as epics or user stories (see Implication I8), it is important to document the desired capabilities of components and subsystems, which follow system requirements; otherwise, it is not sufficiently clear how HF related to essential requirements for automated vehicles can be managed, as implied by S9:

> *"How does this relate to requirements? It is even tricky to define what a safety requirement is. For safety analysis, the human aspects are critical input to system design and testing. That is with safety as a purpose of design. In particular, the person in the car. In trucks, it is mainly for the safety of other road users. But that is very different from functional safety requirements."* — S9 - AV Engineer

However, it is difficult to clearly define these requirements, as well as architectural decisions, in agile projects, as indicated by S3:

> *"Architectural decisions are taken all over the place. The architect must go around and collect them to raise those aspects that should be treated globally. The decisions now are made differently than they were made before. The design decisions should follow system requirements."* — S3 - AV Engineer

Thus, in the experience of our participants, there is a need to document system requirements, which describe how the different parts of the system under construction will address the stakeholder needs. While these requirements are valuable to manage the knowledge about the system with respect to stakeholder needs and HF, they are not suitable input to agile development work. As S10 implies, one needs to closely investigate collaboration in agile system development to identify system requirements.

> *"To be able to create requirements or needs, one has to understand what is the problem with collaboration today."* — S10 - HF/AV Engineer

From the interviews, we derive the implication of using *system requirements to express the relationship of design decisions to HF knowledge*. In the context of the other implications, we suggest that this implies the need to allow teams to *create system requirements together with the system*, i.e. while developing its software and the corresponding tests, and not before. Requirements would be provided during development (in the form of stories) rather than at the beginning. This sequence allows the requirements to remain up-to-date with the current implementation, rendering them useful for informing future system evolution.

Thus, a general approach that fits our interview data is as follows: teams would run experiments during a sprint and then modify the system accordingly for the next release. They would also, at the same time, describe the updated capabilities of the system and *trace system requirements to related existing/future HF experiments, in order to provide rationales for the decisions.*

This implication is based on *(P1) iterative incremental work.*

**Summary and important questions.**
As with HF, the implications for RE call for a changed role for requirements engineers. A high percentage of requirements will be discovered and managed just-in-time by agile teams. RE experts, therefore, will increasingly provide infrastructure and coaching, which raises important questions:

1. How can epics and user stories be positioned as a means to learn rather than to specify?
2. How can agile teams be enabled to use prototyping to perform HF experiments and discover and manage requirements?
3. How can system requirements be used to efficiently express the relationship between design decisions and HF in continuous development?

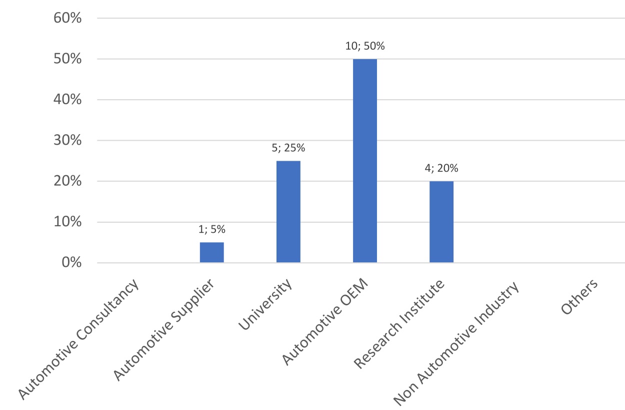
## 5. Evaluation study

We evaluated the results using a questionnaire-based survey in a workshop setup. By presenting the topic to the audience and directly answering their questions, the workshop format allowed us to ensure that participants understood the topic

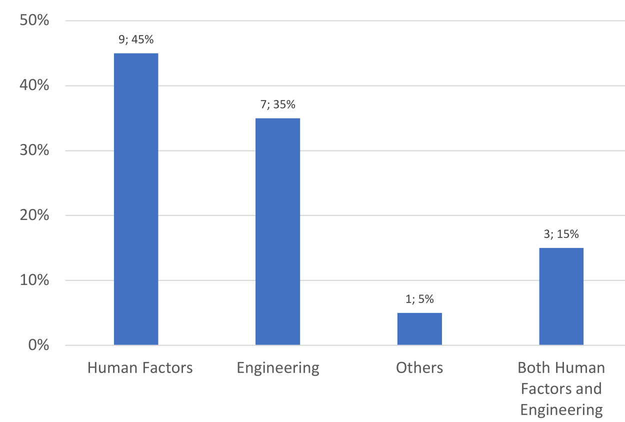
The anonymous questionnaire started with basic demographic questions to assess basic response behavior differences between participants based on their background. We then provided the context, introduced the main topic in the presentation form, and explained the research questions. Next, we explained the research results so that participants could better understand the topic. Keep in mind that the context and description of the outcome of the paper were also provided to participants before the session. Afterward, we asked participants to indicate their level of agreement (on a 5-point Likert scale) with the stated impacts of the properties of agile and HF on AV development. Finally, we asked for the participants' agreement on the implications of the agile way of working, HF, and managing requirements in AV development.

### *5.1. Participants' demographics*

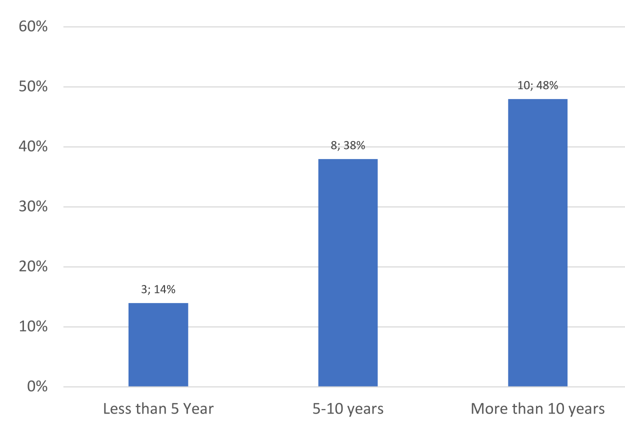
Fig. 3 presents the demographic data of the workshop participants. It displays the absolute number and percentage of respondents for each answer. For this survey, participants were invited from different automotive companies and research institutes, mainly based in Sweden. There were 28 participants in the workshop and we asked three basic demographic questions. We did not include participants from the original interview study, to avoid bias. On average, 17 participants responded to each question, and the rest (on average 11) chose not to answer. Fig. 3(a) depicts the overall results and shows that the majority (50%) of participants work for automotive OEMs, 5% work for automotive suppliers, 20% work in research institutes, and the rest were from academia.




(a) Area of work - (20/28 Respondents)




(b) Work Perspective -(20/28 Respondents)




(c) Work Experience - (22/28 Respondents)

**Fig. 3.** Demographics. (Semicolon ';' separates absolute numbers and percentages of respondents.)

Out of the total participants, 20 responded to the second demographic question 3(b). Among these respondents, nine had human factors work perspective, seven had an engineering perspective, and three had experience in both fields. Regarding the third question about work experience, eighteen participants responded, and Fig. 3(c) depicts that 48 percent of participants have more than ten years of work experience.

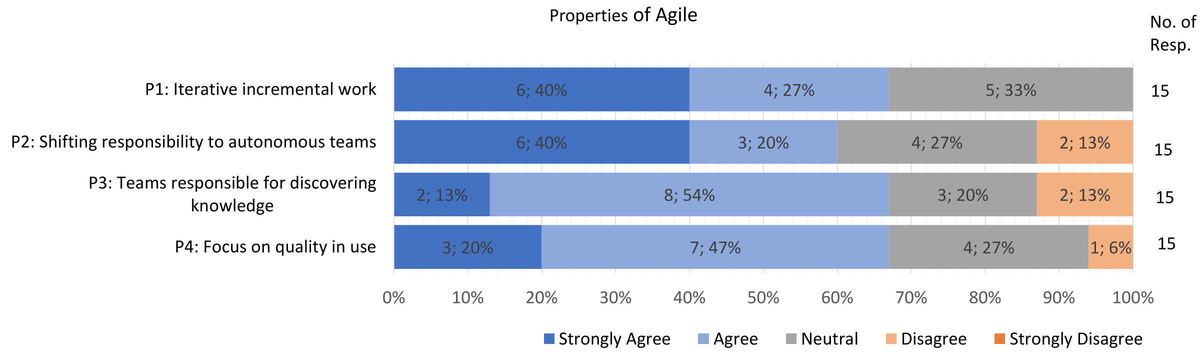



**Fig. 4.** Level of agreement regarding the impacts of the properties of Agile on AV development. (Semicolon ';' separates numbers and percentages of respondents.)

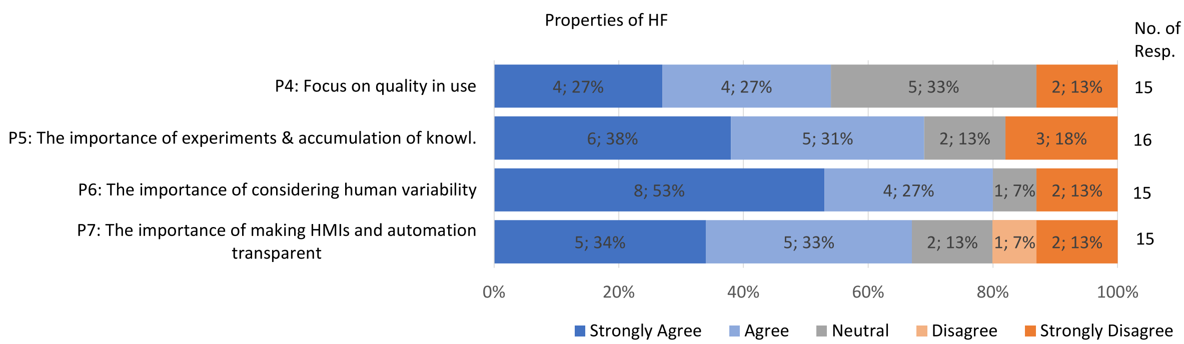



**Fig. 5.** Level of agreement regarding the impacts of the properties of HF on AV development. (Semicolon ';' separates numbers and percentages of respondents.)

Overall, the fact that all participants were from Sweden limits the generalizability of the results. However, the survey aimed to evaluate our already identified findings (which were obtained using industry experts in Sweden) rather than arriving at a general conclusion or discovering new implications/properties. At the end of the workshop, we asked the participants if we had missed any critical topics.

### 5.2. Evaluation of properties of agile and HF

On the next questionnaire page, we started with RQ2 and explained the properties of agile and HF which can impact AV development. We then asked the participants to indicate their level of agreement with our interview study findings (on the 5-point Likert scale), in order to assess whether the participants identified the same properties as important.

The survey results are shown in Figs. 4 and 5 for the properties of agile and HF, respectively. The blue bars on the left indicate the percentage of participants who agreed (light blue) or strongly agreed (dark blue) with the findings. The grey bar in the middle shows the percentage of neutral participants, the light orange bar depicts the percentage of participants who showed disagreement, and the dark orange bar on the right shows strong disagreement.

Fig. 4 shows that the majority of participants agreed with *(P1) iterative incremental work*. Five participants were neutral, and nobody disagreed with *(P1)*. For *(P2) shifting responsibility to autonomous teams*, 13% of participants were slightly in disagreement. 40% and 20% of the participants strongly agreed or agreed, respectively, while the rest were neutral. Fifteen participants rated *(P3) teams responsible for discovering knowledge*, majority of participants showed their agreement (54% agreed and 13% strongly agreed) with *(P3)*. For *(P4) focus on quality in use*, 67% of respondents agreed with the statement. One participant strongly disagreed, and the rest were neutral. Fig. 5 presents the properties of human factors. The survey results show that the majority of participants agreed with all the statements, while only a small percentage of respondents disagreed.

The majority of participants either agreed or were neutral with the identified properties for both agile and human factors. Thus we can say that our initial impression that these properties are critical for defining HF requirements in agile AV development is supported by the participants.

### 5.3. Evaluation of implications

With respect to RQ3, the questionnaire presented Likert scale statements about the implications of combining the relevant properties of HF and scaled agile into the agile way of working, HF, and managing requirements in AV development. The survey results are presented in Figs. 6, 7, and 8, which show the distribution of responses for each implication. In these figures, semicolons ';' are used to separate the numbers and percentages of respondents.

We started with the agile implications, asking the participants to rate their level of agreement for each implication. Fig. 6 shows the findings for each implication of scaled agile on the agile way of working. For both *(I1) AV developers must run human factors experiments* and *(I2) experiment design & lessons learnt must be created, re-used, and updated efficiently*, 50% of participants showed strong agreement, and 72% in total expressed their agreement with the stated implications. The majority (57%) of participants strongly agreed with *(I3) human factors expertise must be included on the teams*, and 64% of participants agreed with *(I4) the role of suppliers in agile AV development that integrates human factors must be defined strategically*.

Generally, more than 50% of respondents agreed with the stated implications of HF and RE (presented in Figs. 7 and 8, respectively). An exception was *(I6) put questions on teams, not requirements*. An equal number of participants agreed and disagreed; however, as 40% of the participants were neutral, there was no clear-cut disagreement. This result suggests that *(I6)*

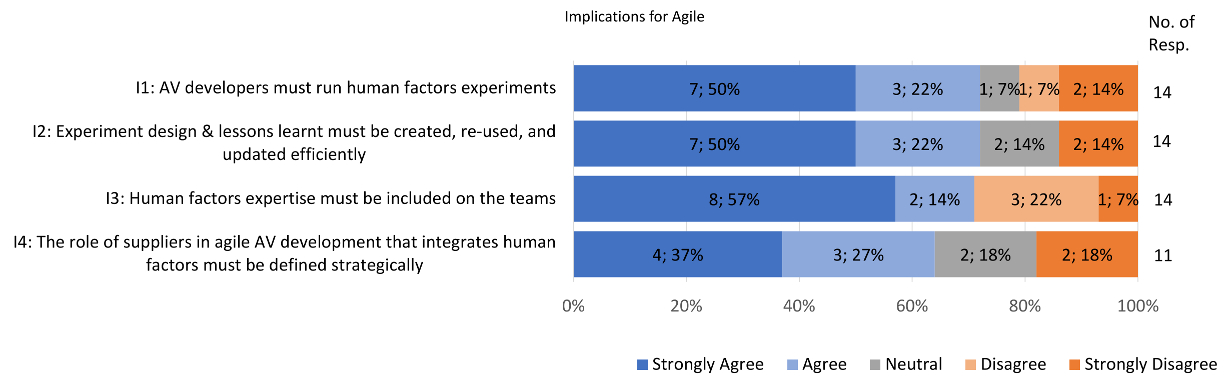



**Fig. 6.** Level of the agreement for the implications for the agile way of working on AV development.

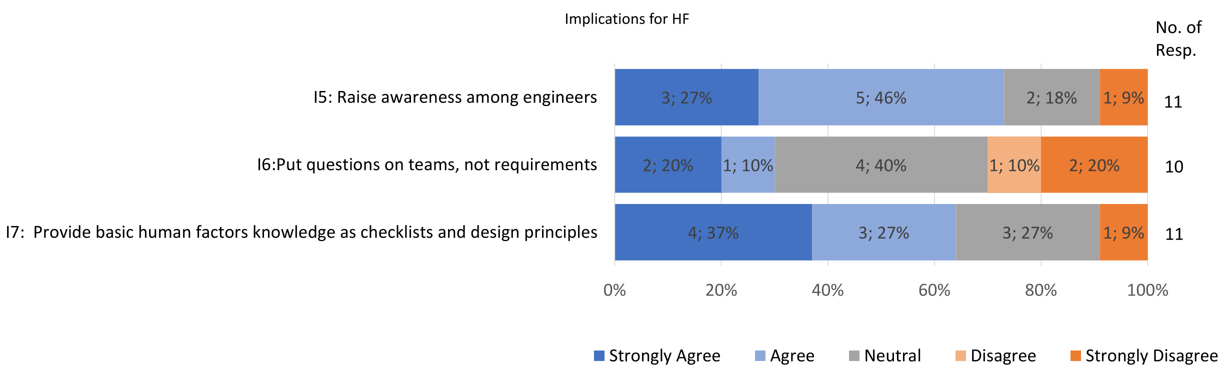



**Fig. 7.** Level of the agreement for the implications for the HF on AV development.

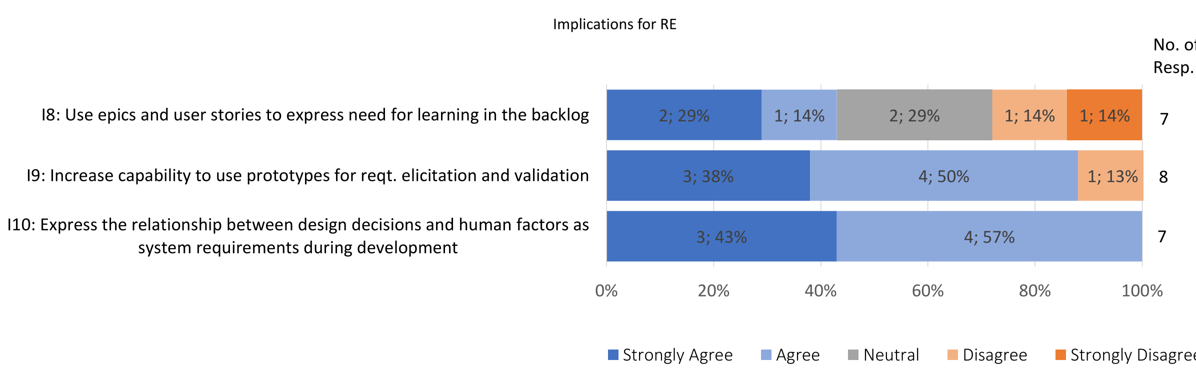



**Fig. 8.** Level of agreement for the implications for RE on AV development.

should be investigated further. *(I8) use epics and user stories to express a need for learning requirements in the backlog* also showed mixed agreement, indicating the need for extended research on how to represent the need for HF knowledge to AV developers.

For *(I10) Express the relationship between design decisions and human factors as system requirements during development*, all the participants indicated their agreement (57% agreed and 43% strongly agreed).

The results for HF and AV Engineers were similar for most of the questions. However, two HF experts (one with more than ten years of experience and one with less than five) rated the implications for HF very low. On the other hand, all AV engineers rated them highly.

Generally, the majority of participants agreed that all the implications that we derived from the interview notes were relevant and important for bringing HF knowledge into an agile way of working for AV development.

## 6. Discussion

Based on an exploratory interview study with ten experts from the industry and two experts from academia, this paper charts the landscape of human factors (HF) in relation to the agile development of automated vehicles (AVs). We adopted a Requirements Engineering (RE) perspective, since requirements are traditionally the mechanism for notifying automotive engineers about conditions that should be met by their systems as well as capabilities that the systems should possess (IEEE, 1990; Liebel et al., 2018).

### 6.1. Implications for practice

We argue that our findings can provide valuable insights for both HF experts and AV engineers in the automotive industry. Particularly, our findings on how to integrate HF and communicate HF requirements during the development should be useful for guiding practitioners. Previous work shows how crucial it is to integrate HF into the RE process. Our results support this finding (e.g. in our themes P5-P7 and I1-I7), but also identify that actually doing so is more difficult with agile development (c.f. themes I1-I10). This is also the case because, the traditional approach to RE has been challenged by the success of agile methods (Meyer, 2014) and their adoption in systems engineering (Liebel et al., 2018). We also acknowledge that areas of AV development that are relatively new, such as AV functionality development based on artificial intelligence (AI, including machine learning) (Nascimento et al., 2019), may require specific focus in the integration of HF. Otherwise, the impact on humans (drivers, occupants, and surrounding traffic) of the (typically highly data-driven Bosch et al., 2018) AI approaches can easily be overlooked.

*New roles for HF and RE.* Our study took place at a pivotal time in the automotive industry. The automation of driving tasks is proceeding rapidly, adding significant complexity to automotive systems. Automotive companies are transitioning to agile approaches in order to enable shorter development times despite this increased complexity. We were surprised by the strong focus on agile methods in all of our interviews. At the same time, the role of HF knowledge and requirements becomes less clear in the agile setting. Standard RE processes, such as multi-stakeholder analysis, are therefore hard to systematically apply, as discussed by Cheng and Atlee (2009). RE appears to play a smaller role, partially replaced by increment planning and backlog management. Moreover, RE often focuses on specific technical aspects such as functional safety.

This adds to another trend: Automated systems development often prioritizes the technology, without much consideration of HF (Carayon and Hoonakker, 2019). In fact, HF is rarely considered in the early phases (Dul and Neumann, 2009), although our results highlight the importance of doing so. We suggest that this change be enacted through RE, which may help to identify a role for HF in organizations that seek "to inform AV development by providing fundamental knowledge about human capabilities and limitations throughout the design cycle so the product will meet specific quality objectives".

We also suggest further refining the role of RE so that it can better adjust to the needs of agile development, while also improving the support required to integrate HF knowledge into agile development. We envision a role that is less prescriptive and focused on setting requirements for developers, and instead more supportive: enabling developers to explore, document, and re-use requirements-related knowledge. This role will be particularly useful for identifying HF knowledge (e.g., results from experiments) that is no longer valid due to system/software changes—thus, calling for new experiments.

Finally, our findings likely also have implications outside of the actual development of AVs. For example, it may have implication on how computer sciences, agile methods, requirement engineering, and human factors are taught at university level. Exactly how teachers should integrate it in their teaching is out of scope of this study, but it may be relevant to at least talk about the engineer/human factors communication gap, as well as how experts from different domains can contribute to, for example, experiments that include both technology and HF.

*Testing and experiments.* The field of HF highly prioritizes experimenting and testing. With agile's fast, iterative way of working, there is a need to test regularly and quickly while keeping accumulated knowledge in mind. In contrast with fields such as software testing, in which tests are very formalized and mature, HF has a few substantial challenges:

1. In the context of AV development, formalization of (most) experiments is not mature enough.;
2. Humans are adaptive and unpredictable, making the formalization of experimental protocols and passing thresholds difficult.

Thus, we encourage future research to improve the integration of tests and experiments from an HF perspective into AV development, keeping accumulated knowledge and ensuring that HF experts are part of the experimental setup.

### 6.2. Implications for research

*Common understanding of terms.* Definitions provided by our interviewees differed substantially, not only between the HF experts and the AV engineers, but also among the HF experts. This ambiguity identifies a critical communication gap (Bruseberg, 2008). In this work, we propose a slightly refined definition of HF, geared towards the development of AVs (see Definition in Section 4.1) and relating specifically to the essential phases of system engineering. Our results, however, call for future research to achieve an aligned understanding of HF and related concepts through all the systems engineering disciplines involved in AV development.

*Raise awareness and develop mindset in agile engineering.* It is important to raise awareness and develop an HF-friendly mindset in development teams, in order to improve the communication of HF requirements and their incorporation in the development process. A suitable mindset would consider not just the user experience or HMI, but all aspects of human interactions with a system. Many HF experts agree with this assessment (Wickens et al., 2003; Salvendy, 2012; Flemisch et al., 2008); however, to our knowledge, there is little awareness in systems and software engineering, areas where research is highly encouraged. Awareness could be raised by training engineers in interdisciplinary work so that it becomes easier to integrate HF experts in agile teams (as in I3). In addition, research is needed to determine how to increase the ability of agile teams to manage open questions (see I6) as well as their experimentation infrastructure (see I2) (Fagerholm et al., 2017b; Schermann et al., 2018; Fabijan et al., 2017).

*Need to develop and empirically evaluate new approaches to manage HF knowledge.* This qualitative study presents several implications which human factors experts, AV agile teams, and requirement engineers can adopt to integrate the knowledge of HF during the agile AV development process.

> *"Or should the team explore the HF? But then we would need a really good model that the team can explore and a lot of expertise that the team can assess. On the high level, we may only have a very crude understanding."* — S8 - AV Engineer

In particular, the need to have AV developers participate in (or even run) HF experiments *(I1)* requires the attention of researchers. In continuous software development, there is a trend towards data-driven decision making and experimentation (Fabijan et al., 2017; Schermann et al., 2018; Meyer, 2015; Kohavi et al., 2009; Kevic et al., 2017).

It could be exciting to compare such experiments on variants of software with HF experiments and investigate possible synergies, which might provide insights into how HF experiments can be integrated into the fast-paced agile development environment.

*In summary.* We believe that our exploratory study provides a foundation for future research that could improve RE in AV development, as well as refining communication about the HF perspective within the agile way of working. Both HF and RE experts should re-interpret their roles, enabling and facilitating agile teams seeking knowledge—instead of providing comprehensive and detailed knowledge themselves. We anticipate that future research in agile work will formalize ways to manage HF experiments, as well as their results, efficiently. Being able to keep knowledge across design cycles will contribute to a mature synergy between these formerly disparate ways of working.

### 6.3. Discussion of quality

Our particular epistemological stance (critical realism with influences from pragmatism and constructivism) and choice of method for data collection and analysis also influence the discussion of research quality. In particular, the predominant positivist approach to validity – in terms of construct validity, external validity, internal validity, and generalizability – fits this study poorly. Instead, for this qualitative inquiry, we followed advice from Leung (Leung, 2015), discussing validity, reliability, and generalizability in terms that are a better fit in the context of this study.

#### 6.3.1. Credibility

The credibility of our study is supported by the diverse background of the researchers and our ability to interview the leading experts in the domain. This was the first joint interview study of the authors, which allowed us to bring in complementary perspectives by recruiting interviewees from each author's personal network. Further, we asked each interviewee to suggest additional candidates to mitigate a potential selection bias. By inviting such a diverse group of interviewees and collecting their potentially contradicting perspectives on the topic, we had to challenge and overcome pre-conceptions. We described our background assumptions in detail in Section 2 and challenged them throughout the analysis of our data. This approach has led us to construct our mental model about HF in agile system development. For example: We learned that most participants had only recently moved to agile development approaches. We understand that in such approaches, teams are expected to generate knowledge as needed to implement features. We learned that high-quality HF knowledge stems from experiments and relies on a high level of HF expertise. Thus, we conclude that HF expertise must be included in agile teams to facilitate agile system development that includes HF knowledge, an implication that fits the data from our interviews well and resonated also with participants in the evaluation workshop. The credibility of this study also relies on the quality of answers that we received, both during the interviews and the evaluation activities. Most of our interviewees have to solve the challenges described in this paper as part of their daily job. Significant events can of course influence the answers we receive and we assume that potential challenges encountered at individual case companies with the ongoing agile transformations may fall into this category. We also understand that the context of each expert matters to a degree, therefore, a different sampling might have caused variation in our findings. We mitigated such effects to the best of our ability through an in-depth analysis and construction of what we believe to be the underlying causal relationships, as dictated by critical realism. It is our estimate that such variations would mainly affect ideas about suitable solutions, and to some degree the implications that we derived from our interviews, while the definition and the properties would have been affected to a lesser degree.

#### 6.3.2. Resonance

Through our data collection and analysis, we aimed to establish resonance, e.g., by asking for clarification when we felt that our assumptions were challenged. One such example occurred when we learned that something that was described as relatively easy to accomplish by one participant was described as very difficult by another participant. We learned that in the first case (driver monitoring), a rich set of models, checklists, and design principles exists, which was missing for the second (monitoring of cyclists). The lack of these resources made communication and incorporation of HF considerations considerably more difficult in the second case. Thus the apparent contradiction was explained, providing us with a richer understanding of possible challenges. Implication I7 (provide basic HF knowledge as checklists and design principles) and our definition of HF in the context of the design and development of automated vehicles both reflect the lesson learned.

#### 6.3.3. Usefulness

We believe that our study, albeit a preliminary exploration, is significantly useful. Integrating the design cycle into our working definition of HF in the context of the design and development of automated vehicles is one example of its utility, since the new definition makes it possible to specify where in the design cycle HF knowledge becomes useful. In addition, we believe that our implications provide useful knowledge to those who are tasked with the design of methods and tools for development, as well as to HF experts who aim to increase their impact on AV development. We derive confirmation of these conclusions through feedback received after presenting the study results to the participating companies.

#### 6.3.4. Transferability

Case studies aim to investigate a phenomenon in depth within its natural context. They do not generally aim for generalizable findings in the same way, as for example, an experiment would. Instead, as qualitative research, case studies should lead to theoretical generalizability: concepts that are transferable in principle. Wieringa and Daneva, for example, highlight the ability to provide a causal or structural (architectural) explanation as a theoretical generalization (Wieringa and Daneva, 2015), which then can be transferred to other contexts.

In our study, we provide such explanations through the properties of agile and HF, and the implications for agile, HF, and requirements. Fig. 2 provides an overview of these findings in a qualitative model, specifically relating the concepts (implications) to assumptions (properties) that we have identified through our interviews with experts. In this way, we provide both causal explanations (properties of agile and HF generate implications) and structural explanations (integrating HF into large-scale agile system development will benefit from addressing implications in the area of agile, HF, and RE). This knowledge is transferable, allowing experts from different domains to judge how our concepts apply to them.

Our results stem from the automotive industry, including considerations of automated cars and trucks, and should be applicable to other cases in that domain. We further believe that our concepts are transferable, not only beyond the national AV hotspot where we recruited most of our interviewees, but also to other automated vehicles such as aircraft or ships. It would be harder to transfer beyond the realm of automated vehicles, and even more so if no physical product is created. For example, we would assume that a web application will have very different constraints on prototyping and testing.

## 7. Conclusion

In this paper, we present an exploratory, qualitative inquiry into how to manage HF knowledge during AV development. Our investigation revealed the fundamental role that large-scale agile development plays in the automotive sector. From our data, we

**Table A.3**
Overview of themes in relation to codes.

| Themes | Example codes |
|---|---|
| Human factors in relation to AV development | HF relates to safety; HF relates to limitations and capabilities; HF relates to user preferences; Designing in light of understanding; HF is human–machine interaction; Understand, Create and evaluate cycle; HF journal definition |
| Properties | |
| (P1) Iterative incremental work | Agile transformation; Agile way of working; Iterative work; Mindset-Agile way of working; Iterative work |
| (P2) Shifting responsibility to autonomous teams | Teams responsible for topic; Work with agile teams; Teams' autonomy |
| (P3) Teams responsible for discovering knowledge | Guerrilla requirements; Teams responsible for topic; Knowledge by discussion; Teams' autonomy; Knowledge discovery by Eng. |
| (P4) Focus on quality in use - Agile | Testing and quality; Quality in use; User centered design; User-centric development |
| (P4) Focus on quality in use - HF | Quality assessment with HF knowledge; quality improvement with HF knowledge; Assist people |
| (P5) The importance of experiments | Assumptions and experiments; Continues test and HF experiments; Test assumptions; Agile support; Criticality of human aspects; Agile Experiments |
| (P6) The importance of considering human variability | Empirical data; Demographic and culture; Human variability; Consideration of different parameters; HF expert evaluate differently |
| (P7) The importance of making HMIs and automation transparent | Clear HMI; User understandability; Transparency; User trust and comfort |
| Implications | |
| (I1) AV developers must run human factors experiments | HF experiments by engineers; Teams & HF knowledge; Engineers & HF requirements; Engineers & HF knowledge; Test with human subject |
| (I2) Experiment design & lessons learnt must be created, re-used, and updated efficiently | Experiments design; Experiment Model; Use of accumulated knowledge |
| (I3) Human factors expertise must be included on the teams | HF in teams; Lacking HF people; HF in teams; HF in the teams; Include HF in teams; Improvement with HF in teams |
| (I4) The role of suppliers in agile AV development that integrates human factors must be defined strategically | HF knowledge by Suppliers; HF requirements by OEM; Work with OEM; OEM's thoughts; OEM' s role |
| (I5) Raise awareness among AV developers | HF awareness; Mindset; HF marketing; Awareness by engineers |
| (I6) Provide teams with questions, not requirements | Knowledge transfer; Ask questions, not requirements; HF on crucial questions; No requirements, only discussion; HF on teams |
| (I7) Provide basic HF knowledge as checklists and design principles | Human experience via guidelines; Provide HF data; checklists by HF; HF Req as checklist |
| (I8) Use epics and user stories to express a need for learning requirements in the backlog | Tell stories; SAFe & backlog; Stories & Epics |
| (I9) Increase capability to use prototypes for requirements elicitation and validation | Prototyping for Req elicitation & validation; Prototyping for requirements; Use of prototyping; Prototyping for requirements and evaluation |
| (I10) Express the relationship between design decisions and human factors as system requirements during development | Design Decisions; Decision and requirements; Purpose of design; Identify problem with collaboration |

derived a working definition of Human Factors for AV development, discovered the relevant properties of agile and HF, and defined implications towards agile ways of working, managing HF knowledge, and managing requirements.

Experiments and experience are integral parts of HF. It is a challenge to fit HF knowledge (and the corresponding requirements) into the agile way of working that the automotive industry is moving towards, with its fast pace of change.

As our properties and implications reveal (e.g., P3 and I3), there is an increased need to bring HF expertise to the development teams, caused by the team-based approach and team responsibilities inherent in agile AV development. The paucity of HF experts and the intermittent need for HF expertise in many agile AV development teams makes the inclusion of HF expertise in teams a challenge. In addition, fast, iterative increments do not typically allow time for the rigorous experiments that HF experts may need in order to ensure user-centered quality. In general, reflections from this study and responses from (especially but not exclusively) the HF experts indicate that it is important to push for an HF culture in companies, in the same way that many automotive companies have a safety-first culture. Why not safety and human factors first? Our exploratory study, admittedly limited in scope, relies on 12 interviewees, mainly recruited from a national hotspot of AV development. We believe that our study demonstrates the relevance of this research topic, as well as the value that additional interviews (beyond the scope of this study) could provide.

While further research is still required, our study indicates the potential benefits of integrating HF into the agile way of working. This integration may include protocols where the process can support an environment suitable for iterative HF experiments and user studies based on accumulated knowledge, epics, user stories, and HF checklists. Over time, these protocols will enable developers to create knowledge and data with good reliability. Hence, future work will have to provide a conceptual framework which HF experts and AV engineers can use to support iterative experiments and to accumulate HF knowledge over time. Implementation of this framework would help the automotive industry and individual agile teams alike.

## CRediT authorship contribution statement

**Amna Pir Muhammad:** Conceptualization, Methodology, Writing – original draft, Investigation, Formal analysis, Data curation. **Eric Knauss:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Investigation, Validation, Visualization. **Jonas Bärgman:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Investigation, Validation.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

We have linked interview guide and code book in the manuscript.

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## Appendix. List of themes and related codes

Table A.3 provides all the themes covered in this paper and their corresponding codes. Details (e.g., which code was provided by which interviewer) can be found at the following link 10.5281/zenodo.5562487.

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