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Autonomous vehicles: The Race to Safety

A case study of High Reliability Theory in autonomous trucks and busses

Abstract

The development of autonomous vehicles is still in an early stage, but incumbent manufacturers are already under pressure. They are asked to develop safe products while facing great market pressure and internal changes. This research is carried out to understand how incumbent manufacturers of commercial vehicles organize internally to develop safe and reliable autonomous vehicles (AV). By using an in-depth and context-rich single-case study, the authors look at one firm's organizational intricacies through the lens of High Reliability Theory (HRT). Applying an emergent framework of HRT, the authors explore how HRT principles can be applied to enhance the safe development of AV. The results indicate that this firm indeed is moving into a high-risk environment and that the organizational changes that follow can be framed within the spectrum of HRT. The authors also find that the role of managers is transforming to enable the change, and with that the idea of leadership. By making this connection, the authors provide guidance for practitioners that today are seeking efficient ways to cope with new posing risks stemming from technological advancements. Moreover, this paper adds to a greater pool of HRT research by 1) providing a new setting to the research field and 2) putting more emphasis on the manager's role in developing high-reliability systems by linking HRT to *servant leadership*.

Authors: Victor Svahn (22993) and Alessio Dastice (41192)
Supervisor: Per Andersson
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About the authors

Alessio Dastice
Alessio has a BSc. in Industrial Engineering from the Politecnico of Milano. He is interested in multinational firms and technically challenging processes. In his MSc. in Business and Management, he specializes within innovation, organization and leadership.

Victor Svahn
Victor has a BSc. in Business and Economics from the Stockholm School of Economics. He is passionate about technology and is running his own start-up related to artificial intelligence. In his MSc. in Business and Management, he specializes within organization, strategy and marketing.

Contents

Glossary

Artificial intelligence (AI): Is intelligent machines, simulating the intelligence of a human by seeing, interoperating and acting on information by itself.

Autonomous vehicles – are vehicles that can operate and guide themselves without the intervention of a human.

Functional Safety: A part of the overall safety of a system.

IEC 615078: Is a technical standard to ensure safety of systems, used in for instance nuclear power plants.

Incumbent commercial vehicle manufacturer: Large and traditional manufacturers of vehicles that operate for a business purpose, in this case trucks and busses.

ISO26262: Is an international functional safety standard for the development of automobiles.

Onboard – All the systems that are situated on an autonomous vehicle, helping the truck to operate in an autonomous way.

Offboard: All the systems that are situated off an autonomous vehicle, helping the truck to operate in an autonomous way.

SAE-level: Is a framework to assess to what level a vehicle is autonomous. The scale goes from 1-5, where 5 implies no human interaction in the driving process.

SAFe – Means Scaled Agile Framework and is used to scale agile and lean process, especially applicable for large companies.

1. Introduction

Technology is shaping the contours of our society. The convergence of computer, information and communication technologies has created a juncture where uncertainty and ambiguity are the norm and where the results of our engagement with technology are complex and often unpredictable (Robbin, 2011). However, it is naïve to assume that the fast-paced technological innovation witnessed today only carries benefits (World Economic Forum, 2017). The World Economic Forum recognized in 2017 artificial intelligence (AI) and robotics as the emerging technologies that indeed carry the highest benefits but also the highest risks. On this same topic much stir was caused when the famous scientist Stephen Hawking claimed:

"Success in creating effective AI, could be the biggest event in the history of our civilization. Or the worst. We just don't know. So, we cannot know if we will be infinitely helped by AI, or ignored by it and side-lined, or conceivably destroyed by it" – Stephen Hawking, 2017

One of the most promising but nonetheless challenging applications of AI and robotics is the development of autonomous vehicles (AV) (Oliver et al., 2018). The benefits that this new technological development has to offer are innumerous and the major claim across sponsors of the technology is that autonomous vehicles are key to reduce the number of fatalities on the road (Claudel and Ratti, 2015). What seems at time neglected however is that the full replacement of the most intelligent system found in nature (yes, us humans!) is not an easy task and conceal many risks for manufacturers, regulators and the public (Ransbotham, 2017).

Despite promising, the technology embedded in AV (e.g. cameras, lasers, AI algorithms) is still immature and works in a reliable way only under specific conditions (Oliver et al., 2018). To date six notable self-driving vehicle crashes are registered of which four brought casualties (Chang and Dormel, 2018). After these tragic events, the development of this nascent technology is under scrutiny from regulators and the public, which seem concerned with the reliability, security and liability of the technology (Kaur and Rampersad, 2018). In a time where one single crash can lead to billions of dollars lost in lawsuits and brand reputation (e.g. Boeing 737 crashes in 2019[1]), the pressure on manufacturers to design and operate safe and reliable systems is therefore higher than ever.

As technological complexity is on the rise and safety appears crucial for the technology development and diffusion, there is a set of special organizations that has been defined by their unique ability to organize for high-hazard technological systems in an almost error-free manner (Roberts, 1990). Naval aircraft carriers (e.g. Rochlin et al., 1987), space shuttles (e.g. Vaughan, 2005) and nuclear power plants (e.g. Bourrier, 1996) are all examples of organizations that have put a premium on the safety and reliability of their systems and

[1] More information on the accident: https://www.bloomberg.com/news/articles/2019-05-11/boeing-crash-fight-will-set-price-on-victims-minutes-of-terror

in doing so they have developed *high-reliability systems*. This makes them *high reliability organizations* (HROs) (Shrivastava et al., 2009).

As with former technological advancements, AV increase the risk that errors in human organizations will be magnified by the technology (Dietterich, 2018). Under these conditions, high-reliability becomes an imperative for autonomous vehicles and a pressing question arises to understand whether autonomous vehicle manufacturers can learn from the example of *high reliability systems* (Adler and Madni, 2017).

1.1 Problematization of Research Opportunity

Research on autonomous vehicles has started to blossom in recent years due to the steady pace of the technology development. It seems that focus in the academic world has been directed towards the engineering research, following logically from the intricacies of the problem. However, some research has been carried out towards themes such as: the social, ethical and environmental implications of autonomous vehicles (e.g. Fagnant and Kockelman, 2015; Bonnefon et al., 2016), user acceptance and preferences (e.g. Fraedrich and Lenz, 2016; Krueger et al., 2016) and business models and strategy (e.g. Attias, 2016). Shedding a light on these topics is relevant to improve the technological development of AV and increase our understanding of this technology's effect on businesses, industries and societies.

Nevertheless, this stream of research looks only at one side of the *business coin*, overlooking the question of how manufacturers should organize internally to develop these new technologies (Yin et al., 2016). In the same vein, little research has been focused on how autonomous vehicle makers can achieve acceptable levels of safety (e.g. Kalra, 2016; Kalra and Paddock, 2016; Adler and Madni, 2017). These two overlooked themes raise an interesting research opportunity in studying how organizations that deploy AV can organize themselves in a robust way to achieve high reliability (Dietterich, 2018).

Contextualizing this research opportunity to the field of High Reliability Theory (HRT), this study will also address two specific research needs that have been addressed across the current literature. First, HRT research has focused on a limited range of organizations and more empirical research is needed to validate the applicability of its principles in new organizational settings (Lekka, 2011). Second, there is a limited amount of research that has tried to connect HRT with leadership to understand the role of managers in high reliability organizing (Martinez-Corcoles, 2018).

The complexity of this nascent industry with the growing importance of safety concerns, combined with a rare opportunity to understand the applicability of HRT in a new empirical field, presents an interesting opportunity for further investigation. With potential beneficiaries both in the academic and business world.

1.2 Purpose and Research Questions

Based on the presented research opportunity, the purpose of this study is to investigate and analyze how an incumbent manufacturer of commercial vehicles (CV) is organizing itself to deliver safe and reliable systems by assessing the linkage between HRT and the development of autonomous vehicles. This will be accomplished by examining the following main research question:

Main research question: "*How does an incumbent manufacturer organize internally to develop safe and reliable autonomous trucks and busses?*"

Inspired by the Problematization section, the authors divide the main research question in two distinct but conceptually interrelated sub-questions in order to examine the phenomenon from a holistic stance. In the previous section the importance of creating high-reliability systems was discussed as a means to develop safe and reliable vehicles, therefore the first sub-question is:

Sub-question 1: "*What role do reliability-enhancing strategies play in the development of autonomous trucks and busses for an incumbent manufacturer?*

Moreover, that section also emphasized the expressed need to investigate the role that the manager plays when developing high-reliability systems. Therefore, the second sub-question is:

Sub-question 2: "*How does the role of the manager change at an incumbent manufacturer of truck and busses to enable reliability-enhancing strategies*?

1.3 Delimitations

Organizational challenges in the wake of the development of autonomous vehicles open up many interesting areas of research in the field of management and technological innovation. The centrality of safety emerged both from primary and secondary research and limited the study to understand how manufacturers are organizing for reliability. The lack of technological knowledge of the authors steered the focus towards the organizational and management practices that can enhance reliability rather than detailed technical engineering issues that of course bear relevancy in this context.

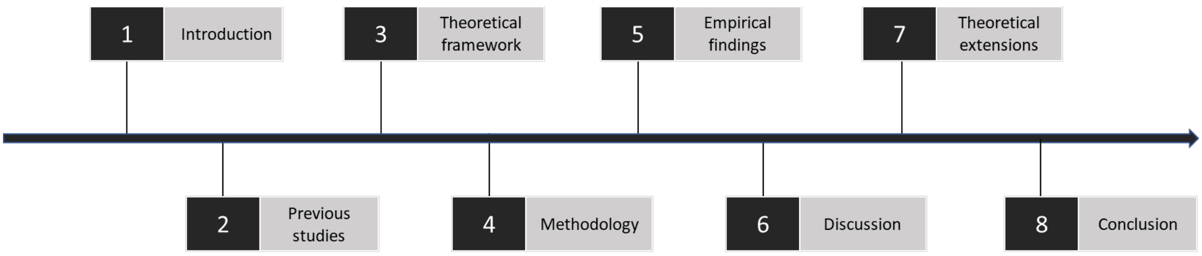
Moreover, the focus of the research is on the development of AV at incumbent CV manufacturers, which limited the scope to exclude passenger cars. Despite passenger cars have attracted most of the media attention, CV are most likely to be in the forefront of the autonomous-driving revolution due to their applicability in industrial settings and highway environments (McKinsey & Company, 2016). Moreover, the analysis of a CV manufacturer allows to engage an organization that already has real environment applications of its technology in closed field environments such as mining (e.g. Agrawal et al., 2016; Welsh, 2016).

Lastly, the study was also limited to the R&D department of the Swedish manufacturer of trucks and buses (the case company) due to the fact that AV are currently developed and industrialized on a very small scale only within the R&D. The ultimate delimitation relates to the use of a single case study, as the nascent nature of the AV industry required a profound exploration.

1.4 Research Outline

The outline of the research is as the model below:

Figure 1: Research Outline



1.5 Background and pre-study

This section introduces a background to the automotive industry as well as displaying some more pressing organizational and managerial challenges. The background is emerging sequentially from the pre-study, which consisted of five interviews with experts from the case company and secondary data research.

The automotive industry (i.e. *all companies and activities involved in the manufacture of motor vehicles*) is one of the many traditional industries that are undergoing what some scholars call a *paradigm shift*, which is defined as a *significant change in the `problem field` in innovation research, policy making and practice* (Baldwin and von Hippel, 2011). Four technology-driven trends (electrification, connectivity, diverse mobility and autonomous driving) are now reshaping the industry, destabilizing incumbent firms and allowing the entrance of new actors from other industries (McKinsey & Company, 2016). Within this paradigm shift, CV manufacturers see AV as the next disruptor of the industry due to its technological and economic benefits (Winterhoff et al., 2016).

As explained to the authors in the pre-study interviews, a commercial AV is for instance a truck or bus equipped with hardware and software technologies that allow the vehicle to move and run operations without a driver. The technology is built on the taxonomy of robotics:

" In order to produce an autonomous vehicle, you need three things. It is the taxonomy taking from robotics. So, you need to see the world, you need to think, and you need to act". – Engineer 3

This robotic solution depends upon many layers of interconnected hardware and software technologies. The main subsystems are identified by the experts as *offboard* and *onboard*. The onboard system is the set of embedded systems situated on the truck (e.g., radar, lidar, camera, spatial imaging, HMI). Analogously, the offboard system is made of all the technological layers not situated directly on the truck (e.g. wireless infrastructure, cloud servers, etc.). See more about components of an AV in Appendix 1.

From a commercial standpoint, the industry belief is that many of the current pain points such as driver's shortage, fuel consumption and utilization inefficiencies will be mitigated by autonomous trucks (Nowak and Vierickl, 2018). The opportunities are many, but among practitioners and regulators *safety* emerges as the primary benefit stemming from AVs. Many optimists claim that AV will reduce crash rates immensely given that human error contributes to 90% of accidents world-wide (Fagnant and Kockelman, 2015; Arbib and Seba, 2017). But this assumes that they work close to perfect. What practitioners and media at times overlook is that autonomous technologies also introduce additional risks such as hardware and software failures, hacking, etc. (Hsu, 2017; Koopman and Wagner, 2017). This factor translates into new organizational challenges for the manufacturers:

"It is a huge organizational challenge to have a highly complex software behaving in a safe and predictable way" – Engineer 2

In a time where the automotive industry is transforming into a software-driven industry attacked by disruptors on multiple fronts, incumbent CV manufacturers are challenged to quickly adapt their organizations and operations to be able to survive and thrive in the long run (Muro and Maxim, 2018; Ansari and Krop, 2012).

From the pre-study it emerges that incumbent CV manufacturers also have a managerial challenge to develop a system where the new product is more technically complex but also calls for higher reliability. This is in line with the argument that technological advancement comes with costs and challenges (Litman, 2018).

"*I believe it is a huge challenge for the managers since so many things are changing. At the same time, you face large technical and ethical problems"* – Engineer 1

The pre-study has allowed the authors to understand how the CV manufacturing industry is facing a shift of a magnitude never experienced before because of the introduction of AV. This shift is however not an effortless maneuver and the pre-study indicate that managerial and organizational complications arise, congruent with the overall industry outlook. With large investments and the belief from the media and industry that AVs are the future, these issues seem somewhat downplayed. From a development perspective, the organization needs to develop a system that calls for higher level of technological knowledge and for it to perform more reliably than before. Thus, it seems like new organizational and managerial practices should be put in place to face off these new challenges and thus it poses as an interesting query for further investigation. In the next section, a thorough review of the organizational literature that deals with safety and accidents in complex technological environments will be presented in order to align the empirical introduction with organizational theory.

2. Previous Studies

The following chapter gives an overview of previous studies that analyzed organizational factors underlying safety and reliability. In section (2.1) the authors introduce the two most prominent schools of thought that have looked at complex and high hazard organizations. In section (2.2) a thorough review of the existing literature in HRT is presented. Thereafter its new applications are demonstrated in (2.3), ending with a synthesis (2.4).

2.1 Explaining Accidents in Complex Systems – The NAT and HRT Debate

For a few decades, scholars were divided when trying to understand how organizations can design and operate hazardous technologies and systems in a safe and reliable way. On the one side, Normal Accident Theory (NAT) developed by Charles Perrow (1984) assumes that accidents are inevitable when dealing with complex systems and technology. On the other side, High Reliability Theory (HRT) elevated *high reliability organizations* (HROs) as best practices for organizations that handle hazardous technologies in a near error-free manner.

2.1.1 Normal Accident Theory

NAT was developed as a theory subsequently to the studies of disasters in complex technological environments by Charles Perrow (Marais et al., 2004). In his studies, Perrow (1984) has argued that *complexity* and *tight coupling* (see definition in section 3.1.1) are specific characteristics of complex and high hazard organizations for which accidents become inevitable (Roberts, 1990). These characteristics according to Perrow (1984) render these organizations high-risk (Lekka, 2011).

According to basic principles of organizational theory, decentralization allows organizations to cope with complexity and centralization to cope with tight-coupling (Beierly and Spender, 1995). According to Perrow (1984) it is structurally impossible for an organization to be centralized and decentralized at the same time, hence accidents are unavoidable (Shrivastava et al., 2009).

While giving an important contribution to the understanding of complex socio-technical systems, NAT does not provide any insight on how the risks for accidents might be reduced (Hopkins, 1999) and ignores empirical phenomena where complex systems do not fail (Weick et al., 1999).

2.1.2 High Reliability Theory

Around the same time Perrow (1984) articulated NAT, scholars from Haas Business School at Berkley gathered to study how *high-risk organizations* are capable of sustaining high levels of safety performance (e.g. Roberts, 1990; La Porte and Consolini, 1998). HRT originally focused on systems such as naval aircraft carriers (e.g. Rochlin et al., 1987), nuclear power plants (e.g. Bourrier, 1996), and space shuttles (e.g. Vaughan, 2005). According to HRT scholars, these organizations have something in common despite being different, i.e. they are complex socio-technical systems that put a high premium on reliability (Hopkins, 2007). Differently from NAT, HRT scholars have a positive view in relation to the nature of complex systems since they argue that organizations can achieve reliability by developing the appropriate processes and cultures (Tolk et al., 2015).

2.2 High Reliability Theory Review

In the literature there has been much debate regarding how to identify and define HROs (Lekka, 2011) and what HRT defines as reliability (Shrivastava et al., 2009). The next two sections will shed light on these two debated concepts and will serve as a guideline for the rest of the paper.

2.2.1 Defining HROs

The original characterization of HROs has been based on the idea that these organizations have the ability to achieve almost error-free performance over a long period of time (e.g. Roberts, 1990, 1993). Later characterizations of HROs bring into focus the types of processes and practices that equip organizations to reach high levels of reliability (Hopkins, 2007). These scholars have recognized the inevitability of errors and the emphasis on a limited degree of trial-and-error learning (La Porte and Consolini, 1991), the influence of exogenous factors like regulation and public perception (Rochlin, 1993; La Porte and Rochlin, 1994) and the pursue for multiple objectives (e.g. safety and innovation) (Beierly et al, 2008). Emphasizing *reliability-enhancing* processes and characteristics to improve safety performance thus broadens the spectrum of analysis for HRT and recognizes that HRO's status is open to various kinds of organizations (Lekka, 2011).

2.2.2 The concept of reliability in HRT

In HRT, reliability implies long-term stability, safety and robustness in the face of steadfast perturbations (e.g. Klein, 1977; Roe and Schulman, 2008; Wildavsky, 1991). It is necessary to point out in this section that HRT treats safety and reliability as equivalent. For instance, when scholars in the field refer to a "culture of reliability" they assume that reliable systems will lead to the absence of accidents (Leveson et al., 2009).

2.2.3 Characterizing HRO

From the plethora of studies conducted in the field of HROs, it is possible to extract what appeared as recurring characteristics and patterns that HROs share with each other (Tolk et al., 2015) and that Weick and Sutfcliffe (2007) defined as *reliability-enhancing*. The table below summarizes (to the knowledge of the authors) most of the processes described in HRT studies. The first set of HRT studies focused on processes that mainly relate to the field of organizational design and the second set focused primarily on the cognitive and social processes found in these organizations (Weick et al., 1999).

Table 1: Processes described in HRT studies

Process Nature	Process Name	Author
Organizational Design	Migrating distributed decision making	Roberts, 1993; Libuser, 1994; LaPorte and Consolini, 1998
	Management by exception	Roberts, 1993; Libuser, 1994
	Develop the "big picture"	Roberts, 1993; Libuser, 1994
	Climate of continuous training	Roberts, 1993; Roberts and Bea, 2001
	Duplication of safety critical information channels	Roberts, 1990, 1993
	In-built redundancies	Roberts and Rousseau, 1989; Roberts, 1990, 1993; LaPorte, 1994
	Formal rules and procedures	Roberts and Rousseau, 1989; Libuser, 1994
	Deference to expertise/Underspecification of structures	Weick et al., 1999; Weick and Sutcliffe, 2007
Cognitive/Social	Perception of risk	Libuser, 1994
	Organizational culture	Weick, 1987; Roberts, 1993; Beierly and Spender, 1995
	Collective mind and heedful interrelating	Weick and Roberts, 1993; Beierly and Spender, 1995
	Preoccupation with failure	Weick et al., 1999; Weick and Sutcliffe, 2007
	Reluctance to simplify	Weick et al., 1999; Weick and Sutcliffe, 2007
	Sensitivity to operations	Weick et al., 1999; Weick and Sutcliffe, 2007
	Commitment to resilience	Weick et al., 1999; Weick and Sutcliffe, 2007

It can be noted that the characteristics and processes identified by HRT researchers are numerous but some of these characteristics just refer to the same concepts under different headings (Lekka, 2011). An example can be found in the concept of *migrating distributed decision making* (Roberts, 1993) which has the same meaning as *deference to expertise* (Weick and Sutcliffe, 2007).

2.3 Broadening the Spectrum of HRT

The original studies in the field of HRT were mainly carried out on a small range of organizations and industries (Tolk et al., 2015). Later on, distinguished researchers started to claim for the applicability of HRT principles to a broader set of organizations and industries (Weick and Sutfcliffe, 2007) and called for the need of more theoretical and empirical knowledge in this theoretical field (Waller and Roberts, 2003). This opened new empirical and theoretical opportunities that aimed at solidifying this field of research and increase its applicability (Lekka, 2011).

2.3.1 Recent applications of HRT

In recent years, emphasis was put on applying HRT principles to other empirical contexts, namely healthcare (e.g. Roberts et al., 2005; Madsen et al., 2006; Chassin and Loeb, 2013; Sutcliffe et al., 2016), software (e.g. Vogus et al., 2003) and virtual organizations (e.g. Grabowski and Roberts, 2016), manufacturing (Schulz et al., 2017).

The application of HRT in new empirical fields still remains narrow and more research seems required to extract the HRT processes that might be applied in other organizational contexts (Lekka, 2011).

2.3.2 Leadership in HRT

The importance of the role of managers as enablers of high reliability organizing was visible since early studies of HRT (e.g. Guy, 1990; Roberts, 1993; La Porte and Consolini, 1998). While management processes and strategies were part of HRT since its inception, according to Lekka (2011) a specific attention to the function of leadership to implement and sustain HRT practices started to be found across the HRT research only in later studies within healthcare (e.g. Madsen et al., 2006; Frankel et al. 2006). In the same vein, few studies later attempted to connect HRT to the theory of transformational leadership (e.g. McFadden et al., 2009; van Stralen, 2018) but there seems to be a lack of cohesiveness on the matter in the research circles (Martinez-Corcoles, 2018).

2.4 Synthesis of Previous Studies and Research Opportunities

In this section, the authors presented NAT and HRT as the two main schools of thought concerning organizational aspects of safety. HRT is the theory that will be used as the main theoretical lens throughout the thesis as this theory has shown that organizations can organize to create safe and reliable systems. Nevertheless, presenting NAT was fundamental to introduce the concepts of *tight coupling* and *complex interactions* as they will be introduced in the theoretical framework.

Subsequently, the authors presented the major studies in the field of HRT. The authors showed that the latest research on HROs agreed to define these organizations based on their core processes and characteristics rather than their industry of origin. The authors introduced the concept of reliability in HRT and explained that safety and reliability are treated here in an equivalent way. Finally, the authors displayed a summary of main HROs characteristics and processes.

Lastly, the more recent applications of HRT were presented together with the attempts by some scholars to connect leadership theories and HRT. The review of previous studies highlighted interesting research opportunities that this thesis aims to pursue. First, more research is needed to understand the applicability of HRT's core principles and processes in other organizational settings (Lekka, 2011). Second, more research should be devoted to understanding the impact of leadership in HROs (Martinez-Corcoles, 2018).

3. Theoretical Framework

Using HRT as the main theoretical lens throughout the thesis, the authors introduce in this section concepts that will serve as the main framework to analyze the empirics. In (3.1) the concepts of *complexity* and *tight coupling* are defined and introduced as sources of technological risk. In (3.2) HRT strategies and processes are presented as will serve as important concepts in the study. In (3.3), the major concepts of servant leadership are also introduced as characteristics of this leadership philosophy emerged early in the research process.

3.1 Technology as a Source of Risk

The conceptualization of *high-risk systems* elaborated by Charles Perrow (1984) led HRT scholars to also identify *complexity* and *tight coupling* as two important sources of risk embedded in complex socio-technical systems (Roberts, 1990). The concepts of *complexity* and *tight coupling* are hereby examined and exemplified.

3.1.1 Complexity

With *complexity,* Perrow (1984) defines *interactions of unfamiliar sequences, and either not visible or not immediately comprehended*. Beierly and Spender (1995) give a definition of *complexity* in a system as *"having a large number of highly interdependent subsystems with many possible combinations which are non-linear and poorly understood"*.

3.1.2 Tight Coupling

According to Perrow (1984), the technologies that are at the core of *high-risk organizations* are *tightly coupled, mechanistic and brittle (in an engineering sense)*. *Tightly coupled* interactions are defined by Beierly and Spender (1995) as interactions where *"perturbations are transmitted rapidly between subsystems with little attenuation"*. Subsystems in this definition include people, equipment and procedures (Lekka, 2011).

Complexity and *tight coupling* were identified among HRT scholars as the two main sources of technological risk in complex socio-technical systems (Roberts, 1990). Roberts (1990) designed a model to understand the reliability needs of organizations based on their technological risk and reliability levels (see fig. 2).

Figure 2: Technological risk and reliability

Adopted by Roberts (1990)

In this model HROs fall either on the right side of cell 3 or in cell 4 while organizations in cell 2 can be considered "*in trouble*" (Roberts, 1990).

3.2 Reliability-Enhancing Strategies

In section (2.2.3) of the Previous Studies, the authors presented the strategies described by HRO scholars as the core principles for high-reliability. Abovementioned, among the multitude of strategies that different scholars identified as characterizing HROs there are some that recur more frequently. As part of the emerging theoretical framework, the authors introduce those *reliability-enhancing* strategies that seemed conceptually linked, recurred across different authors and that were suitable to analyze the empirical setting of the case study. As a result of this process, three main sets of principles were identified that will be referred to as: *structural strategies, social strategies* and *management processes.*

3.2.1 Structural Strategies

The first set of strategies are referred to as *structural strategies.* These strategies refer to processes and characteristics that relate to the organizational design, formal processes and structures found in HROs (Weick et al., 1999).

3.2.1.1 Redundancies

The concept *redundancies* as a common characteristic of HROs is found across many HRT studies (e.g. Roberts and Rousseau, 1989; Roberts, 1990, 1993). In-built redundancies in HROs comprise both the installment of technology-driven back-up systems (technical redundancies) and the people that are part of the whole socio-technical system considered (people redundancies) (Roberts, 1990).

3.2.1.2 Rules and Procedures

Procedures and rules are a key aspect in reliable functioning (Roberts and Rosseau, 1989). These organizations present well-defined procedures for both normal and non-routine situations with well-known decision rules (Libuser, 1994). The adherence to standards and procedures is often emphasized in these organizations to avoid fatal errors and guarantee safety (Libuser, 1994).

3.2.2 Social Strategies

The second set of strategies are referred to as *social strategies.* These strategies denote the cognitive and social processes that characterize high reliability functioning (Weick et al., 1999).

3.2.2.1 Perception of Risk and Preoccupation with Failure

According to Libuser (1994) *perception of risk* is identified as a recurring factor in HROs. Members of HROs seem to be attentive to the existing risk involved in the work they do and consequently act upon it in order to mitigate it. The continuous search to mitigate the risks around HROs leads its members to be characterized by the *preoccupation with failure* (Weick et al., 1999). According to the same article, HROs continuously worry about failure even if they are a rare occurrence and resources are spent to investigate deviances or near misses. Every deviance or near miss is an occasion for the organization to improve its processes and provide an opportunity for learning. Moreover, reporting of errors is encouraged and rewarded as much as a success.

3.2.2.2 Organizational Culture and the development of a Collective Mind

Weick (1987) was among the first to conceptualize *organizational culture* as the mode of control in hazardous organizations. Instead of focusing on the technological reasons behind the failures, he argued that accidents may occur because the humans who manage these complex systems are not competent enough to sense and anticipate the systems´ problems (Beierly et al., 1995). According to Weick and Roberts (1993) members of HROs are often characterized by the development of a *collective mind* which is paraphrased by Beierly and Spender (1995) as a *higher-level collective knowledge which can support individuals when they are under pressure in high risk organizations.* The development of a *collective mind* creates a common ground for both new- and oldcomers to make sense of situations and stimulate the alertness required in high-reliability settings (Weick and Roberts, 1993). Through a well-developed *collective mind,* the *organizational culture* acts as a mode of control at different levels and allows *centralization based at the collective level to coexist with decentralization at the individual level* (Beierly and Spender, 1995).

3.2.3 Management Processes

The third set of principles are referred to as *management processes* as defined by Roberts (1993). These denote the processes that sustain the development and implementation of the social processes and structures needed to run near-error free operations (Roberts, 1993).

3.2.3.1 Migrating distributed decision making

Weick et al. (1999) propose that effective decision making enhances reliability in HROs. Instead of keeping a closed hierarchical structure, HROs create an environment where decision-making migrates along with the problem, meaning that hierarchical rank is subordinated to experience and expertise (Weick et al., 1999). *Migrating distributed decision making* provides local decision making with the possibility for managers to intervene when their expertise is needed (Roberts, 1993). The migration of decision-making is also accompanied by remarkable degrees of accountability and responsibility to low level employees (Roberts, 1990).

3.2.3.2 Management by Exception and development of the "Big Picture"

The process of *migrating distributed decision making* goes hand in hand with the concept of *management by exception*. Managers only have an overview over decisions and intervene only if necessary (Roberts, 1993). With *management by exception* the focus of managers is directed towards strategical and organizational decisions (Bass, 1999). A direct consequence of *management by exception* and *deference to expertise* is that both managers and operators HROs are able to grasp the grand scheme of events or the so called "big picture" or "bubble" (Roberts, 1993). In this way, members of the organization can truly understand the organization they work for and frame their activities within the overall umbrella of the organizational setting.

3.3 Servant Leadership

Throughout the interviews conducted in the case study, it emerged that the organizational changes occurring in the organization have led to the emergence of a new leadership philosophy resembling that of a *servant leader*. In this section, servant leadership theory (SLT) will be defined and its key concepts will be introduced to allow for a theoretical discussion about the connection between SLT and HRT later in the thesis.

3.3.1 Servant Leadership Theory

Coined back in 1970 by Greenleaf, the field of research that goes under the name of servant leadership revolves around the figure of a servant-leader that is focused specifically on the growth of its followers and its attitude allows for strong and safe relationships inside the organization (Luthans and Avolio, 2003). A servant leader becomes then a "primus inter pares" (i.e. first among equals) and commits himself/herself to secure the growth of its followers, the survival of his/her organization and the welfare of its community (Reinke, 2004).

3.3.2 Key Concepts of Servant Leadership

From the plethora of literature that covers SLT (e.g. Liden, et al. 2008; Liden et al., 2014), the main concepts that characterize servant leadership were gathered in a model by Northouse (2015). This model specifically characterizes servant leadership as a behavior rather than a trait.

Northouse (2015) has identified seven multidimensional behaviors that are central to servant leadership: (1) *conceptualizing* refers to the leader´s thorough understanding of the organization´s purpose, complexities and mission; (2) *emotional healing* involves recognizing followers´ problems and provide them with the support; (3) *putting followers first* show followers that their interest is put in front of the leaders´ agenda; (4) *helping followers grow and succeed* refers to facilitating the professional and personal growth of the followers allowing them to reach their fullest potential; (5) *behaving ethically* implies that servant leaders never compromise their moral principles to achieve success; (6) *empowering* is the behavior that allows followers to be independent and make decisions on their own and; (7) *creating value for the community* stems from the actions that servant leaders give back to their communities.

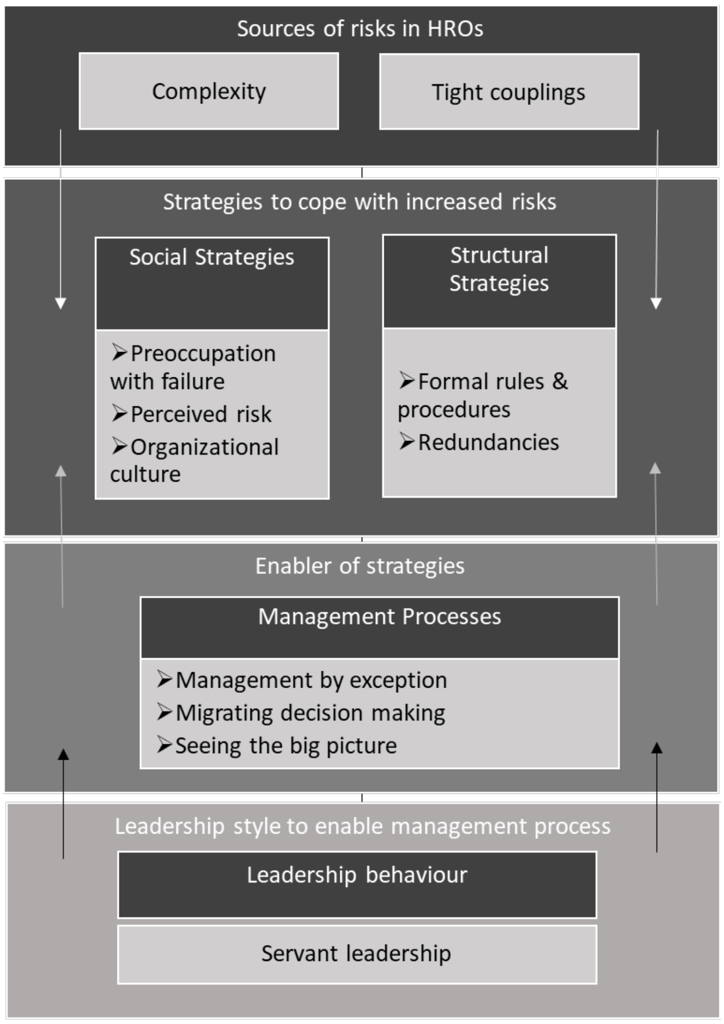
3.4 Theoretical Framework Synthesis and Visual Representation

In this section, the authors introduced the theoretical concepts selected to help answer the main research question: *"How does an incumbent manufacturer organize internally to develop safe and reliable autonomous trucks and busses?"*

The theoretical framework depicted in figure 3 below builds upon the conceptualization of *complexity* and *tight coupling* as sources of technological risk in organizations. The *reliability-enhancing* strategies presented in the section come into play as the mean of HROs to cope with the risks stemming from the interplay between *complexity* and *tight coupling* (Roberts, 1990,1993; Weick et al., 1999; Lekka, 2011). The authors leverage these concepts to answer sub-question 1: *"What role do reliability-enhancing strategies play in the development of autonomous trucks and busses for an incumbent manufacturer?"*

To analyze the role that management plays in building a reliable organization, *management processes* are introduced. Lastly, as leadership plays an important but at times overlooked role in HROs (Martinez-Coroles, 2018) servant leadership concepts, which emerged from the *"field",* are presented and will be analyzed as antecedents to the *management processes*. This part of the framework will help answer sub-question 2: *"How does the role of the manager change at an incumbent manufacturer of truck and busses to enable reliability-enhancing strategies?"*

Figure 3: Conceptualized overview of Theoretical Framework



4. Methodology

In this section the methodology of this paper's research is showcased. Presenting a thorough methodological explanation is a way to create reliability of the study, and it also fulfills a growing concern in the academic world emphasizing that methodology ought to fill more room in academic papers, especially in qualitative research (Gehman et al, 2018). This section starts with explaining the methodological fit (4.1), then the design of the study (4.2) ending up with casting light on the quality of both the research, outcome and data (4.3).

4.1 Methodological fit

The call for methodological fit within qualitative research has been encouraged by many leading academic management methodologists (Gehman, et al, 2018; Edmondson and McManus, 2007). The field of autonomous vehicles is in a nascent stage of development, and little research has – to the knowledge of the authors – been performed in relation to organizing. With limited research in the field, the authors deemed it suitable to give a rich and in-depth understanding of the research question by connecting the phenomenon of the "development of AV" with the context of "organizing for CV manufacturing". This was achieved using a qualitative case study, since "case studies provide unique means of developing theory by utilizing in-depth insights of empirical phenomena and their contexts" (Dubois and Gadde, 2002). By doing so, the research is also supporting the *Kuhnian insight* that a scientific discipline without meticulously elucidated case studies, is a discipline without systematic understanding (Flyvbjerg, 2006).

To answer the research question, an abductive research methodology called "systematic combining" was applied (Dubois and Gadde, 2002). The research was carried out using semi-structured interviews to grasp the "complex social reality" the experts were operating in (Alvesson, 2003). The data was gathered and analyzed in an iterative, non-linear and abductive way, jumping between the framework, the empirical world, the case and the theory which is a strategy to develop theory from a conceptualized reality (Dubois and Gadde, 2002). Single case studies are however criticized for that they "suggest they are relying on some notion of statistical generalization" (Easton, 1995). That is not the goal with this research, it rather sets out to find analytical inference (Dubois and Gadde, 2002; Yin, 2014). Lastly, different quality measurements were consulted to strengthen the impartialness of the study (Pandey and Patnaik, 2014).

4.2 Design of study

The research design is a framework consisting of assumptions about how to organize, assess relevance and analyze the evidence that is brought forward in the research (Bryman and Bell, 2011). Yin (2014) puts it in an even more elegant way stating that it is the "logical blueprint" of the research. Importantly, a qualitative study does not have a customary design (Yin, 2014). To structure it, the concept of a "Research Onion" was an influential component (Saunders et al, 2018), this approach starts with the core philosophical approach of the authors and thereafter move closer to the data and analysis.

4.2.1 Research philosophy

Research philosophy refers to a set of beliefs and assumptions about knowledge (Sunders et al, 2018). From an epistemological orientation the authors consider themselves interpretivists (Silverman, 2013), applied to this research it means that the social world is best understood by analyzing the experts' perspectives (Bryman and Bell, 2011). This research philosophy enabled the research to legitimize the choice of research method (systematic combining) and the results that followed. Moreover, from an ontological perspective, a constructivist orientation was applied (Silverman, 2013), coming with the assumption that the experts interviewed are social actors that create meaning and knowledge through their experiences (Twomey and Fosnot, 2013).

4.2.2 Research approach

Bearing the research philosophy in mind, an abductive and multimethod research approach built on "systematic combining" was applied (Dubois and Gadde, 2002; Brewer and Hunter, 1989; Saunders, Lewis and Thornhill, 2015). Systematic combing enabled the authors to jump between the empirical world, the case, the framework and the theories in an iterative way which is an opposite to the positivist school that entertain a path-dependent, logical and sequential route (Eisenhardt, 1989). Thus, the researchers could confirm and build theory from a discovery-driven process (Dubois and Gadde, 2002). The idea of an "emergent-spontaneous" approach was also used – which was a way to "keep the eyes open for opportunities along the research" (Alvesson, 2003). By doing so, the authors also countered the argument by Sandberg and Tsoukas (2019) that much research today leads to "sterile outcomes".

4.2.3 Research strategy

This part explains how the authors responded to the research question in an orderly fashion (Saunders et al., 2007). In line with the abductive approach in an emergent field, the authors did not merely set a research question to pursue "gap-spotting" (Alvesson and Sandberg, 2011). Instead, inspiration came from "problematization", a concept from the same authors pointing to the fact that research questions should question the assumptions of theories already in use thus aiming at finding research problems out in the real world (Kilduff, 2006). To answer the discovery-inspired research question, a single-case study was carried out. This research method complies with "problematization" and fulfills the expressed need of "better stories rather than better constructs" and embolden researchers to conduct context and detailed-rich single case studies (Dyer and Wilkins, 1991). On this basis the research question emerged.

Autonomous vehicles are still not a part of our everyday life and companies working with the technology are few. This called for some additional issues leading to the creation of the following criteria: 1) AV is still in an early stage of developed and often rests within the R&D department. Therefore, the research needed to be conducted within the realms of R&D to be related to organizing; 2) the company needed to be working with autonomous vehicles on SAE-level 4-5; 3) all work needed to be made in-house, in order for the authors to fully capture the organizational problems and; 4) granted access to secondary resources and interviewees was a must, this is particularly problematic since much of the development is considered a "competitive advantage" and safe-guarded by intellectual property. On this basis the case company was decided.

After weighting these considerations a Swedish manufacturer of trucks and buses was chosen as an excellent option to answer the research question. The confidentiality of the topics covered have resulted in the necessity to anonymize the manufacturer which will be called the case company. This in turn was *bounding* the research, meaning that a delimitation was created between the case company and the empirical world (every other relevant aspect to the research) (Yin, 2014).

4.2.4 Data collection

The data collection was carried out from the primary source of interviews, and from secondary sources such as: academic research, industry reports, company reports and charts. Before the main study, a pre-study was carried out which helped the authors zoom in their research scope.

4.2.4.1 Pre-study

A pre-study was conducted to help the authors narrow down the research questions (Flick, 2014). Before that, a thorough literature review and academic advisors were consulted to construct a deep understanding of the overall industrial and academic landscape. The pre-study in itself was carried out with five interviews with AV experts at the case company (see appendix 3). The goal with the pre-study was with exploratory interviews to: 1) understand if there were any organizational challenges that came with developing of AV and 2) if the company applied or thought of implementing any strategies to solve these issues.

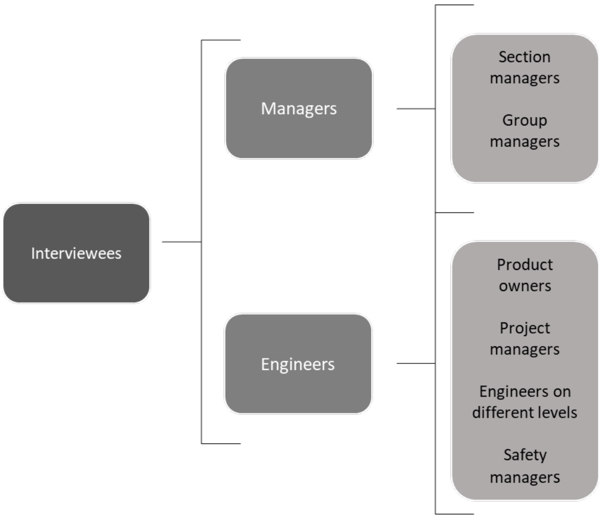
After assessing the pre-study interviews, and matching it to industry reports and academic literature, it stood clear organizing for reliability has not been researched in relation to autonomous development. It also became apparent that this was relevant as several organizational problems seemed to be apparent at the case company.

4.2.4.2 Data sample

It is argued by (Yin, 2014) that the units of collection need to be "an appropriate reflection of the main topic of study". Following this avowal, the study focused on extracting information from experts within the case company– these were the employees who worked with AV and faced the organizational challenges that came with it. The data sample consisted of interviews all around one hour. The main sample consisted of 12 interviews, and two follow-up interviews.

Because of the sensitivity of the responses, the authors let "informed consent" be a guiding principle (Flick, 2014). Therefore, all material was assured to be used in a way that did not affect any interviewee negatively. Consequently, these interviewees were clustered into two groups – managers and engineers, where the managers have responsibility by law of the wellbeing of the employees, this group consisted of five respondents.

Figure 4: Overview of Interviewees



4.2.4.3 Sampling method

The overall sampling was done to get as broad and truth-near data as possible (Kuzel, 1992). The sampling procedure was influenced by two different – yet related – strategies. *Purposive sampling* was used to "yield the most relevant and plentiful data" (Yin, 2014), in this case it meant that the data would be consistent with the research question. This was achieved by interviewing experts within the field, using systematic combining and operating in an iterative fashion (Dubois and Gadde, 2002). In the sampling process, *theoretical sampling* became more apparent later in the process (Glaser and Strauss, 1967). This approach was harnessed as it is a continuous process with the aim at matching reality (the case company) to theoretical concepts (especially HRT) which is the fundamental idea of systematic combining (Dubois and Gadde, 2002). The sampling frame was therefore designed to interview at least three persons with similar roles at the firm (Yardley, 2009), as well as interviewing all levels of the firm that actively work with autonomous vehicles in the R&D department.

4.2.5 Interview design

There are many decisions that need to be considered when designing interviews (Qu, Dumay 2011). In this paper – the amount, the role of the interviewer, interview style and the following strategy to analyze the data were considered (Rubin and Rubin, 2005; Kvale, 1996).

The interviews were conducted in a semi-structured manner which is the most frequent way of conducting qualitative interviews (Alvesson and Deetz, 2000). Since the interviews where discovery-driven, semi-structured interviews were an obvious choice as they are said to be "capable of disclosing important and often hidden facets of human and organizational behavior" (Kvale and Brinkmann, 2009).

Before each interview, an email had been sent out with a short background of the authors, information about the collaboration with the case company and a brief overview of the research topic, in line with best practices (Arksey and Knight, 1999). Furthermore, two interview guides – one for managers and one for engineers – were created to guide and systemize the interviews (Qu and Dumay, 2011), see examples in appendix 5 and 6. They were created to mimic the cornerstones of a semi-structured interview (Alvesson, 2003; Berg, 1998), to be positive, have a flow, be unbiased and unjudgmental (Hannabuss 1996; Schensul et al., 1999). First, *introduction questions*, were asked to warm up and free potential tensions. Then *structural questions* were asked in an open-ended fashion to disclose the opinion of the expert but also to discover unknown unknowns, called *unk-unks* (Mullins, 2007). The authors then wrapped up by asking if there were any related topics or things the interviewee wanted to address.

Moreover, this approach is inspired by a dyadic interaction between the interview, the interviewer and the interviewee – with resemblance to a conversation (Qu and Dumay, 2011). This insight was important because of three reasons: 1) it helped the authors to modify its questions along and between the interviews; 2) it let the authors focus on different aspects depending on the experts' knowledge and 3) it opened up for the interviewees to share how they make sense of their worlds (Alvesson, 2003).

Moreover, the line of a *reflexive interview strategy* has been asked for from scholars (Qu and Dumay, 2011). Specially, Alvesson (2003) argues that methodological, reflexive and novel accounts ought to be considered when interviewing. This was also considered in the process, by for instance asking questions with different wordings.

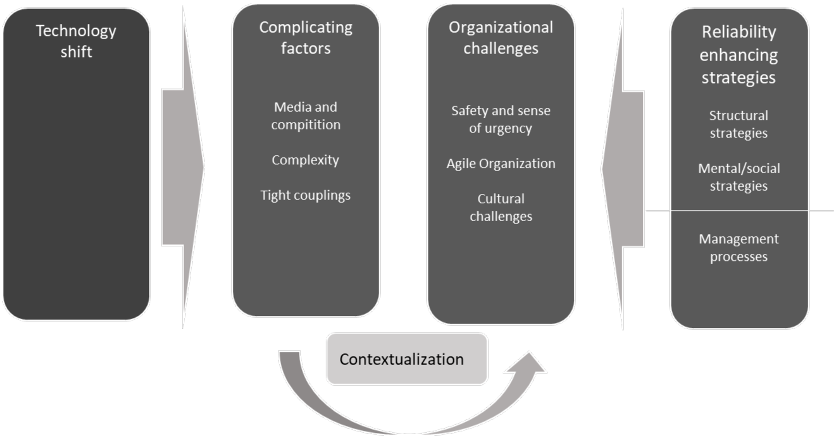
4.2.6 Data analysis

There are no best practices when analyzing qualitative data (Hannah and Lautsch, 2011). As been argued for previously, this thesis' methodology is built on systematic combining – where the case, the framework and the empirical world emerged in an iterative fashion. As argued by Glasser and Strauss (1967) the authors used a loose yet emerging framework to capture potential new findings but keeping the scope manageable. All interviews were attended by both interviewers and transcribed – upon which the authors' views were compared, something called *investigator triangulation* (Yin, 2003).

After that, two steps of the analysis took place, one empirical analysis to logically structure the data, and one theoretical analysis to match theory to the empirics. These two approaches co-existed and evolved through the interview and post-interview process in line with systematic combining.

During the data collection period, the "loose yet emerging" framework was iterated and then after the interviews it was re-iterated. Thereafter two analytical strategies were applied, in line with systematic combining. First, *matching* was used to jump between the case, the empirics and the framework to let findings emerge (Dubious and Gadde, 2002). Second, the data was *directed and re-directed* by juxtaposition facts and in so doing scope an otherwise ever-ongoing process (Dubious and Gadde, 2002). These processes enabled the analysis to exclude "rivalry explanations" and crystalize four logical sequences of events. These were as the model explains below: the technological shift that brings complicating factors to organize for AV. These are then contextualized with the case of the case company. Moreover, reliability enhancing strategies are displayed to show how to cope with these newfangled organizational challenges. Lastly, the analysis had the ultimately goal of matching the framework and the case to create and solidify theories (Dubois and Gadde, 2002).

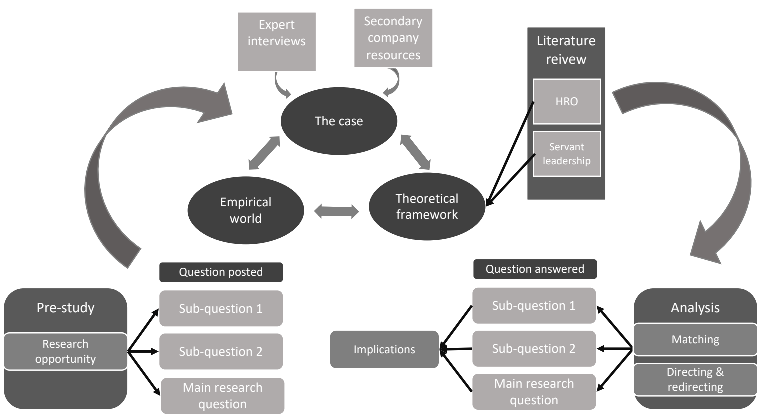
Figure 5: Accumulated structure of data processing and emerging theory through systematic combining



4.2.7 Research process

To summarize the abovementioned research process, the model below explains the systematic combining process, which is iterative and builds on abductive logic (Dubios and Gadde, 2002). Moreover, there are three main steps of the research, as indicated by the model. However, these three steps are not linear and the authors were jumping between the different steps in a consistent way throughout the research (Flick, 2014).

Figure 6: Research process



4.3 Research and data quality

The measurements to assess the quality of a qualitative study is not as clear-cut as in a quantitative (Bryman and Bell, 2011). As the researchers point out, the problem is inaugurated already with the word "measurement"! However, scholars have developed different models to meet these challenges most notably: Guba and Lincoln (1985), Guba and Lincoln (1994), Yardley (2000), and Miles (1979). Whereas none of them are perfect and are inspired by the positivistic school of thought (Dubois and Gadde, 2013), they still provide assurance for the overall quality of the research. In this paper the criteria of trustworthiness (Guba and Lincoln, 1994) is the starting point, which then is interlinked with other school of thoughts.

4.3.1 Trustworthiness

Assessing *trustworthiness* is a way to ensure the quality of this research. It can in turn be divided into four sub-categories: credibility, transferability, dependability and confirmability (Lincoln and Guba, 1985). Each of these factors will now be explained separately.

4.3.1.1 Credibility

Credibility is the qualitative equivalent of the quantitative paradigm's internal validity, asking "how congruent are the findings with reality?" (Merriam, 1998). This was done in several ways. First, *respondent validation* was exercised by having consent from the interviewees to publish the material. Another strategy to ensure that the authors understood the social world that the experts engaged in was through triangulation (Denzin, 1970). Triangulation is seen as a way to "check the accuracy of the data", which is somewhat troublesome since each respondent has its own understanding of the world (Dubois and Gadde, 2013). However, the authors used the idea of *method triangulation* as a strategy in the semi-structured interviews by applying different wordings for the same questions (Denzin, 1978), and investigator triangulation as explained in section 4.2.6.

Furthermore, *prolonged engagement* and *persistent observation* was used to ensure credibility in the findings (Lincoln and Guba, 1985). The later refers to the research providing depth (Pandey and Patnaik 2014), and was achieved by using *purposive sampling* and systematic combining which is a research strategy where the author is encouraged to be "open for multiple influences" (Lincoln and Gubba, 1985). The former relates to the scope of the research (Pandey and Patnaik 2014), and was met by interviewing a broad set of experts, being personal and spending additional time at case company's offices. An example of what this resulted in is that the authors in the first interviews became familiar with "safe" which they thought meant the development of a safe product. But as it turned out, it was an abbreviation for an agile strategy (SAFe).

4.3.1.2 Transferability

Transferability refers to the extent of which the study can be transferred beyond the context in which the study was performed (Merriam, 1998). First, this study aims at emersion and contextualization of a phenomenon rather than creating statistical significance, demonstrated by asking semi-structured questions where reflection and personal beliefs are encouraged. This deep emersion and contextualization of case company's culture and procedures is called *thick descriptions* (Geertz, 1973; Ryle, 1949), which is a key aspect to transfer the findings beyond the context (Lincoln and Guba, 1985). Also, the sampling process was carried out in a way to interview experts on different levels in the organization to obtain a holistic view of the research question. This process ended when the phenomenon studied was considered saturated (Merriam, 2009), occurring after 14 interviews, where the five pre-study interviews played a vital role. To what degree this research is transferable is however up to the reader to decide, in line with the focus of systematic combining (Dubois and Gadde, 2013).

4.3.1.3 Dependability

Dependability is the qualitative equivalent of the quantitative paradigm's reliability (Bryman and Bell, 2011), meaning that similar results would be seen under similar circumstances (Pandey and Patnaik, 2014). This quality measurement is fulfilled by applying "Inquiry audit" where an external researcher assessed the quality of the research. In this thesis – both the supervisor and a PHD student with ties to the case company assessed the quality of the paper. This was however not considered enough. To increase the dependability an extinguished American professor with relation to HRO theory assessed the quality and provided "food for thought" on how HRO and AV might be connected (Merriam, 1995).

4.3.1.4 Confirmability

Confirmability relates to the quantitative paradigm's idea of objectivity and refers to research being made from the experts' perspectives as far as possible (Pandey and Patnaik 2014), important to notice is however that in systematic combining this is of particular importance in the empirical findings (Dubois and Gadde, 2002).

Confirmability was reached applying different strategies. First, the authors themselves cross-checked all transcripts to ensure accuracy (Gibbs et al, 2007). Second, the authors tried to the best of their abilities to stay as truth-near as possible by systematically attend to the affect the authors may have had on the interviewees. To achieve this a reflexive approach was applied inspired by *deconstructive reflexivity* where the authors continuously questioned – not only each other – but also themselves throughout the entire research process (Johnson and Duberley, 2003).

Lastly, in line with the recommendation of Cresswell (2014), the authors would like to share two potential biases: first, since the collaboration with the case company is a close cooperation it might render in unintentional feelings of reciprocity, second: both authors have a passion for and belief in technological development. Both these factors may have left the research tainted with optimism.

5. Empirical findings

The empirical findings are presented with the narrative voice of the authors as they were presented by the interviewed experts. This implies that no judgements from the authors have been applied in this section which is particularly important in systematic combining since the truth is created in the eyes of the experts (Dubois and Gadde 2002). Some information has however been elevated to give a broader and richer contextualization. To systemize the findings and by doing so making the content more feasible and graspable for the reader, the case is divided into five sections: (5.1) background and introduction to the case company and the development of AV, (5.2) an assessment of the complicating factors affecting the development of AV, (5.3) the organizational challenges arisen due to these complicating factors, (5.4) the strategies that are emerging to foster safety and reliability in the development of AV and (5.5) the managers´ role in this process. For the interested reader, examples of the quotes from each section are systemized in appendix 4 as an example of how the case emerged to the authors.

5.1 The case company and the autonomous department

The case company is a Swedish manufacturer of CV with a long history in the industry. It is one of the largest CV manufacturers in the world. With a focus on the future, this organization is leading the development of environmentally friendly transport systems and allocates substantial resources to the development of AV.

Today the department (autonomous department) that works with AV at the case company consists of 250 people, but that was not always the case. The case company has for more than a decade worked with different types of automated solutions on the SAE Level 1 and 2 (see SAE scale in the Appendix 2) and has collaborated with academia and technological partners in the research for AV for many years. Before the creation of the autonomous department most research and development activities were carried out in scattered groups across various departments of R&D. After a couple of years, the long-term strategic relevance of these new solutions started to call for more attention from the top and autonomous driving initiatives started to receive more interest and investments from the firm. Because of the fast development of the technology and the realization that lagging behind in the development of AV might hinder the long-term success of the firm, more projects started to ramp up in different parts of the case company and it became difficult to oversee them all. As a result, a department was established in 2017 to better structure the different projects and initiatives in the field of autonomy. The department's ambition was high and called for more resources, which in turn was granted from the company's R&D budget. One of the managers explains the rapid movement of the department's growth:

"When we started with autonomous vehicles it was in pre-development. As often happens, the pre-development became bigger, it was very interesting for the company and they gave us resources and very interesting projects started to flock." – Manager 3

From 2017 until today the department underwent several reorganizations to cope with its fast growth and to optimally balance resources across different streams of development. Before the year that this thesis is written (2019) a new reorganization has recently taken place to better allocate resources for SAE 5 research, SAE 4 development and large-scale industrialization of SAE 1 and SAE 2 technologies.

Contextualizing the case within the environment of constant reorganization and conflicting goals for the department is important when bringing forward the challenges that emerged in the next sections of the empirics. The focus of this empirical section is nonetheless on the small-scale industrialization of AV (SAE 4) as it covers the most pressing organizational issues that the case company is facing, moving into the development and future commercialization of AV.

Historically, the company produced 10,000s of CV per year but developing and testing AV is done in a smaller scale. Moreover, the staggering growth of the department and the level of complexity of the products moved the company from a stable environment with long product cycles of hardware to a more nascent situation where hardware and software are intertwined. This leaves the R&D department in a peculiar organizational situation, more thoroughly explained below.

5.2 Complicating Factors

This section addresses factors complicating the autonomous department's organizing during the development of AV. These factors are both exogenous and endogenous in their nature and affect the organization and the system under development.

5.2.1 Exogenous complicating factors

Exogenous complicating factors during the development of AV are the influence of the public scrutiny and competition.

5.2.1.1 Increasing public attention and scrutiny around AV

Public attention and the resulting scrutiny towards AV are considered to be an unneglectable component that affects those working with the development of the technology. From experts and regulators to journalists and everyday people, the debates around the deployment of this technology is growing and different opinions are emerging in relation to its effect on society. One of the major concerns that is under discussion today is specifically the safety of the systems, especially after the first accidents involving the loss of human life. An engineer explains:

"When it comes to safety, autonomous vehicles are in some sense more dangerous or at least public opinion regards them as that. There is much more focus. And you also have media specifically focusing on the safety issues." – Engineer 9

The increased level of public scrutiny does have an impact on the development of AV according to the interviewees. Specifically, there is a belief that every early fatal crash might result in a stall of development and in stricter rules for public testing as this engineer explains:

"When there is a news of a Tesla crash it becomes even harder for us since we need to prove even more the safety of our products." – Engineer 8

Media's and the public opinion's view on the safety is playing a role by affecting the social worlds in which the experts interviewed are acting in and puts pressure on engineers and managers working with the development of AV.

5.2.1.2 Role of competition

The second exogenous complicating factor is competition. If the media is a bellwether for safety, the competition is instilling the case company with a sense of urgency. Making a parallel to the digital revolution taking place in the early 2000s, there is a group of employees that dread that the company will face the same destiny as companies like Kodak and Nokia did, if the case company is not one of the first to launch AV[2]. This places the case company in a peculiar situation since the organization must invest resources to meet two conflicting goals, safety and fast development.

5.2.2 Endogenous complicating factors

Endogenous factors making the organizing for AV problematical for the case company are the increased complexity and tight coupling of the subsystems that form the vehicle.

5.2.2.1 Increased complexity

"Self-driving vehicles are several orders of magnitude harder than space flight." – Engineer 4

The CV manufacturing industry has always produced a complex product. However, the addition of multiple layers of technology in both the hardware and software has increased the number of subsystems of the AV. As a consequence of the removal of the human from a CV built with SAE 4 technologies, an exponential growth of complex interconnections between the subsystems has emerged. As humans, we have a very high level of cognition to handle complicated and dynamic tasks. The growth of complexity reflects in a greater amount of work for the engineers:

"*It is much more complex (with the introduction of autonomous), and it is much harder for us to test and confirm we have tested all the combinations (of the sub-systems) to make the product safe."* – Engineer 8

A higher number of subsystems and increased interrelatedness has led to a situation where combinations are endless and at times even unexpected as exemplified by this manager:

"So, we will have unexpected situations where we didn't know that there was a coupling between this and that, that we didn't foresee." – Manager 4

The complexity of the system together with the novelty of the technology impacts the efforts to guarantee the safety of the solution. Since the system is fundamentally complex, it is in fact much harder to prove its safety and no standard or best practices are available to facilitate this work.

[2] Read for instance "Kodak and the Digitial Revolution (A)", (Gavetti, Henerson, Giorgi, 2005) Harvard Business School

5.2.2.2 Tightly coupled systems

CV at the case company are characterized by a unique modular design that allows for incremental innovation and a vast range of customizations. The components are loosely coupled from a production and design perspective but are tightly coupled from a functional perspective since the failure of one component can compromise the performance of the overall system. With the introduction of AV and the removal of the driver, the subsystems are not only becoming more complex – which was argued before – but also more tightly coupled. The functioning of the AV depends on interconnected subsystems that capture a great amount of information. This allows the vehicle to perceive the world around it and take decisions. In such a system a small error or failure can have great ripple effects if not caught early in the process as exemplified by a manager here:

"I have always been working at the end of system. You get the information about the map that you are using, information on the obstacles, moving objects around you and your positioning on the map. Then you reason about that and decide for a trajectory to be executed. So, one of the problems we had at a certain point was that the sensor stopped delivering fresh information and one of the systems got stuck at an obstacle it saw. It thought the obstacle was static and kept repeating the information. What we obtained was something that we didn't see. Not because the planner made a mistake but because the sensors stopped delivering information that we could use properly. So, error-wise the ripple effects are dramatic." – Manager 3

Mitigating all the risks that stem from the many interdependencies found in an AV is one of the priorities to ensure the reliability and safety of the system. Nevertheless, mapping out the interdependencies of the subsystems and creating an overall robust system is easier said than done. Interconnections among subsystems are oftentimes hard to predict due to the complexity of the overall system and its tight couplings make error propagate with dreadful consequences.

5.2.3 Concluding Remarks

There are four main factors that are complicating the development of AV. The first two are the public scrutiny and competition which are pushing for a safe yet fast development. Then, if looking at the technology itself, it becomes evident that the subsystems are becoming more complex and tightly coupled. These two endogenous forces are mutually reinforcing, making the system challenging to design and operate.

5.3 Contextualized organizational challenges

In this section, three overarching challenges are introduced. These challenges are contextualized versions of the *complicating factors (5.2)* – displaying how these factors materialize in reality. One challenge is related to safety and sense of urgency (5.3.1), one revolves around the deployment of agile methodologies in an incumbent manufacturer of CV (5.3.2) and the last one relates to the clash of cultures in the organization (5.3.3).

5.3.1 Challenge 1: sense of urgency and safety

How to develop a reliable and safe product in a fast way was presented as one of the main challenges for the organization. As stated above, the interviewees' opinion is that they cannot fall behind their peers in the development of autonomous. At the same time, creating an AV that is unsafe could have an analogous effect. An engineer explains it as following:

"If you could trace safety against the development speed, that is always a tradeoff for all companies. You read about the Boeing incident[3] and they were criticized for being a bit too far in one direction of the prioritization and that will be the same case when an autonomous vehicle kills a person." – Engineer 6

The overall impression from the interviews is that this is an ongoing, ever-present and ever-growing tradeoff as the software technology is intrinsically fast-moving. This tension between safety and speed is challenging but there are also some managers that highlight that these two factors – if harnessed in a smart way – can be mutually reinforcing.

"I am the one that believe that speed can actually improve quality and safety. If you do it together, at least four eyes on everything and release often, then both can be achieved." – Manager 5

The challenge of developing safe and fast is a pressing issue – fueled by the media and the competition and simultaneously complicated by the increased complexity and tight coupling of the subsystems. This challenge has also reinforced two other challenges, discussed next.

5.3.2 Challenge 2: Implementing an agile organization in an incumbent CV manufacturer

To better cope with the new technological nature of an AV and the fast speed required by its development, an agile way of working has been introduced and the methodologies and frameworks used stem from the Scale Agile Framework methodology (SAFe) (see Glossary). The old way of working "in the line" that is found across the rest of the R&D at the case company meant that each module of the truck had a specific group assigned to it – one group for the chassis, one for the driveshaft etc. The need of coordination and cross-functional work was minimal, but that is changing. In the development of AV tasks require a holistic understanding, cross-functional knowledge and quicker decision-making which is achieved by working in cross-functional projects. This is something that the new agile way of working tries to achieve. It is however burdensome for the case company since their structures are built for the "in line" type of work:

"There is a clear conflict between the worlds of the vehicle and the new software. All the structures and processes are built around producing things in the line. All of a sudden we need to build something totally different and that is a challenge for sure." – Engineer 8

[3] Referring to two Boeing crashes in the early 2019.

Another challenge that is brought up by the use of agile methodologies in this setting is the clash of their principles with the traditional principles of functional safety. The common view among engineers on this topic was that there is a potential for agile development to benefit the safety of the system but that new approaches need to be defined:

"Functional safety and agile are not a hand-in-hand processes. They are actually quite different. At the same time, we are creating new ways of working with functional safety in an agile way." Engineer 4

The implementation of an agile organization is sparkling a change in the decision structure of the department. From the interviews it was understood that the managers cannot keep track on every technical aspect because of the sheer complexity of the novel technologies deployed. Consequently, the technical decisions are often being delegated to the engineers, with the manager still being accountable for the end-result. The challenge from an organization point-of-view surfaces as the managers within R&D historically got recognition in the organization thanks to their technical rather than people competences. Now, they must make a transition by letting go of technical decisions and focus on enabling people to reach their full potential.

"I think that this is a bit of a challenge because now we are actually breaking out a lot of the technical project decisions from the line structure or hierarchy (where managers traditionally have decision-power) into a new project structure (where engineers have more decision-power)." – Manager 5

The shift to this new decision structure does not come without challenges since both managers and engineers are expected to go through a great amount of change in their duties and responsibilities. Moving responsibilities downstream requires first of all engineers to have the willingness to do so and this does not seem to always be the case:

"There are very skilled engineers here, but they are not feeling comfortable taking the responsibility because they do not always get the support they might need." – Engineer 8

Finally, the new decision structure enforces two additional challenges between the manager and the engineers according to the interviews. First, the saying "too many chefs in the kitchen" is applicable in the sense that everyone wants to take decisions, which makes the process inefficient. Second, it is difficult to have an overview of who is responsible for what. It can lead to confusion especially for newcomers who have less knowledge about the ins and outs of the company.

5.3.3 Challenge 3: The clash between different cultures

The manifested complicating factors have also affected the corporate culture. Traditionally, a CV manufacturer was working with hardware and some software. That is now changing in the autonomous department. As a result, software engineers are flooding the floors of the company. Moreover, the challenge of culture goes back to the basic values these different engineers have. The first difference is that employees with a hardware background are generally more used to deal with the issue of functional safety:

What I can say as an engineer with both a hardware and software background is that hardware is much more focused when it comes to safety and there are processes for it that are more recognized. – Engineer 7

To create an organization where there are many newcomers that need to merge into the traditional company culture and where people with diverse professional and educational backgrounds need to collaborate closely becomes a clear challenge in the autonomous department:

"I think that at the moment there is less of a group identity. We will see if that is going to happen in the future. At the moment we are still in the middle of this process of transformation." – Manager 3

This overall challenge of the culture is seen as a problem by most. But just as with the challenge considering safety and sense of urgency, there is also a stream of criticism to this problem emphasizing that forcing alignment at all levels can be counterproductive. Instead, some encourage a complementary view by embracing the challenge and understanding that indispensable differences between hardware and software employees are inevitable. This is accentuated in the quote below:

"Those cloud developers that have a really agile mindset, let them have that. Don't force the hardware people to go all the way there, and vice versa. We must skip the right or wrong thinking. We should accept that we do things differently, and that we can learn from each other." – Manager 5

5.3.4 Concluding Remarks

These three organizational challenges – the sense of urgency and safety concerns; the implementation of an agile organization; the cultural clash between hardware and software – are a result of the three previously identified *complicating factors*. Moreover, in the last section of the empirical findings the authors categorize what strategies the company find suitable to cope with the three organizational challenges explained in this section.

5.4 Reliability enhancing strategies at the Autonomous department

This section of the empirical findings describes the organizational strategies and management processes typical for HROs that are emerging in the autonomous department in response to the development of AV. Two sets of categories are presented: structural *reliability-enhancing* strategies and social *reliability-enhancing* strategies.

5.4.1 Structural strategies

These strategies are structural in the sense that they relate to organizational design, structures and processes.

5.4.1.1 Rules and procedures

Safety standards and rules based on industry-wide practices have always been important at the case company to ensure the safety of its vehicles. Nonetheless, the development of autonomous CV has increased the work of safety managers and engineers in the organization as the industry standards available for the overall automotive sector are not comprehensive enough to ensure the safety of this new technology. An engineer explains:

"*Since we are working with autonomous vehicles, following the traditional standards is not really enough because there are other aspects that you need to take into account.*" – Engineer 4

The guiding standard for the development of automatic systems at the case company and in the industry is the ISO26262 standard which is an automotive functional safety standard for electronic systems that was developed in 2011 (see Glossary). But the overall consensus in the interviews was that these standards are not sufficient to ensure and prove the safety of fully AV, because they were produced when SAE 2 functions such as cruise control and automatic brakes were the most advanced technologies available. To overcome the limits of current automotive standards, the department is extracting safety practices from more general functional safety standards that usually find application in fields such as rail software, process industries and nuclear power plants.

Next to new safety standards the development of AV requires engineers to go through a great amount of testing to prove the effective and safe functioning of all the subsystems. The amount and nature of the tests implemented is well explained by an engineer:

"You do a unit test. It means that the software will test itself. Then, you test the interface using a simulation environment. "Does it respond as it should?" After that, we go to the level of virtual vehicle testing where I can virtualize both the hardware and software. The next step, especially on the onboard side is to test using test rigs. At this place, electricity systems of an actual autonomous truck are built on racks and then you have terminators that are simulating and responding as a vehicle." – Engineer 5

The development of an autonomous CV makes it necessary to also test the complete system. Subsequently, the testing is carried out through a *Factory Acceptance test* as such it is tested in a factory and after that, a *Site Acceptance test* is performed which is a way to demonstrate functionality and safety to the customer in a real setting, making it the ultimate litmus test. Lastly, formal procedures and guidelines exist to verify that the reliability is maintained and does not get downgraded over time.

To summarize: as exhibited in standards, rules, guidelines and procedures the company is pushing itself to deliver safe products. Many challenges still lie ahead since no standards and practices are publicly available and the organization needs to adapt practices from other industries and develop its own processes.

5.4.1.2 Redundancies

Redundancies was a debated topic among the interviewees and their use is manifested on several different levels of the company. Attention is assigned to redundancies because the largest redundancy in the system is disappearing, which is that of a driver.

"It is more sensitive of course (referring to the stability of the system), when we don't have the driver any more. So, that is why a lot of redundancy requirements are put on the systems." – Manager 4

The first type of redundancies discussed is to have duplication of hardware such as multiple cameras, lidars, electronic control units and software. For the hardware type of redundancies, there is a concern among engineers that this strategy comes with weaknesses on a systems level as exemplified here:

If you have a strong transmitter disturbing the system and if you have two sensors that are both disturbed by the same environmental influence, then redundancies are useless. Then you need to design the complete system so that it is capable of still doing the tasks and that is perhaps the hardest thing." – Engineer 7

The focus then is on designing the overall *system* in a robust way to ensures safety. In the case of the mining industry, the solution is now found in the interplay of the onboard and offboard systems together with the surrounding infrastructure. Consequentially, if one subsystem fails the other should be able to detect the error and correct it.

Moreover, redundancies are also found at the human level. Important technical decisions are in fact taken by a group of engineers rather than by a single individual. Furthermore, in the software development the organization is promoting developers to work together rather than individually:

"So instead of three people writing a piece of the code each, why don't you sit down three people around the computer and then write all parts together. Then you will get that kind of feedback going and you will get to learn from each other all the time." – Manager 5

But redundancies are also somewhat of a double-edged sword. They are making the whole system fundamentally more complex which could lead to undiscovered couplings:

"*The more redundancies you add the harder it gets to analyze. With the driver the redundancy is very simple. The driver can just press the break paddle and you would break."* – Manager 2

Overall, redundancies both at a technological and human level are an important component to ensure the reliability of the AV but raise much discussion in the organization.

5.4.1.3 Concluding Remarks

Structural strategies in the shape of standards, procedures and redundancies are applied and discussed as suitable ways to ensure the safety and reliability of the AV, but some interviewees might argue otherwise.

5.4.2 Social strategies

These strategies are social in the sense that they relate to the interrelation among members of the organization, their socialization and their individual cognitive state.

5.4.2.1 Risks and mitigations in developing AV

Safety has always been a pressing concern for employees at case company´s R&D due to the nature of the technology developed (a fast moving and heavy object operating in public places) and the risks of design errors are well perceived by the engineers and managers:

"It can be about life or death when it comes to deviations." – Engineer 8

Every deviation and error are analyzed with the maximum care and is used by the organization to learn and improve its systems and this attention to details and small errors has been passed on to the Autonomous department as well:

"I know we had a non-commanded movement last year in a trial. That is when the truck does something it was not intended/programmed to do. There are still activities on how to document and make sure that we do not have those issues again." – Engineer 9

The existence of an individual perception of the risks involved in developing and operating AV is indeed necessary but becomes only a strength when it translates into a cohesive culture of safety:

"You have to build it (safety) into the organization as a culture, or a ritual where every person has to think about it not to get overwhelmed by it. It has to be part of a collective way of actually thinking about safety." – Manager 5

In the opinion of some managers, the creation of a strong culture of safety passes not only through the perception of the individual but also through the creation of a collective social process. The next section will describe the role of the development of a *collective brain* at the Autonomous department.

5.4.2.2 The development of a collective brain

An ongoing strategy – something that was discussed as important in the interviews by the managers – is the role of a cohesive organizational culture together with common goals and vision:

I realized that SAFe (agile way of working) or less or anything else, it is not important. What is important is to have the same mindset in the culture and understand what we want to achieve together." – Manager 5

The abovementioned quote points to the fact that aligning the mindset through the culture is a strategy to overcome the organizational challenges that the company faces. But the opinion on to what degree that is achieved diverges. An engineer explains:

"What is our main goal on a high level? That is not clear within my organization. Probably I have colleagues that do not agree but.... It is not clear to everyone at least." – Engineer 8

Even though the views diverge, the intension and the willingness to unify the culture is clear on all the studied organization's levels. The company aims at having somewhat of a collective consciousness where collaboration, listening and participating is important:

"You must have your own ideas and you really have to use your brain and have this collective brain. The collaborative skill is more about listening, participating, pitching your ideas but also listen to other ideas. Not making up your mind. I think that listening is a really important thing here. Even if you have strong opinions on how you want to do it - you are flexible, and if there is a better option – go for that. – Manager 5

5.4.2.3 Concluding Remarks

The level of how the social strategies are implemented in the organization is not the key conclusion. What this section was designed to demonstrate is that there is an all-encompassing urge from all parts of the organization to apply these strategies to cope with the organizational challenges that follow with the development of AV.

5.5 A new management role in the Autonomous department

Organizing for high reliability also requires managers and engineers to adopt different roles and responsibilities and develop the right mindset, which is what this next section will cover.

5.5.1 Management by exception

"I try not to get involved but obviously if someone of the group asks me for advice or if he wants just to run an idea with me, I am very happy to go back and talk details and get to the whiteboard." – Manager 3

The *modus operandi* for the manager is as abovementioned shifting. As a consequence of the organizational challenges, the managers' deliberate strategy is to not employ much technical management, but rather keep track of the full picture. If something happens however, the manager intervenes, but that should be an exceptional case. The new role is built on trust where the managers still are accountable for the end-result but leaves the responsibility to the engineers as exemplified by this manager:

"I will not say this on page three what is that? I will go there and ask if they can take full responsibility and ask if that stuff is the best you can do and that you at least believe that. If they say "yes" then I approve it." – Manager 5

This is in line with the increased complexity of the product, making it harder for the manager to take all decisions related to technologies. Moreover, some of the interviewees reason differently to what degree this is achieved in the production today, but there is a consensus that the strategy should be applied.

5.5.2 Migrating decisions to the teams

In the same vein as above, the managers are re-allocating technical decisions down the hierarchy and try to focus on enabling the engineer. Decisions are moving where the technical expertise lies, which is in the teams of engineers or the experts. An engineer explains the delegation process in its group:

"In the normal development, you have the group manager that delegates the responsibility to a system owner or a team. From my understanding, the manager has delegated that role and now is available to solve organizational issues" – Engineer 4

The distribution of decision making also bring a greater amount of shared responsibility that earlier mostly rested on the managers:

"The responsibility is much more splitting I would say. A lot more people, have the mandate to say stuff" – Manager 6

The result of this process is that the teams of engineers are encouraged to take more responsibility and decisions and are encouraged to think critically while standing for their beliefs.

5.5.3 The emergence of a new leadership style

When the managers start to be more of a facilitating force, there is still a need to comprehend the big picture in order to make the overarching decisions correctly. The R&D department is trying to adapt a new leadership style to cope with these challenges. Even though the perspectives diverge regarding how far they have achieved this new style it is evident that what everyone is aiming for is a leader that now – more than ever – enables the engineer to excel. This is done by giving them a tolerant and stable context to develop:

""That is also a lot of servant leadership, so giving them guidelines, a frame and a context. It should not be a dot but rather a square otherwise it is micro management. Don't tell them how to do it or when to do it because that is micro management, as long as you achieve the big goals that we have set up, how you do it is completely up to you. We trust you to do it to the best of your capabilities." – Manager 5

Putting the follower first is still only made on a local level and some engineers argue against this trend. But when it is argued against, there is still an expressed urge to implement a structure reminding of the one above:

"We have the C3 and C4 (senior engineer titles) who are seniors and experts and the managers should be asking the right questions and support them. They should be technical but have more focus on people and leading through people" – Engineer 7

To summarize this section, the company is trying to implement another leadership style to enable the engineers to play a more pivotal role. There are however some inconsistencies between engineers and managers on to what degree this is achieved, but a consensus on the fact that it should be implemented.

5.6.1 Concluding Remarks

The findings show that the development of AV is affecting the interplay between managers and engineers and changing the roles and responsibilities in the organization. The implementation of new management processes is reflected in a change of the type of leadership that is sought after by the members of the organization.

5.7 Summary of empirics

In this empirical finding section, the development of autonomous vehicle has been dissected from an organizational and a division-of-responsibility perspective. Three complicating factors were introduced as a result of working with autonomous vehicles. These where then contextualized in the challenges the company is facing. Lastly, three strategies – structural, social and managerial – to cope with the challenges were presented.

6 Discussion

In the following chapter, the empirical findings will be analyzed and discussed using the theoretical framework developed in section 3. First, (6.1) the authors discuss how the exogenous and endogenous factors that affect the development of AV increase the relevance to apply HRO strategies in this setting. After that, the two sub-research questions are answered by analyzing and discussing the empirics in light of the theoretical framework (6.2 and 6.3).

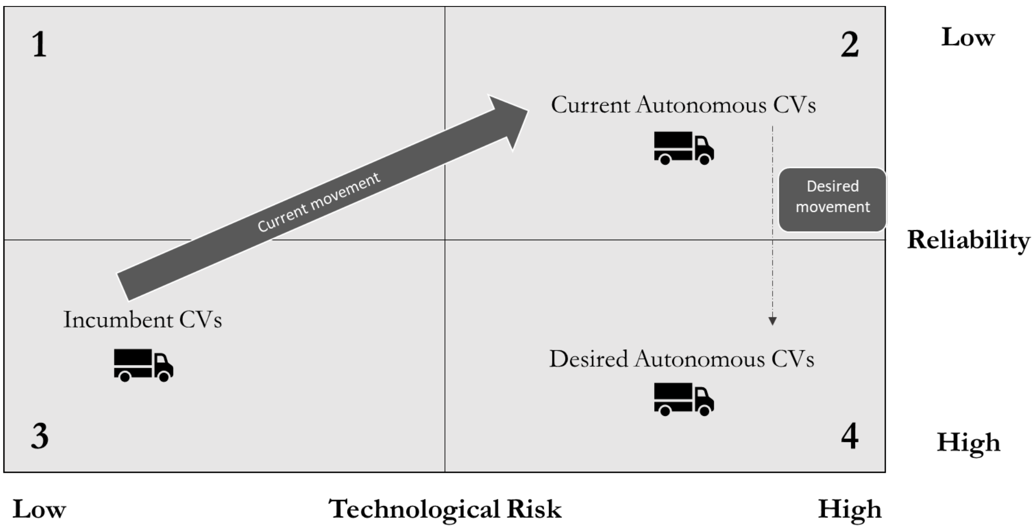
6.1 Incumbent CV manufacturers entering a new field

In this part, the authors analyze the emergent environment the case company's AV department is entering and draw parallels between developing AV and the field of HROs.

6.1.1 Technological risk as a source of challenges

After decades of stability, truck manufacturers are now faced with a technology-driven *paradigm shift* and the organizational challenges deriving from it (Yin et al., 2016). To understand the challenges that have arisen, the technological risk and reliability taxonomy developed by Roberts (1990) introduced in section 3.1.2 is used to visualize the shift when moving from the development of traditional to autonomous CV.

Figure 2 expanded: Technological risk and reliability



The empirical findings support the view that the substitution of the driver with a robotic system increases the technological risk because of higher *complexity* and *tight coupling* (5.2.2). Moreover, reliability today is arguably rather low because of the immature stage of the technological development (Mutschler, 2017; Litman, 2018). The combination of high technological risk and low reliability currently positions manufacturers of autonomous CVs in cell 2 of the matrix, that according to Roberts (1990) means that an organization is in *major trouble*.

With this movement, the challenge for CV manufacturers is now to develop a highly reliable socio-technical system based on technologies that were never core capabilities and simultaneously guarantee higher safety and reliability than the traditional technology in order to be publicly accepted (Fraedrich and Lenz, 2016). In this manner, reliability-enhancing strategies of HROs could help guide incumbent CV manufacturers to solve the organizational problems presented in the empirics.

6.1.2 Public scrutiny and competition affecting the development of AV

A new technological system embedded with higher risks and the radical change stemming from its development are not the only factors that complicate the development of an AV. This nascent industry has been surrounded by public scrutiny and many interviewees shared their concern regarding the possibility that accidents at this early stage might slow down or even compromise the deployment of AV (5.2.1). This turbulent environment has resemblance with the description by Weick (1999) of the *unforgiving social and political environment* that surrounds HROs thereby displaying yet another parallel between AV development and HROs. At the same time, the interviewees stressed a sense of urgency because of the competition, and a fear of becoming the new Kodiak or Nokia (5.2.1). This element poses as an interesting opportunity to address one of the weaknesses of HRO, namely that organizations within its scope usually were not faced by the conflicting goals of safety with that of competition and market pressure (Leveson et al., 2009).

6.1.3 Concluding Remarks

Despite Waller and Roberts' (2003) argument that any organization can benefit from core HRO processes, the authors argue that this is particularly true for the development of AV. As displayed above, the nature of AV and its immature state entail higher technological risk and low reliability resulting in the movement to a troubling situation for CV manufacturers. This phenomenon ought to be further investigated on the basis that *reliability-enhancing* practices distilled from HROs can help AV manufacturers achieve the goal of developing safe and reliable systems.

6.2 What role do reliability-enhancing strategies play in the development of autonomous trucks and busses for an incumbent manufacturer?

The parallel drawn between AV and HROs paves the way to analyze the changes occurring at autonomous department in the light of the principles of HRO. In this section, the authors will answer the first sub-question by applying the theoretical framework to analyze what *reliability-enhancing* strategies are emerging in response to the development of AV. Each strategy will then be discussed in connection to the organizational challenges introduced in the empirics.

6.2.1 Structural reliability-enhancing strategies

Through the case the authors have identified structural *reliability-enhancing strategies* that are emerging as a way to mitigate the risks embedded in the development of AV. The emergence of *redundancies* and *formal rules and procedures* at the autonomous department is hereby presented and discussed.

6.2.1.1 Analyzing redundancies in the development of AV

The empirical findings have highlighted how *redundancies* are a debated but apparent strategy (5.4.1.2). Both *technical* and *people redundancies* as described by Roberts (1990) found confirmation from the empirics as possible strategies to mitigate the risks of both human and technical errors.

Technical redundancies have been criticized by some scholars who claim that they add complexity to the overall system, encourage risk-taking and are inefficient when design-errors are anticipated (Levenson et al., 2009). This criticism has found ground in the empirical findings where some experts pointed out how duplicating a sensor or a camera might be of no value in the presence of a perturbation that affects both the primary and back up sub-system (5.4.1.2).

Lastly, a third type of redundancy emerged, which supports the systemic approach to safety by Levenson et al. (2009) and goes beyond the idea of *technical redundancy*. The authors will refer to it as *systemic redundancy*. An example of systemic redundancy is the use of different layers of the whole system to cover the possible deficiencies of the single subsystem such as the onboard or offboard system. In the case of the AV, a systems approach to safety seems to be most effective given the interconnectedness of the subsystems and the immature state of the single technologies.

6.2.1.2 Discussing how redundancies relate to current organizational challenges

Differently from traditional HROs, safety and reliability are just one of the main conflicting goals for an autonomous CV manufacturer to the long-term success of the organization. The so-called *race to self-driving vehicles* is eliciting a strong sense of urgency that appears to be clashing with the goal of safe development. In this challenging environment, *redundancies* appear to be a *reliability-enhancing* strategy that is supporting the case company in achieving acceptable safety performances while maintaining a fast pace of the development. Especially the use of *systemic redundancies* allows the engineers to mitigate the risk of deploying immature technologies and allows for a quicker roll out of the AV.

6.2.1.3 Analyzing formal rules, procedures and standards in the development of AV

The development of AV is inducing engineers and managers to question the validity of old safety standards and procedures. As exhibited in the empirics (5.4.1.1), the members of the organization agree on the importance to develop new safety standards, procedures and testing to cope with the regulatory gap. Across the whole automotive industry there are concerns regarding the lack of consensus about the minimum safety levels and the ways to prove safety (Karla, 2017). Despite the case company itself putting effort in adapting the old processes to the new technology, more effort and collaboration seem needed at an industry level between different manufacturers and regulators to develop effective safety standards. The lack of cohesiveness and homogeneity in safety standards seems to be a potential source of risk in the development of AV. The idea of Roberts (1989, 1993) that *formal rules and procedures* are key reliability-enhancing strategies finds corroboration in this case and calls for more effort and resources across the industry to create appropriate standards and procedures that address the issues embedded in the development of AV.

6.2.1.4 Discussing how formal rules, procedures and standards relate to current organizational challenges

The analysis above has confirmed that *formal rules* and *procedures* are indeed deployed in the development of AV. But the empirics have also revealed another side of this *reliability-enhancing* strategy. The standards and procedures that are emerging as a way to validate and maintain the safety of an AV clashes at times with the agile way of working (5.3.2). On the one side, the choice of agile development comes quite natural because of the software-heavy nature of an AV[4]. But agile calls for rapid production cycles and trail-and-error, whereas the formal industry-wide practices require long testing periods of AV (5.3.2) more in line with the traditional waterfall approach[5] at the case company. Some of the experts interviewed have shared their belief that functional safety and agile development can coexist but that the matter is complicated. It is interesting to highlight that the suitability of agile methods with the development of safety-critical systems is not a problem specific for this case, and research is emerging to understand how organizations can leverage the benefits of agile methods in this new field (e.g. Boehm, 2002; Vuori, 2011; Wolff, 2012).

6.2.2 Social reliability-enhancing strategies and the development of AV

In this section, the authors will analyze how relevant cognitive processes are in the development of AV for the incumbent firm and how cognitive infrastructures appear to be vital to create *reliability-enhancing* strategies.

6.2.2.1 Analyzing perception of risk and preoccupation with failure in the development of AV

In the empirical findings interviewees referred to the extreme possibility of human loss in accidents involving an AV and explained how the autonomous department is developing its systems and practices keeping safety as highest priority (5.4.2.1). The *perception of risk* (Libuser, 1994) and the consequent *preoccupation with failure* (Weick, 1999) that characterizes HROs seem mirrored in the mental state of the individuals interviewed and in the enacted processes (5.4.2.1).

The attention to deviations and the scrupulous analysis of failures and near-misses was highlighted to be a characteristic historically present in the company and now successfully transmitted to the R&D department. This type of mentality is revealing to be important in an environment that concedes limited trial and error because of strict regulations and custom-built hard-to-replace hardware. The analysis of disfunctions and near-misses becomes for the case company – as much as for the HROs presented by Weick (1999) – a fundamental opportunity to learn and improve in an environment where learning opportunities are limited.

6.2.2.2 Discussing how perception of risk and preoccupation with failure relate to current organizational challenges

The chronic worry that persists among members of the autonomous units is an important aspect to achieve the state of mindfulness which is a key strength of HROs (Weick, 1999). There is no doubt that the *perception of risk* and *preoccupation with failure* are indeed necessary when developing and operating a system that cause

[4] SAFe was built for the software industry according to interviews

[5] A waterfall approach in engineering is a strategy where the production is done in a linear and sequential step-by-step process.

great damage if mishandled. Nevertheless, that alertness should never transform into anxiety for the members potentially leading to reluctance of assuming responsibility of technical decisions. From the empirics it has emerged that the state of uncertainty and continuous change experienced in the autonomous department has led to a situation where engineers sometimes do not feel comfortable to assume the responsibility for important technical decisions that come with the deployment of an agile organization (5.3.2). In this way, there is the risk that *the perception of risk* and *preoccupation with failure* transform into an overwhelming sense of worry and become a hindrance to the process of *migrating distributed decision making* (5.5.2) (Roberts, 1993) .

6.2.2.3 Analyzing organizational culture in the development of AV

The knowledge about the system seem to reside at a collective level since the granularity of the technological and system complexity is close to incomprehensible. In this setting, the development of a *collective mind* (Weick and Roberts, 1993) as a tool to enable mindful coordination and collaboration becomes a requisite for the successful development of AV. The empirical findings (5.4.2.2) have also highlighted that safety should be built at the cultural level of the organization. The conceptualization from Weick (1987) of organizational culture as a source of high reliability is supported in this context since it can act as a catalysator for members to assume new roles and be comfortable to act in an organization filled with professional and cultural diversity. It follows that the development of a cohesive organizational culture transpires as an urgent stepping-stone that the department needs embrace in its "autonomous journey".

6.2.2.4 Discussing how organizational culture relate to current organizational challenges

The empirical findings (5.4.2.2) display that with the complexity and newness of the system, higher levels of collaboration and coordination between different teams are needed. According to Weick (1987) and Beierly and Spender (1995) members of HROs are often characterized by similar professional backgrounds and experiences that allow to share similar values around safety. This is however not the case at the moment where one of the organizational challenges is that of hardware and software engineers' perception of safety. This could be a source of unreliability as coordination becomes challenging and time consuming. In light of this situation, the creation of a new shared organizational culture that glorifies the different views and competencies seems to be an imperative for the case company.

The new role that managers and engineers are assuming with the deployment of an agile organization has also materialized challenges and anxiety between the roles. This is harmonious with the explanation that the creation of a system where centralization and decentralization are simultaneously present is hard to design (Weick, 1987). The development of a strong organizational culture emerges then as a possible solution to this organizational challenge as well. Organizational culture can potentially be used as a substitute for 1) the centralization that previously was obtained through the "line structure", 2) facilitate the delegation of decisions to the agile team and 3) keep together the new decentralized decision-structure on a technical level.

6.2.3 Concluding Remarks

In this section, the authors responded to the question of what reliability-enhancing strategies are emerging to develop autonomous transport systems. The *reliability-enhancing* strategies presented in the section have been first analyzed in relation to its perceived relevancy in this context and then discussed in connection to the organizational challenges that surfaced from the empirical study. A relevant finding is that *structural* strategies in the shape of *redundancies* and *formal rules and procedures* play an important role in the development of AV. Nevertheless, structures alone seem not enough to ensure the reliability of a complex socio-technical system and the development of *social strategies* seem a necessary complementarity. Despite all the strategies discussed not being fully developed, all of them appeared to some extent relevant in the field as the members of the department underlined their importance. In the next section, the second sub-question is handled.

6.3 How does the role of the manager change at an incumbent manufacturer of truck and busses to enable reliability-enhancing strategies?

The development of AV is eliciting organizational responses that mirror some of the *reliability-enhancing strategies* commonly found among HROs. These *reliability-enhancing strategies* are not implemented in a vacuum and affect the way members are working. In this section the authors analyze and discuss the management processes that emerge in response to the development of AV. By doing so the second sub-question is studied. In the second part of the section, the authors will explore the type of leadership these management processes require and ground the conceptual linkage between servant leadership and HROs in the empirics.

6.3.1 Management Processes in the development of AV

The development of AV is causing a high degree of change to the responsibilities that managers and engineers assume. On the one side, managers become more estranged from the technical decisions and are supposed to put their attention to strategic and organizational issues. At the same time, the team of engineers receive more power over the technical decisions, consequently leading to a greater degree of responsibility. Compared to the traditional "line organization" where managers were mostly technical leaders, the new organization fosters a manager that is still technically knowledgeable but that acts as a facilitator for the technical teams and intervenes only when necessary. This new way of organizing mirrors the management processes of *migrating distributed decision making* and *management by exception* that Roberts (1993) presented as a key to develop *reliability-enhancing strategies* that HROs use to engage in error-free operations.

It is important to highlight that from the empirical findings (5.5.2) the management process of *develop the "big picture"* was barely mentioned as a key aspect for managers and engineers in the organization despite the higher complexity, its intrinsic systemic nature and its presumed relevance for the company´s long term success. Because of the nature of the system, with increasing amounts of cross-functional work and the overlap of competences between engineers, the development of the big picture for managers of the organizations appears as an important step to their growth.

6.3.2 Discussing the relation between management processes and organizational challenges

The migration of decisions to the bottom of the organization has a double effect in this empirical setting since it helps to enable both speed and safety in the development. As previously discussed, the complexity of the systems and their continuous transformation makes it hard for the managers to take care of both technical and organizational decisions. In-depth knowledge of the technological systems is now rooted in the engineers and the delegation of technical decisions becomes fundamental to make sure that the systems developed are robust and safe. Moreover, the distribution of decision-making and the *management by exception* help the organization to keep a flexible decision structure and allow for a quicker development of the technology. In this manner, the teams of engineers have the authority to make technical decisions without formally passing through the hierarchy reducing overall lead times.

All the above-mentioned *management processes* are corroborated by the principles of SAFe that the organization is implementing. This theoretical connection between agile methodologies and HRO management processes will be further discussed in section 7.2.

6.3.3 Servant leadership at the Autonomous department

The empirics revealed the importance to deploy the appropriate management strategies to foster the development of AV and enable the agile transformation. The management processes of *migrating distributed decision making, management by exception* and *develop the "big picture"* require managers to assume a role that is very different from that of traditional R&D managers. From the empirical findings (5.5.3), it emerged that the new role of the managers entails the adoption of a new leadership style. In this manner, the ideal leader is described as a coach and facilitator that empowers its team, supports the development of each individual and granting them greater responsibility. The leader described appeared to be able to bring forward the engineers and empower his/her team while almost downplaying their own importance. These described behaviors were labelled mainly under the notion of the *servant leader*.

Servant leadership is in fact the new philosophical standpoint that has been promoted from the top of the organization and has come in response to the implementation of an agile organization (5.3.2). While not grounded among management scholars, the relationship between agile organizations and servant leadership has become a common topic among practitioners (e.g. Philip, 2019; Aghina et al., 2018). The relevance of servant leader behaviors such as *empowering, putting followers first, conceptualizing* and *help followers grow and succeed* presented by Northouse (2015) surfaces in this case. Specifically, *empowering and putting the followers first* emerge as part of the decentralized decision-making (5.5.2), *conceptualizing* emerges as the need for the leader to develop the big picture (5.5.3) and *help follower grow and succeed* plays an important role to foster the increased responsibility for the engineers (5.5.3).

6.3.4 Concluding Remarks

In this section the authors analyzed how the role of the manager changes due to the development of autonomous systems at CV manufacturers. First, the authors analyzed the management processes that are being implemented in the organization under study and discussed how these processes relate to the current organizational challenges. *Migrating distributed decision making* and *management by exception* as HRO management processes emerge as relevant in this context. The emergence of these processes as the result of the implementation of agile frameworks contributes to drawing a parallel between agile methodologies and HRO practices. Second, the authors analyze how the changes in the role of management has led to the rise of a new leadership philosophy (i.e. servant leadership) and discussed how HRO management processes identified in the organization build on some of the behaviors characterizing a servant leader.

7 Theoretical Extension

In this section, the authors extend the concepts of HRT by reasoning on the interdependence among the various *reliability-enhancing strategies* introduced in the theoretical framework and by assessing the theoretical connection between HRT and servant leadership.

7.1 Extension on reliability-enhancing strategies and management processes

The majority of empirical studies on HROs tend to offer in-depth descriptions of the strategies in place but miss to critically explain how these various strategies are interlinked (Lekka, 2011). Nevertheless, in this empirical study interesting connections among the different strategies emerged and the authors will hereby present these as a theoretical extension.

A common pattern that surfaced throughout the study was how different *reliability-enhancing strategies* can reinforce each other and allow for high reliability organizing when applied together. Specifically, the deployment of the *structural strategies* reveals itself as an important factor to reduce uncertainty in the organization and instill trust among its members. This element appeared critical for members to positively leverage the *social strategies* of *perception of risk* and the *preoccupation with failure* instead of being overwhelmed by them. In an environment where the cost of a mistake is high, the use of structures and institutions to enforce trust and create a protective environment becomes necessary so that the *preoccupation with failure* and the *perception of risk* needed in an HRO setting does not transform into fear of action and paralysis.

Moreover, the management processes of *migrating distributed decision making, management by exception* and *develop the bubble* are presented by Roberts (1993) as requirements for organizations to develop both *social* and *structural strategies*. This conceptualization had a key role to link the first and second research sub-question as it connects the role of managers in the organization to the role of *reliability-enhancing* strategies. But, in this empirical setting it emerges that the aforementioned management processes find some barriers to their applications when there is a lack of a cohesive organizational culture. Building on this case, it appears as if the management processes of *migrating distributed decision making* and *management by exception* and the development of a *reliability-enhancing organizational culture* mutually reinforce each other and should therefore be considered simultaneously when organizing for high reliability.

7.2 Agile principles and HRO

The current transformation of the roles for managers and engineers is an outcome of the agile (SAFe), methodologies and frameworks that are being implemented. A deeper analysis of these principles reveals an interesting parallel with the HRO management processes developed by Roberts (1993). According to the official SAFe methodology the adoption of scaled agile development entails decentralization of decision that are frequent and centralization of decisions that are strategic. The resemblance of this agile principle with the concepts of *migrating distributed decision making* and *management by exception* is striking and opens up opportunities to investigate this connection further.

The linkage drawn in this sub-section also serves the purpose to strengthen the connection between servant leadership and HRT. Servant leadership has received particular attention by practitioners in the field of agile management and the servant leader has been presented as a prerequisite for the implementation of agile principles (e.g. Montgomery, 2014). It follows that an organization that supports *management processes* (6.3.1) – which align almost perfectly with agile principles – might benefit from the figure of a servant leader.

7.3 Servant leadership and HRT – a theoretical discussion

Many of the strategies identified as *reliability-enhancing* by HRO scholars involve the work of managers and leaders (Lekka, 2011). Nevertheless, the HRO literature lacks a common conceptualization regarding the type of leadership that is required in these complex organizations (Martinez-Coroles, 2018). *Migrating decision making, management by exception* and *developing the big picture* require managers to willingly let others take decisions that previously were within their domain, making the followers to assume a heavier load of responsibility and accountability (van Stralen et al., 2018).

When comparing a servant leader´s behaviors outlined by Northouse (2015) with the management characteristics gathered by HRO theorists, more than one commonality is found. The behavior of *conceptualizing* aligns with the management strategy of *development of the big picture* (Roberts, 1993). This seems in broader terms as an important behavior for leaders that need to create a cohesive organizational culture which indeed was deemed as source of reliability by Weick (1987). HRO theorists have not outlined explicitly how HROs develop a structure where managers lead by exception and decision-making is migrated to the best equipped expert in the organization (Madsen et al., 2006). The empirics have shown that prioritizing the development and empowerment of the followers (i.e. *putting followers first, empowering* and *helping followers grow and succeed*) are crucial stepping-stones for the engineers to embrace the higher authority and responsibility requested by the proposed organizational setting. Moreover, the development and maintenance of *high-risk systems* whose mishandling may cause harm to humans call for management actions that follow strong ethical principles (Guy, 1990). This type of behavior is indeed well represented in the figure of a servant leader since *behaving ethically* is one of the cornerstones of servant leadership (Northouse, 2015).

HRT and servant leadership present some commonalities, but it is important to mention that between the two theories a perfect match is yet to be found. Servant leaders' behaviors such as *creating value for the community* and *emotional healing* (Northouse, 2015) do not find any specific correspondence among relevant aspects for the role of leaders in HROs. Moreover, the prioritization of organizational goals over those of both leaders and followers is often found as an important aspect for HROs and for this reason some authors have connected HRT to transformational leadership (e.g. van Stralen et al., 2018). In the empirical setting of this research, servant leadership was justified by the increased focus on enabling followers (engineers) and the centrality that the agile teams played for the organization, but this might not hold for other HROs.

However, debating the intricacies of to what degree servant leadership and HRO is connected, is a redundant exercise left to the wrestlers in the ivory tower. The purpose of the connection is perhaps not to be bulletproof but rather of inspiring character. Eventually enabling the engineers to excel and in doing so maximize their performance, which is what organizing, and leadership ultimately set out to do.

8. Conclusion

This research sets out to understand how an incumbent truck manufacturer organizes internally to develop safe AV. This broad research purpose entailed three overarching and interrelated conclusions.

First, it was showcased how the company was moving into a high-risk technological environment as a result of 1) increased complexity, 2) a higher degree of tightly coupled systems and 3) increased public scrutiny on the development of the technology and its safety.

Second, the need to cope with complexity and tight coupling has shown the applicability of HRO strategies and processes in the development of commercial AV. The case company was applying or expressed the intent to implement two sets of *reliability-enhancing* strategies. These were: 1) *structural strategies* in the shape of *standard rules and procedures* as well as *redundancies* and 2) *social strategies* as *perception of risk* followed by *preoccupation with failure* as well as the deployment of the *organizational culture* as a source of reliability. Interestingly to the authors, these strategies seemed to be rather interconnected and mutually reinforcing. It was also noted that while all the strategies were deemed as relevant in the organization, social strategies were perceived as the building block to enable the full realization of structures and processes.

Third, the changing role of the manager in the organization was found to be aligned with the *management processes* described in the HRT as required by the development of structural and social strategies. The emergence of these management processes was found to go hand-in-hand with the rise of a new idealized leader in line with the philosophy of servant leadership. The notion of leadership surfaced in the empirics which has been downplayed by previous HRO literature. By drawing a link between servant leadership and HRO processes in the setting of commercial AV, the research concluded that many of the attributes found in a servant leader were expected to navigate and lead the incumbent firm into unknown territory.

8.1 Theoretical contribution

The research contributed to the literature of HRT and to a general stream of literature for autonomous vehicles.

The theoretical contribution in HRT was made in two ways. First, scholars called for the need to build new theoretical and empirical knowledge to broaden the scope of the field. Studying the role of HRT strategies in the field of commercial AV has paved the way for the applicability of HRT in a new setting. Second, in the HRT literature, scarce attention is given to leadership. Grounded in the empirics and strengthened by theory, some of the key behaviors of the servant leader appeared to be complementary to the type of role that a leader in HRO should assume. Linking servant leadership theory to HRT has to the knowledge of the authors not been made before.

Lastly, as explained in the introduction, previous studies within the development of AV have overlooked the internal organizational challenges and changes faced by the manufacturers.

8.2 Managerial implications

The role of the manager plays a central role in this research. In addition to the necessity for managers to adopt the behaviors of a servant leader, three additional managerial implications are forwarded.

First, managers in this empirical setting should prioritize organizational and strategic issues and delegate technical decisions to the engineers. With an increase in complexity and tight coupling managers cannot keep their position as the technology bellwether and have to put emphasis on enabling the engineer to develop fast and safe AV.

Second, following the fast injection of newcomers with diverse professional and educational backgrounds, the manager ought to put efforts into establishing a strong group identity through the development of a cohesive organizational culture. In doing so, safety can be instilled as a ritual in the organization and the diversity of the group can be transformed from a weakness into a strength.

Third, managers should proactively turn their attention to the principles of high reliability organizing and look into how to foster the implementation of principles that currently are only discussed within the organization.

8.3 Limitations

The authors have identified three limitations that impede some of the findings in this research. First, the data on the media and public opinion refers to autonomous vehicles on public roads. The data gathered in this case is collected from AV development on industrial sites, which could be a limitation. But since the public perception is viewed through the eyes of the participants they still bear some holding since it affects this development, rendering this limitation rather ambiguous. Second, regulators play a large role in the development of AV. Rules are in the making and there is a large body of regulatory risk that in this research is not covered because of the uncertainty and speculative character of it. Third, systematic combining and quality precautions were applied to increase the transferability of the data. However, because of the nature of the single-case study and the narrow – yet rich – context, more research is needed to transfer the research to a broader audience.

8.4 Future research

During the process, several future research streams surfaced. Here the four most notable are covered.

First, in the wake of the call by Thomas G. Dietterich (2018) to explore the implications of HRT in the development and application of AI technologies, more studies are needed to understand to what extent HRT principles presented in this study are applicable to other types of autonomous systems, e.g., for passenger cars, drones, trains, ships etc.

Second, a first interlinkage between servant leadership theory and HRT was drawn. The study has given evidence for the synergies between the two theories but to what extent this is verifiable was outside the scope of this paper and constitute an opportunity for future research.

Third, this paper has uncovered a potential linkage between agile management and HRT principles, but its further exploration was outside the scope of the research. This connection seems worth further research, especially since agile methodologies are spreading among practitioners to develop AI-based systems.

Lastly, this paper only focused on how to internally organize for safety and reliability. Therefore, there is an opportunity to look at internal organization through other lenses e.g., technological performance, stakeholder management etc.

In conclusion, the authors hope that this paper can help sprout future researchers to deepen the knowledge further in this field.

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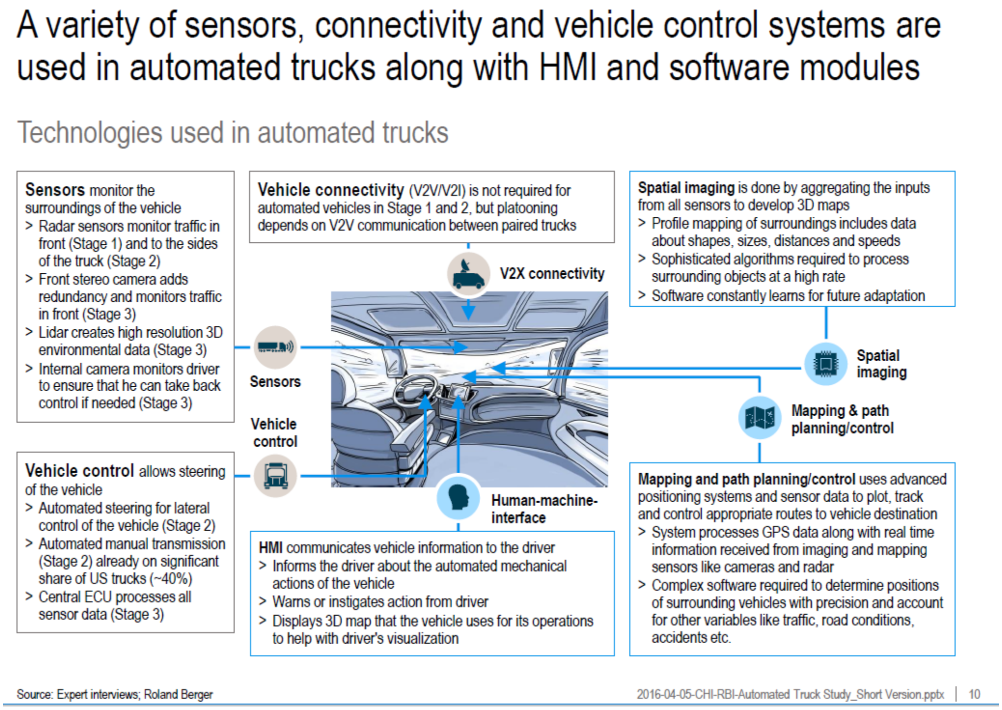
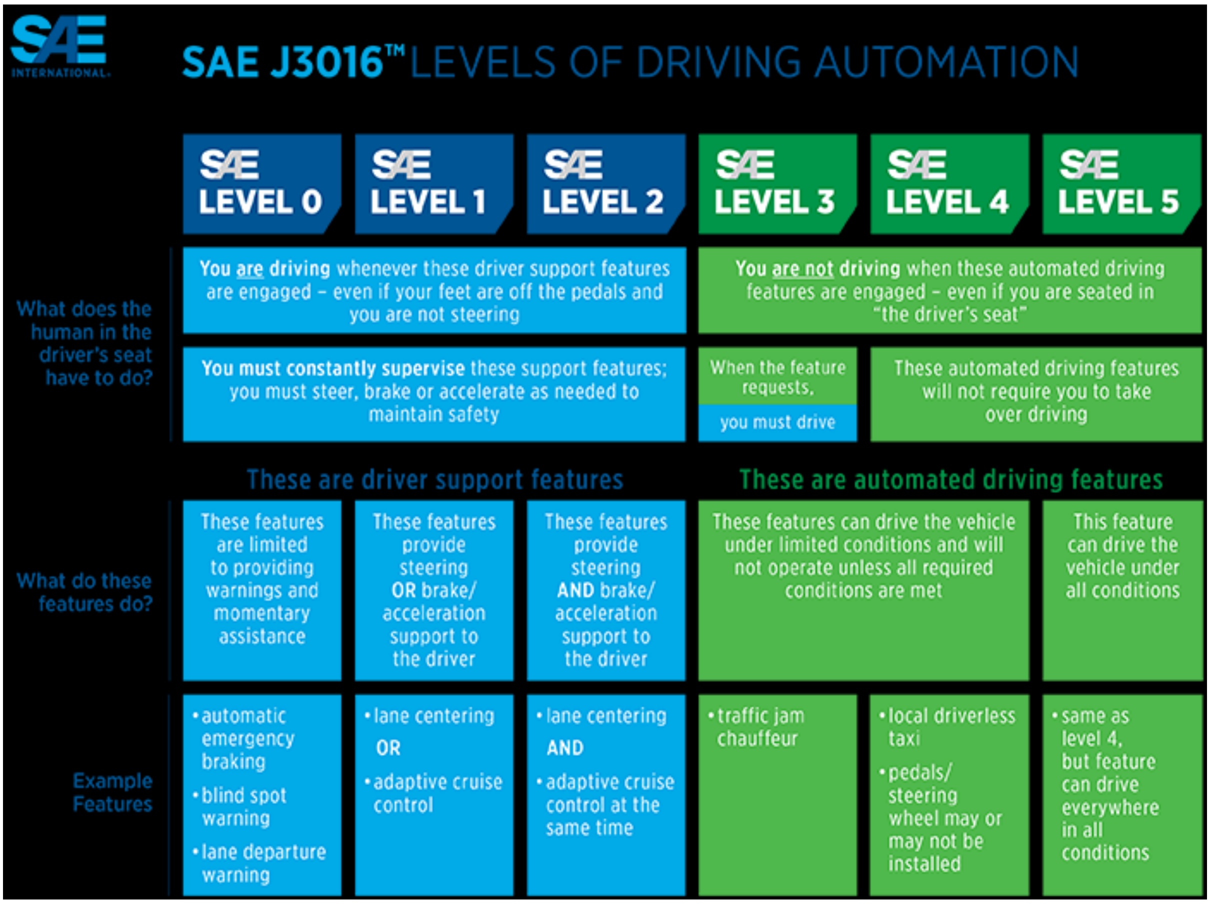
Appendix

Appendix 1: Explanation of technology in an autonomous vehicle



Appendix 2: SAE-levels

(Borrowed from the SAE official webpage: https://www.sae.org/news/2019/01/sae-updates-j3016-automated-driving-graphic. Extracted 2019-05-12



Appendix 3: Interviews overview (anonymized)

Pre-study Interviews

Interviewee	Duration	Date	Type
Engineer 1	60 minutes	13/3/2019	In person
Engineer 1	90 minutes	13/3/2019	In person
Manager 1	60 minutes	13/3/2019	In person
Engineer 2	60 minutes	2/4/2019	In person
Engineer 3	65 minutes	3/4/3019	In person

Main study interviews

Interviewee	Duration	Date	Type
Engineer 4	75 minutes	5/4/2019	In person
Engineer 5	55 minutes	8/4/2019	In person
Manager 2	60 minutes	8/4/2019	In person
Manager 3	60 minutes	10/4/2019	In person
Manager 4	50 minutes	10/4/2019	In person
Engineer 6	60 minutes	12/4/2019	In person
Manager 5	60 minutes	12/4/2019	In person
Engineer 7	45 minutes	12/4/2019	In person
Engineer 8	65 minutes	15/4/2019	In person
Manager 6	60 minutes	16/4/2019	Skype
Manager 7	60 minutes	18/4/2019	In person
Engineer 9	60 minutes	18/4/2019	In person
Engineer 2	25 minutes	8/4/2019	Follow-up via telephone
Engineer 8	30 minutes	24/4/2019	Follow-up via telephone

Appendix 4: Examples of quotes

<table>
<tr><th colspan="2">Complicating factors section 5.2</th></tr>
<tr><td colspan="2">Exogenous factors</td></tr>
<tr><td>Media</td><td>“When it comes to safety, autonomous vehicles are in some sense more dangerous or at least public opinion regards them as more dangerous and that you can do dangerous stuff with these controllers. There is much more focus. And you also have media focus on the safety issues”. - Engineer 9

“I think we are in the middle of the media and therefore it becomes much bigger. Of course, we have some challenges and we have to create the architecture for this system to work. It is much simpler to bring a truck from A to B than making sure that nobody gets hurt in that environment. That requires a lot of work. It creates 10 times more work to do it safe”. - Engineer 9</td></tr>
<tr><td>Competition</td><td>“This is all about in the software industry. Who comes first and maybe second but there is no space for number 5. It is speed and that is the main challenge”. - Engineer 1

“We don't want to end up like Kodak or Nokia, so we have to work in a fast pace and stay close to what is going on in the industry" - Engineer 6</td></tr>
<tr><td colspan="2">Endogenous factors section</td></tr>
<tr><td>Complexity</td><td>“Their finding was that self-driving vehicles is several orders of magnitude harder than space flight - quiroga
When you build a vehicle and on top of that you build automation system, then you are locked to a time frame. It could be that in n months we introduce another hardware that could be better for steering, for braking. Then at the same time we can improve the software in it but if you improve the software in a brake system then you might change the interfaces to some other systems then you need to do the same change on the other side. This creates a complexity and at the same time it might not be feasible to change the sensors every month because there are new sensors” - Engineer 4

“I would say that the truck itself is a very complex creation. There is extremely high amount of various systems on the truck today. Everything from brake systems to radio communication to instrumentation. There is a lot. I would say in main areas we define 28 main areas for the truck’s domains. It is a huge challenge to have a highly complex software behaving in a safe and predictable way that has to guarantee safety”. - Engineer 6

“I would say that the technological risk has increased. Whenever you increase the complexity of the system it gets prone to make mistakes. However, consider how a truck is now, would you consider a truck to day safer than a truck in the 1920s?” - Manager 2

“If you build a system you need to deploy updates all the time. It is much more complex, and it is much harder for us to test and say we have tested all the combinations and now it works. With the complexity it is impossible to say that” - Engineer 9

“Even though the complexity is a factor 10 or a factor 100 more complicated than before. At the same time decreasing the led time. It is really hard to find an answer to this”. Manager 4</td></tr>
<tr><td>Tight couplings</td><td>“A lot of this boils down to interfaces. How can you actually create clean interfaces between components so that you don't have too much dependencies. Because dependencies are what slows you down. The less dependencies you have, the faster you can act, and you have extremely lot of dependencies than in the physical truck and software you have less to start with and software it is easy to refactor”. - Engineer 5

“How can I make sure that the sensor is not tilted? In that case the whole world will be tilted. That can have huge life-threatening consequences”. - Engineer 5

“I have always been working with the end of the chain. You get the information about the map that you are driving in, information on the obstacles, information about other moving objects around you and then your positioning on the map etc. Then you reason about that. Then you decide for a trajectory to be executed. So, one of the problems we have at a certain point was that the sensor stopped delivering fresh information. One of the systems got stuck at an obstacle it saw. It thought the obstacle was static and kept repeating the information. What we obtained was something that we didn't see. Not because the planner made a mistake. because the sensors stopped delivering information that we could use properly. So, error-wise the ripple effects are dramatic”. - Manager 3

“We see all the systems in our society tightening up. How do you that in a care when you replace an ECU in the system that the rest of the system... A truck has 20 ECUs. Electronic computer unit. It is fairly easy to fake something in a system. Now all the data you have in each subsystem needs to be verified somehow. I am getting this information from the brakes and I know it is from the brakes. Today it is fairly easy to put something in and fake data”. - Engineer 9</td></tr>
<tr><th colspan="2">Organizational challenges 5.3</th></tr>
<tr><td colspan="2">Challenges related to safety and sense of urgency</td></tr>
<tr><td colspan="2">“We are still trying to find the sweet spot to send something out that is worth and at the same time not risking anything big”. - Manager 3

“Even though the complexity is a factor 10 or a factor 100 more complicated than before. At the same time decreasing the led time. It is really hard to find an answer to this – Engineer 5</td></tr>
</table>

<table>
<tr><td colspan="2">If you could trace safety against the development speed of development, that is a tradeoff always for all companies. You read about the Boeing incident and they were criticized for being a bit too far in one direction in the prioritization and that is the case when an autonomous vehicle kills a person". - Engineer 7

"I am the one that believe that speed can actually improve quality and safety. If you do it together, at least four eyes on everything and you release often, then both can be achieved" - Manager 5</td></tr>
<tr><td colspan="2">Decentralization of decisions</td></tr>
<tr><td colspan="2">"What we try to achieve with some kind of method is to be able to work with a couple of 100 developers or maybe 30-40 development teams to actually try to work together. We want to have teams that can focus but we also need to align stuff of course. If you are a basement company with five developers, then it is easy. Now we are this large, then we have to figure out how to align stuff." - Manager 6

"There is a clear conflict between the worlds of the vehicle and the new software. All the structures and processes are built around producing things in the line. All of a sudden we need to build something totally different and that is a challenge for sure." – Engineer 9

"I would say we have been focusing on technical leaders instead of people leaders." – Engineer 8

"So, you are splitting up, what a first manager did in one person before you split it up to product owners (product side), an architects or senior developer takes the more technical side. And the managers role is transitioning into being more of a coach, trying to develop people to be the best architect or the best developer or the best product owner and this is challenging." –Manager 6

"I think that this is a bit of a challenge because now we are actually breaking out a lot of the technical project decisions from the line structure or hierarchy (where managers traditionally have decision-power) into a new project structure (where developers have more decision- power)." – Manager 6

"We are building PM, solution architects, scrum teams etc. And there is no clear communication between them, so I have no idea on who to go to, to ensure that I can take a decision: Should I go to my manager or the scrum project manager?" – Engineer 7</td></tr>
<tr><td colspan="2">Cultural challenges</td></tr>
<tr><td colspan="2">"I think it is easy to think that continuous improvement is built into the company and that we therefore as a part of the company has it in our DNA. But here at Skutan (office name), a bit physically away from the rest of R&D, we just assume that we are working with continuous improvements, but we have a lot of new people and we are talking about something new so maybe we don't spend enough time taking care of our capabilities." – Manager 5

"Those cloud developers that have a really agile mindset, let them have that. Don't force the hardware people to go all the way there, and vice versa. We must skip the right or wrong thinking. We should accept that we do things differently, and that we can learn from each other. WE can be a bit different in the end and we are a team that trust each other anyways". – Manager 5</td></tr>
<tr><td colspan="2">Reliability-enhancing strategies 5.4</td></tr>
<tr><td colspan="2">Structural strategies</td></tr>
<tr><td>Redundancies</td><td>"It is more sensitive of course (referring to the stability of the system), when we don't have the driver any more. So, that is why a lot of redundancy requirements are put on the systems" – Manager 5

"There is a talk about redundancies and I do not know how much we will manage to implement in the next two years with redundancy systems, but I would really like that, and we will discuss this with the group as fast as we can". - Manager 4

"If you have a strong transmitter disturbing the system and if you have two sensors that are both disturbed by the same environmental influence then component redundancies are useless. Then you need to design the complete system so that it is capable of still doing the task and that is perhaps the hardest thing." –Engineer 7

"So instead of three people writing a piece of the code each, why don't you sit down three people around the computer and then write all parts together. Then you will get that kind of feedback going and you will get to learn from each other all the time." - Manager 5

"Just analyzing a system of this complexity and finding all the problems with 100% and no dependencies so that a single fault does not cause a system failure is quite hard. The more redundancies you add the harder it gets to analyze. With the driver the redundancy is very simple. The driver can just press the break paddle and you would break." – Manager 3</td></tr>
<tr><td>Formal rules & procedures</td><td>"Since we are working with autonomous vehicles, following the traditional standards is not really enough because there are other aspects that you need to take into account" – Engineer 5

"The way IEC61508 addresses certain aspects is much better in order to look at onboard and offboard as part of a complete system" - Engineer 5

"You do the unit test. It means that the software will test itself. Then, you test the interface using a simulation environment and then you run simulations. "Does it respond as it should?" After that, we go to the level of virtual vehicle testing. That means you have a virtual vehicle. It is like a virtual machine. I can virtualize both the hardware and software. The next step, especially on the onboard site is to test using test rigs. At this place, electricity systems of an actual autonomous truck are built on racks. And then you have terminators that are simulating and responding as a vehicle" – Engineer 7

"We have validation, verification and test afterwards to ensure we reached the level we want. We also check so that this product doesn't become downgraded after half a year, so it still is safe. These are also the aspects that come into play and we need to deal with it." – Engineer 5</td></tr>
</table>

	”We have a senior engineer that is taking care of coding guidelines. And this is already a big part of safety. If you are sure of what you are executing or reasonably sure about what you are executing in the end you have a good control that the software is safe.” – Manager 4 “You need to be able to aggregate different aspects from different standards that can help you ensure that the system can be safe at all states. That is why many of the people that test and develop self-driving vehicles at the moment always have a safety driver to ensure you have an operator that can monitor the automation. That brings a risk on its own because you have to make sure that the person can monitor the situation reliably and act upon it. A person is a lot slower to react than a computer”. - Engineer 5
Social strategies	
Perception of risk/preoccupation with failure	“It needs to be safe, so safety cannot be jeopardized but some other aspects can be jeopardized. For example, if we talk about autonomous vehicles and the industrial area it will be extremely important to handle the requirements between the sight where we are driving, the offboard functionality and the onboard functionality.” – Manager 5 “With vehicles there is this view in the world that you can remove the driver and that the vehicle will be smarter and safer than a human person. I don’t think that this is the correct view of having it and I think that this is very complicated to achieve. But this is the naïve approach that everybody sees and thinks about when they talk about self-driving vehicles”. – Engineer 5 “Reliability is even more important when you go autonomous. Every time something happens you have to send people out to the vehicle. For safety reasons we stop when we detect a minor problem, but what if that truck that stops in a bad place and stops traffic. So, it gets really really messy, really really quickly. So, reliability is even more important than before.” – Manager 3
A collective brain	“I realized that SAFe (agile way of working) or less or anything else, it is not important. What is important is to have the same mindset in the culture and understand what we want to achieve together.” – Manager 5 “What is our main goal on a high level? That is not clear within my organization. Probably I have colleagues that do not agree but.... It is not clear to everyone at least.” – Engineer 9 “You must have your own ideas and you really have to use your brain and have this collective brain. The collaborative skill is more about listening, participating, pitching your ideas but also listen to other ideas. Not making up your mind. I think that listening is a really important thing here. Even if you have strong opinions on how you want to do it - you are flexible, and if there is a better option – go for that”. – Manager 5
Management processes 5.5	
Migrating distributed decision-making	“It comes with agile mindset that everyone really wants to think by themselves, that you don’t want an instruction from a manager. They (engineers) should be out there fighting for their beliefs, and visions”. – Manager 5 “The responsibility is much more splitting I would say. A lot more people, have the mandate to say stuff” – Manager 6 “And I have this saying “sometimes magic just happen” You don’t need to know everything. Good things happen that you would have never found out if you wouldn’t have given your employees the space to develop.” – Manager 6
Management by exception	“I try not to get involved but obviously if someone of the group asks me for an advice or he wants just to run an idea with me, I am very happy to go back and talk details and get to the whiteboard.” – Manager 2 “I will not say this on page three what is that? I will go there and ask if they can take full responsibility and ask if that stuff is the best you can do and that you at least believe that. If they say “yes” then I approve it.” - Manager 5
Develop the ”big picture”	“If my component fails, it should behave like this and that everyone knows each other’s prioritizing as well so that we can get the big picture. At this company ywe are so used to be focused as a group on your single component. Maybe you need to know what the group next to you know”. – Engineer 7 “I was completely non-expert on embedded systems, software or anything but I have seen that is not an issue because we have plenty of technical doctors here but very few people who look at the big picture”. – Engineer 8
Servant leadership	
“We have the C3 and C4 (senior engineer titles) who are seniors and experts and the managers should be asking the right questions and support them. They should have a technical aspect as well. But they should have more focus on people and leading through people, instead of only focusing on the technical aspects.” – Engineer 8 “We want to say that we are a servant leadership team. With that we try to encourage our teams to do a lot of this things, so building knowledge, building the people as much as possible within the teams. We are also trying to coach everyone, to be both leaders and followers. The goal for us is to make this kind of things happen within the teams as much as possible.” – Manager 5 Therefore, as a manager I think I need to be more supporting. So, they get this kind of secure feeling even though everything is moving. I must help as a manager to create a more stable work situation than there actually is.” – Manager 7 “That is also a lot of servant leadership, so giving them guidelines, a frame and a context. It should not be a dot but rather a square otherwise it is micro management. Don’t tell them how to do it or when to do it because that is micro management, as long as you achieve the big goals that we have set up, how you do it is completely up to you. We trust you to do it to the best of your capabilities.” – Manager 5	

Appendix 5: Interview Guide Engineers example

1. Tell me about your background: how long you've been with the company and what do you do today?
2. Can you tell me more about a project carried out within AV?
   - Probe for:
     1. What was the project about?
     2. What was your role?
     3. What was your responsibility?
     4. Do you work in other projects and is the above differing in any way?
3. What are the main differences in functionality between the onboard and offboard of AV?
   - Probe for:
     1. What are the main differences in terms of safety?
     2. How tightly coupled/interdependent are the subsystems that make up AV?
4. How complex is an autonomous truck in development today compared to a traditional truck?
   - Probe for:
     1. System complexity
     2. Technical complexity
     3. Team-work complexity
5. What are the main differences concerning safety and reliability comparing AV to traditional trucks?
   - Probe for concrete examples
6. In which way do you secure that the Autonomous truck is safe when starting a pilot?
   - Probe for:
     1. Where is the threshold?
     2. Who is in charge of deciding when a truck is ready for real environment testing?
7. Do you see any controversies given by working with very innovative and fast changing technologies on the one hand and developing a very reliable product on the other?
   - Probe for:
     1. Tension by rules and structure that affects the development of the best available technical solution.
     2. Are trial and Errors doable and are small failures accepted for product improvement?
8. Do you see any barriers to the development of novel and innovative fastmoving technologies on the one hand being a traditional truck manufacturer on the other?
   - Probe for examples about specific cases related to culture and values within firm
9. Has a change taken place in how much engineers are involved in technical decisions of the trucks?
   - Probe for difference in the autonomous unit and a "traditional" one.
10. Do you believe that the media or the competition affects your R&D department's development of AV?
11. Are there any other tensions/conflicts/problems that you would like to bring up in relation to the development of AV?

Appendix 6: Interview guide managers example

1. Tell me about your background: how long you've been with the company and what do you do today?
2. What are your responsibilities at work? Do you feel you have moral obligations beyond your work description?
3. Can you tell me more about a project carried out within AV?
    - Probe for:
        1. What was the project about?
        2. What was your role?
        3. What was your responsibility?
        4. Do you work as a manager differ in any way?
4. Has the view of safety and reliability shifted when working with AV?
    - Probe for:
        1. Are there differences in perspectives when it comes to safety between groups?
5. Do you see any barriers to the development of novel and innovative fastmoving technologies on the one hand being a traditional truck manufacturer on the other?
    - Probe for examples about specific cases related to culture and values within firm
6. Can you walk us through the process of reorganization that has taken place at the R&D department?
    - Probe:
        1. Why is the reorganization taken place?
7. What type of challenges does the current setup of the autonomous unit bring?
    - Probe:
        1. Project organization vs Line organization
        2. Centralization vs decentralization of decision making
        3. Experiencing any growing pains? Especially with the influx of software engineers
8. As a manager, is it more difficult to navigate the sub-system that you are managing?
    - Probe for.
        1. (If yes): In which way do you solve this issue?
9. Has a change taken place in how much managers are involved in technical development of the trucks?
    - Probe for:
        1. (If yes) – How? And is this difference attributed solely to this unit?
        2. (If no) – why? (considering that the end-product is fundamentally different)
10. Do you believe that the media or the competition affects your R&D department's development of AV?
11. Are there any other tensions/conflicts/problems that you would like to bring up in relation to autonomous?

Figures

Figure 1: Research Outline

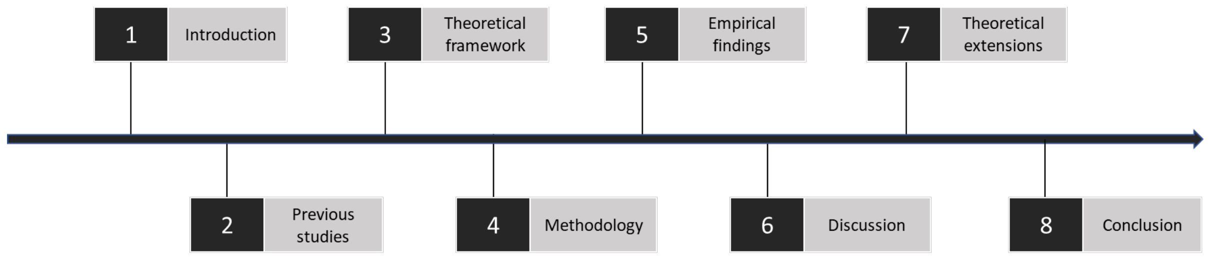


Figure 2 expanded: Technological risk and reliability

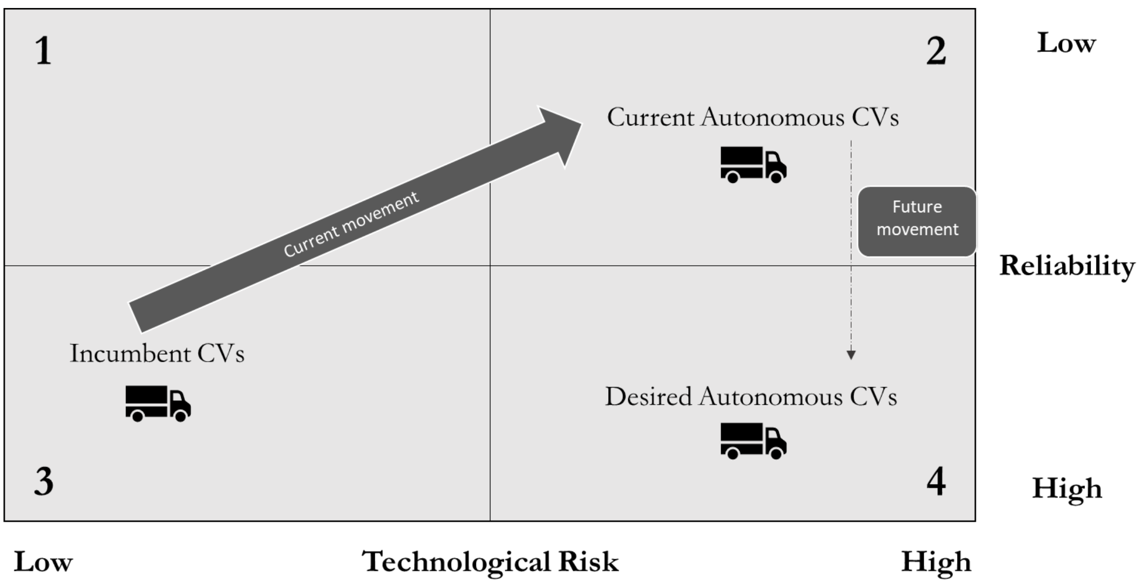


Figure 3: Conceptualized overview of Theoretical Framework

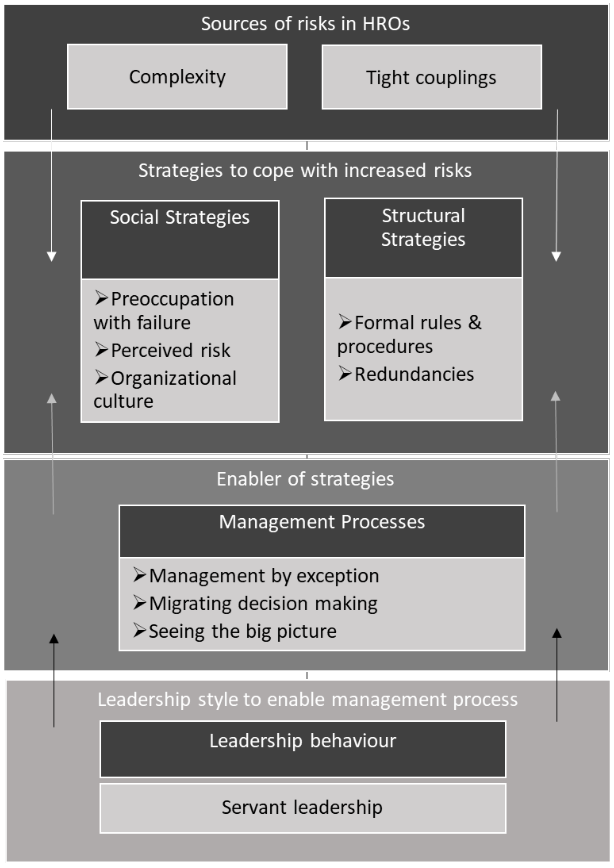


Figure 4: Overview of Interviewees

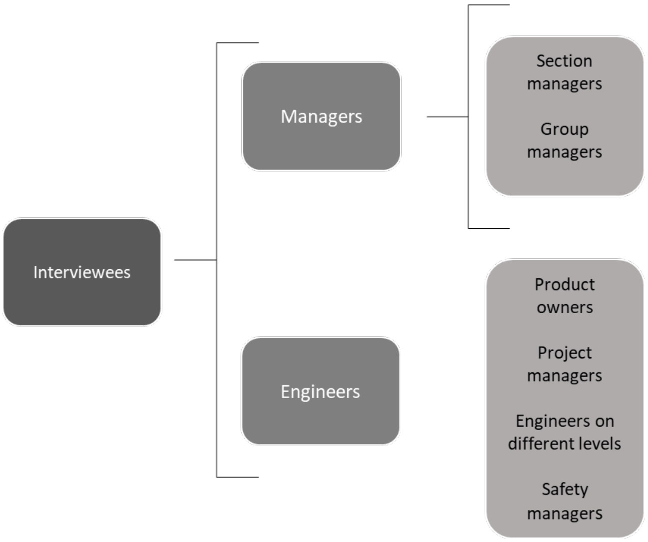


Figure 5: Accumulated structure of data processing and emerging theory through systematic combining

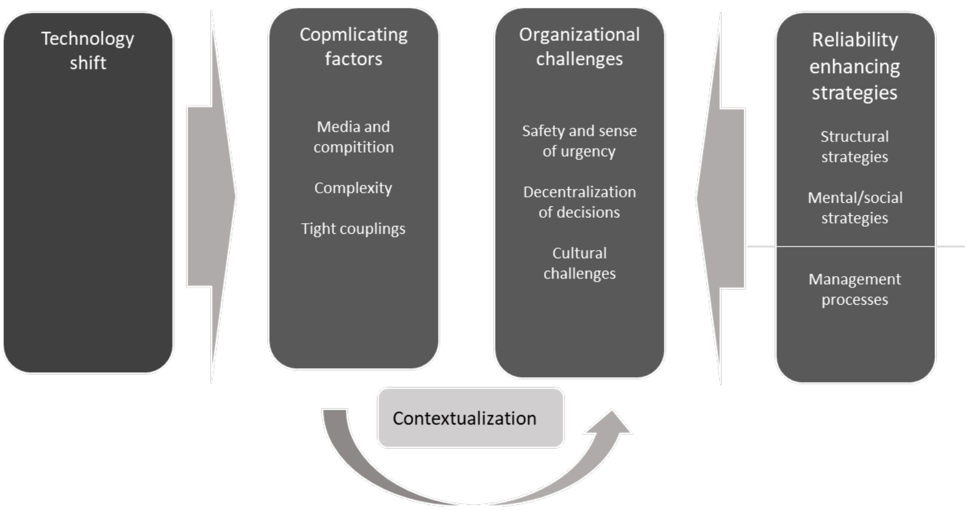
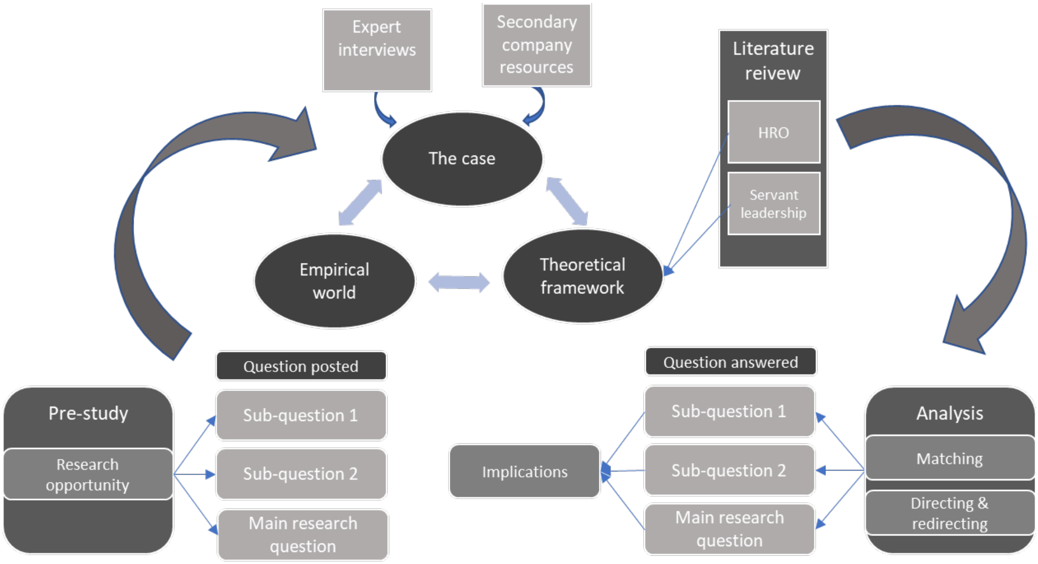


Figure 6: Research process



Tables

Table 1: Processes described in HRT studies

Process Nature	Process Name	Author
Organizational Design	Migrating distributed decision making	Roberts, 1993; Libuser, 1994; LaPorte and Consolini, 1998
	Management by exception	Roberts, 1993; Libuser, 1994
	Develop the "big picture"	Roberts, 1993; Libuser, 1994
	Climate of continuous training	Roberts, 1993; Roberts and Bea, 2001
	Duplication of safety critical information channels	Roberts, 1990, 1993
	In-built redundancies	Roberts and Rousseau, 1989; Roberts, 1990, 1993; LaPorte, 1994
	Formal rules and procedures	Roberts and Rousseau, 1989; Libuser, 1994
	Deference to expertise/Underspecification of structures	Weick et al., 1999; Weick and Sutcliffe, 2007
Cognitive/Social	Perception of risk	Libuser, 1994
	Organizational culture	Weick, 1987; Roberts, 1993; Beierly and Spender, 1995
	Collective mind and heedful interrelating	Weick and Roberts, 1993; Beierly and Spender, 1995
	Preoccupation with failure	Weick et al., 1999; Weick and Sutcliffe, 2007
	Reluctance to simplify	Weick et al., 1999; Weick and Sutcliffe, 2007
	Sensitivity to operations	Weick et al., 1999; Weick and Sutcliffe, 2007
	Commitment to resilience	Weick et al., 1999; Weick and Sutcliffe, 2007