Perceived Software Engineering Challenges Facing the Truck Manufacturing Industry in the 5G Era

Investigating the Need for New Practices

Master's Thesis in Computer Science and Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

[**Context**] A fourth wave of technological advancement known as Industry 4.0 is dawning upon us. Blurring the boundaries between the physical and the virtual worlds, Industry 4.0 will create smart factories that have many beneficial outcomes in terms of productivity, efficiency, flexibility, and profitability. Be that as it may, Industry 4.0 needs 5G to enable all its promises.

The role of Software Engineering is indisputable in Industry 4.0. Given that the manufacturing industry is undergoing a major technological shift with the introduction of 5G, it is necessary to investigate whether manufacturers need to change their current Software Engineering practices in order to successfully adopt Industry 4.0 in the 5G era.

[**Objective**] This study aimed to identify challenges that a truck manufacturer may face during the implementation of a 5G-enabled Industry 4.0 use case given their current practices. It also aimed to examine whether the identified challenges puts the case company in such a position that it needs to introduce new practices in order to take full advantage of the opportunities presented by said use case.

[**Method**] A qualitative exploratory case study was conducted in which interviews constituted data collection. Literature also played a central role: Industry 4.0 challenges that were identified in related work helped determine if the challenges identified in this study were unique enough to require further research and new solutions.

[**Results/Conclusion**] This study found that Industry 4.0 projects in the 5G era will be multi-vendor projects that have strict requirements on system robustness, interoperability, and security. This will reportedly be challenging for the truck manufacturer in question to achieve in view of their current practices and technologies. These challenges do not differ significantly from Industry 4.0 projects unrelated to 5G, meaning that not many of the challenges identified in this study were unique enough to require further research and new solutions. Still, this study compiled Software Engineering guidelines for adopting elements of Industry 4.0 in the 5G era as painlessly as possible.

Keywords: Industry 4.0, 5G, Software Engineering, IoT, AGV, CPS, Cybersecurity, Edge Computing, Case Study.

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Secondly, we would like to extend our gratitude to our industry supervisors at Volvo Group and Ericsson as well as all interviewees (and survey respondents) for their contribution to this study. The completion of this undertaking could not have been possible without them.

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Konstantin Ay & Sofija Zdjelar, Gothenburg, June 2021

"Welcome to the Internet, my friend, how can I help you?"

—HOMER SIMPSON

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Introduction

Technological advances have driven substantial increases in industrial productivity since the First Industrial Revolution. The steam engine helped power factories in the nineteenth century, thus establishing the importance of machines in the modern world. Decades later, electrification of the assembly line led to an era of mass production. Eventually, with the shift from analog toward digital electronics in the 1950s, industry became automated through memory-programmable controls and computers.

Now, a fourth wave of technological advancement known as *Industry 4.0* is dawning upon us, the term being a reminiscence of software versioning. In broad terms, traditional manufacturing is in the midst of a digital transformation that goes beyond simply the automation of production. It will in fact blur the boundaries between the physical and the virtual worlds. Wollschlaeger et al. [1] describe Industry 4.0 as follows:

> "Applying the ideas of [cyber-physical systems] and [Internet of Things] to the industrial automation domain led to the definition of the Industry 4.0 concept, where 4.0 alludes to a fourth industrial revolution enabled by Internet technologies to create smart products, a smart production, and smart services."

From a communications perspective, cyber-physical systems (CPS) and Internet of Things (IoT) rely heavily on telecommunication networks. Within factories and plants, however, current connectivity options cannot meet the demands of many Industry 4.0 use cases – connected and mobile tools, machines, and robots – due to insufficient latency, reliability, and data rates [2, 3]. This makes the introduction of the next generation of cellular technology, 5G, essential to Industry 4.0. The technology will be able to support a huge number of connections while improving latency, reliability, and speed. Burkacky et al. [4] expect that manufacturing will account for over half of all 5G sales for distinctive use cases, that is, use cases that require 5G technology.

1.1 Statement of the Problem

Manufacturers need to find ways to become more flexible and agile. Suffice it to say, they can no longer succeed by merely cost-effectively producing a single product [5]. This is where Industry 4.0 comes in. Interconnected machines, parts, and humans enable faster and more flexible production processes to produce higher-quality products at a lower cost. This, in turn, increases productivity, drives revenue growth, and enables mass customization [6]. The race to adopt Industry 4.0 is already underway in many parts of the world, and companies that are able to keep up will benefit from the competitive advantages available to early adopters [7].

5G is expected to stimulate innovation and enable new Industry 4.0 use cases with advanced requirements [4]. As spectrum auctions are nearing completion, companies are investigating how they can integrate the new wireless technology into their current operations. Consequently, this has left them with many questions: What use cases will generate most value and how do you go about making them a reality?

The success of Industry 4.0 use cases will, at the end of the day, largely depend on software that operates and controls the manufacturing systems. As such, the role of Software Engineering is indisputable [8]: No matter how innovative a use case is, if it can not be realized at low cost, at high speed, and with the required quality attributes then one cannot expect financial return from it. Achieving these goals requires not only specific technical skills but, more importantly, solid Software Engineering practices [9].

Given that the manufacturing industry is undergoing a major technological shift with the introduction of 5G, it is necessary to investigate whether manufacturers need to change their current Software Engineering practices in order to successfully adopt Industry 4.0 in the 5G era.

1.2 Purpose of the Study

The purpose of this study is twofold: On the one hand, it aims to identify Software Engineering challenges that a truck manufacturing company (the case company, to be more exact) expects to face during the implementation of an Industry 4.0 use case in an existing manufacturing facility. This will be achieved by conducting a qualitative exploratory case study in which interviews constitute data collection. During the interviews, a use case that is perceived to be 5G-enabled and aligned with the company's goals for future manufacturing technology is presented. Through a series of questions, the interviewees are asked to explain how they would bring said use case into existence given their current Software Engineering practices. In connection with this, they are asked to think of challenges that they expect to face during this process. Literature will help confirm and further explain said challenges.

On the other hand, this study aims to examine whether the challenges identified during the interviews puts the case company in such a position that it needs to introduce new Software Engineering practices in order to take full advantage of the opportunities presented by said use case (Figure 1.1 below attempts to graphically present this purpose of the study in the form of a Venn diagram). This involves, in particular, exploring what such practices should look like. The first step to this is to investigate whether said challenges differ from those found in Industry 4.0 projects unrelated to 5G. Here, literature will play a central role: Industry 4.0 challenges that are identified in related work will help determine if the challenges identified in this study are unique enough to require further research and new solutions.

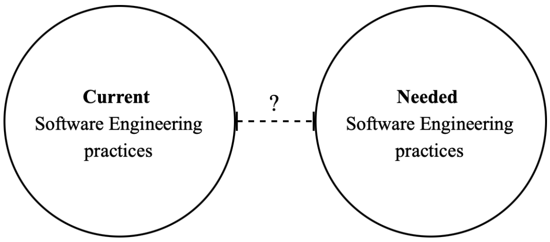

Figure 1.1: Graphical representation of one of the study's main objectives, that is, to investigate whether the case company should introduce new Software Engineering practices in order to take full advantage of the opportunities presented by an Industry 4.0 use case.

Overall, this study extends beyond simply benefiting the case company: It seeks to guide manufacturers of similar kinds who have thoughts of implementing elements of Industry 4.0 in the 5G era, but who are unsure of what this entails. The results of this study can hopefully provide an idea of what challenges they may face during this transition and what Software Engineering practices they should seek to adopt in order to mitigate them. Other topics that will be discernible in the results of the study are Industry 4.0 use cases that 5G is seen to enable and the possibilities that come with them. This information can, to say the least, benefit other manufacturers to take part in as they explore ways to apply these new technologies.

Finally, the study aims to increase knowledge, encourage further research, and formulate questions worth investigating in the future in an area that is both relatively new and relatively unexplored (Software Engineering in Industry 4.0 as a whole and in the 5G era).

1.3 Case Company

This study was carried out in partnership with both Volvo Group Trucks Operations (GTO) and Ericsson in Gothenburg, Sweden, albeit to varying degrees.

Volvo GTO encompasses all production of Volvo Group's engines and transmissions as well as all production of Volvo, Renault, Mack, and UD trucks. GTO is also involved in early phases of new product development to support the design of assembly solutions. Currently, the organization is defining what concepts should be part of their future manufacturing operations. Industry 4.0 is believed to contribute to their future success as it will allow them to grow as the business changes [10]. For example, the diversity in customer offerings is predicted to increase, and Volvo Group themselves claim that their ability to deliver customized products has an important impact on their market position. This requires the flexible and scalable operational system that is achievable with Industry 4.0 technologies. Hereinafter, Volvo GTO is referred to as *the* case company. The purpose of the study is, after all, based on their needs and intends, first and foremost, to identify challenges that they can expect to face.

Ericsson is an Information and Communication Technology (ICT) provider whose portfolio ranges across networks, digital and managed services as well as emerging businesses, all powered by 5G and IoT platforms. Over the past three years, the company has actively engaged in industry collaboration to validate 5G for Industry 4.0 use cases. Convinced that big wins await those who cut the cord and become wireless, they try to disseminate how 5G can unlock the value of Industry 4.0. In this study, Ericsson acts as an external and experienced player who, based on its previous projects and collaborations with other manufacturers, can help identify challenges that Volvo GTO may face in the 5G era.

Two other companies volunteered to participate in this study despite the fact that it was not conducted in partnership with them. These companies were **Atlas Copco** and **HMS Networks** which provide industrial technical solutions (everything from hand-held tools to various software) and products for industrial communication, respectively.

1.4 Research Questions

This study sets out to answer the following four research questions:

RQ1 What Industry 4.0 use cases will 5G enable in the truck manufacturing industry?

RQ2 What are the perceived challenges in engineering the software systems of these use cases?

RQ3 How do these perceived Software Engineering challenges differ from those found in Industry 4.0 projects unrelated to 5G?

RQ4 Is there a need for new Software Engineering practices? If so, what could they be?

1.5 Thesis Outline

The rest of this thesis is organized as follows:

Theory provides background information and theory needed to understand the context of the study and its results. It concludes with a review of Industry 4.0 challenges that have been identified in related work.

Research Method presents the research design of the study, that is, the overall strategy utilized to carry out the study and answer the research questions.

Findings includes the findings of the study, or, in other words, answers to the study's research questions.

Discussion discusses the findings of the study – what consequences they have for the manufacturing industry and Software Engineering research as well as how valid they are.

Conclusion reflects on the purpose of the study. It also summarizes its key findings and comments on implications and consequences.

2
Theory

This chapter provides background information and theory needed to understand the context of the study and its results. More specifically, this chapter addresses the concept of Industry 4.0, the benefits it brings, the societal driving forces behind it, and some of its enabling technologies. The chapter also touches on the next generation of wireless connectivity, 5G, and how it is considered to drive the transition to Industry 4.0.

The chapter concludes with a review of Industry 4.0 challenges that have been identified in related work. These will then help determine if the challenges identified in this study, that is, in the context of 5G-enabled Industry 4.0, are unique enough to require further research and new solutions.

2.1 Industry 4.0

Originally developed in Germany and declared during the Hannover Fair in 2011, the term Industry 4.0 has become a buzzword on a global scale that, in essence, involves applying the idea of CPSs to create a smart factory [1]. Defined as “smart systems that include engineered interacting networks of physical and computational components”, CPSs are designed to sense and interact with the physical world (including humans) [11]. From a manufacturing perspective, a CPS is, put simply, a physical entity (for example, pump or compressor) that is internet-enabled and embedded with processors, software, sensors, and actuators. In a smart factory, a group of such entities can interact with one another and gather real-time data that they can use to, among other things, predict failure, configure themselves, and adapt to changes [6]. This combined with a number of other enabling technologies (analytics, robotics, high-performance computing, and artificial intelligence) makes it possible to gather and analyze data across entire supply chains and product life cycles. Hermann et al. [12] have identified four principles as integral to Industry 4.0:

- Self-organization: CPSs make decisions on their own and perform their tasks as autonomously as possible. Only in the event of exceptions, interference or conflicting goals are tasks delegated to a higher level.

- Interconnection: Machines, devices, sensors, and people are connected.

- Information Transparency: Interconnectivity enables operators to collect huge amounts of data from all points in the manufacturing process and identify key areas that can benefit from improvements.

- Technical Assistance: CPSs assist humans in decision making and problem solving, and help humans with difficult or unsafe tasks.

The smart factory exhibits a promising production paradigm that has many beneficial outcomes in terms of productivity, efficiency, flexibility, and profitability. For example, it can respond to changes (both expected and unexpected) during operation and be reconfigured quickly and automatically to produce multiple types of products [13]. It can also be optimized to improve efficiency and quality [14] as well as reduce resource waste [15].

2.1.1 Drivers

Social, economic, and political changes around the world have been driving the need for Industry 4.0. Referred to as Application-Pull by Lasi et al. [16], these societal drivers are to be distinguished from technological drivers enabling Industry 4.0 (Technology-Push, see section below). On the basis of this distinction, the following section aims to present the main societal driving forces for a paradigm shift in manufacturing.

2.1.1.1 Changing market demands

Customers' demands are changing, and customization in particular seems to be their watchword. In recent years, a change from a seller's to a buyer's market has become apparent, meaning that customers are more likely to define the conditions of the trade [16]. This trend has led to increased customization of products, giving customers the freedom to choose desired options without a corresponding increase in costs [17]. In manufacturing, the concept of mass production has been combined with customization to enable the production of unique goods on a large scale (mass customization). Mass customization provides many benefits [18], but it also makes traditional mass production based on economies of scale obsolete [17]. Instead, manufacturing companies need to make their processes and technologies more flexible to be able to handle, for example, short product life cycles and unpredictable demand patterns (volatility) [19]. This does not necessarily mean that all factories should produce all types of products but rather that the process or layout does not change when another product is introduced [10].

2.1.1.2 Sustainability

Sustainability (defined during the 2005 World Summit on Social Development as economic development, social development, and environmental protection [20]) is indispensable for a simple reason: The world's ecosystems and the desired quality of human life cannot be maintained without human beings embracing sustainability [21]. Consequently, sustainability has become an important issue in all spheres of life and will continue to be so for many years to come.

Manufacturing places a strain on the environment in many ways as it consumes large amounts of energy and natural resources, produces waste, and emits greenhouse gases [15]. Waste, in particular, whether caused by overproduction, quality problems or untapped potential for optimization, has consequences for all three dimensions of sustainable development [17]. Faced with this reality, a large and growing number of manufacturers are beginning to recognize the need for sustainable business practices. Stricter rules related to both the environment and occupational safety and health, increased consumer preference for environmentally friendly products [22], and raw material and energy price trends [15] help promote this change of attitude. The rise of Industry 4.0, and herewith the optimization of the industrial production process, is considered by both researchers and industrialists to pave the way for sustainable manufacturing. It is believed, for example, to offer many opportunities for reducing carbon dioxide (CO_2) emissions (environmental sustainability) [23]. Explained by Gabriel and Pessl [15]:

> "By providing detailed information on each point of the production process, resource and energy use can be optimized over the entire value network (this means optimal resource and energy productivity, optimal resource and energy efficiency). The optimization of the industrial production process can lead to a reduction of CO_2-emissions."

In addition to this, Industry 4.0 is also considered to reduce risk and safety concerns through reduced human intervention (social sustainability) [24] and make a major contribution to sustainable economic development in countries (economic sustainability) [25].

2.1.2 Enabling Technologies

For manufacturers, the transition to Industry 4.0 will depend on the successful use of certain technologies. According to Rüßmann [6], the nine main technologies are autonomous robots, simulation, system integration, IoT, cybersecurity, additive manufacturing, big data and analytics, cloud computing, and augmented reality (presented graphically in Figure 2.1 below). The sections below briefly describe the techniques that are most relevant to this study, that is, those that are necessary for the use case that this study revolves around, and how they are used in manufacturing.

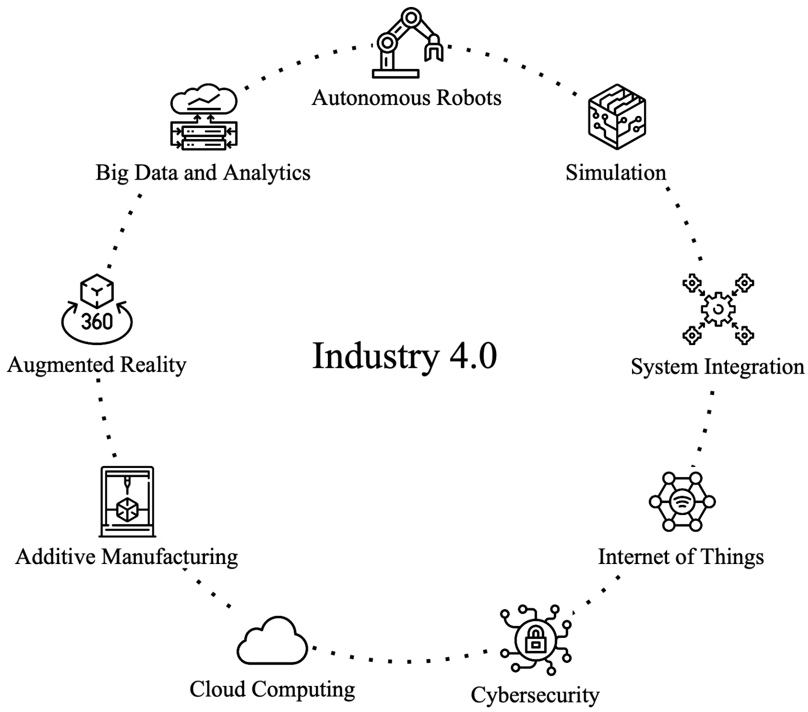

Figure 2.1: The nine main enabling technologies of Industry 4.0.

2.1.2.1 Autonomous Robots

Manufacturers of all kinds have long used industrial robots for tasks that are too dangerous, repetitive or complex for humans to perform [6]. This has helped to achieve safer, faster, and more accurate production processes and reduce manufacturing cost [26]. Today, however, robots are evolving for even greater utility by becoming more autonomous, intelligent, and flexible and providing greater range of capabilities [6]. Firstly, such robots can cooperate and automatically adjust their actions to fit the next unfinished product in line. Secondly, they can, with the help of advanced sensors and artificial intelligence, work side by side with humans in a safe way. Finally, modern robots will be able to use big data to track and assess their own health and overall production performance degradation.

2.1.2.2 System Integration

System integration entails linking components of a system or several other systems into one cohesive system. System integration is divided into three levels, namely the integration of internal system components (vertical integration) and multiple systems (horizontal integration) as well as the coupling of physical and virtual entities within a system (end-to-end integration). In Industry 4.0, system integration will not only be used to merge enabling technologies [27] but also to make companies, departments, and functions more cohesive, thereby creating cross-company, data-integration networks that enable more diverse and combined value chains [6].

2.1.2.3 Internet of Things

IoT is the concept of connecting physical and sometimes everyday objects to the internet, enabling interaction between the physical and digital world (usually referred to as a CPS). In the context of Industry 4.0, this means connecting manufacturing machines and devices to the internet to achieve the goal of smart manufacturing [28]. Such IoT devices are normally embedded with sensors that collect real-time data from their surroundings as well as software that manages and, if necessary, acts on the data that is collected. A single device can also communicate directly with other IoT devices, enabling multiple devices to act on data received from their system neighbors to achieve the goal of a holistically smart system [28]. Therefore, the true value of IoT does not lie in the individual devices but rather in their interconnection (when they work collectively via the internet) [29].

2.1.2.4 Cybersecurity

Cybersecurity entails securing privately owned network-accessed resources from unauthorized access. Historically, security countermeasures in manufacturing facilities have included applying firewalls and intrusion-detection systems to the boundaries of network premises [30]. With the rise of Industry 4.0 technologies such as IoT, CPS, and cloud computing, those boundaries have become more blurred due to the digital world and the physical world becoming merged as well as network traffic traveling more frequently outside the confines of privately owned networks. This has made networks more complicated to secure and more vulnerable to cyberattacks (if correct countermeasures are not taken) [30, 31].

In a manufacturing facility consisting of interconnected devices, cyberattacks against machines and their surrounding infrastructure can not only cause malfunction and safety hazards for manufacturing operators but also financial loss due to the work required to restore a facility to its normal state [32]. Such restoration processes are costly and affect the overall productivity of manufacturing, leading to companies potentially losing their competitive advantage. The negative effects of insufficient cybersecurity has made it a key enabling technology for Industry 4.0 [31].

2.1.2.5 Cloud Computing

Relying only on IoT devices alone is insufficient to fully accomplish sophisticated manufacturing tasks [33]. This is why companies use cloud computing – a centralized computing paradigm that allows the devices to offload computation and storage to highly capable and continuously available data centers. In this way, everything from applications, development tools, and network capabilities are available through the internet or, in other words, the “cloud”. Nonetheless, cloud computing has some limitations when it comes to Industry 4.0 applications that require reduced latency and real-time response [34]. In general, public cloud providers have built a number of large data centers in different parts of the world. This centralization of resources results in a long propagation distance from the end user to the remote cloud center, which in turn increases latency [35]. This limitation of cloud computing has given rise to so-called edge computing – a decentralized computing paradigm that enables edge servers in mini clouds (or edge clouds), which brings cloud computing capabilities closer to devices. Edge computing has many beneficial outcomes such as low latency, energy savings, reliability (there is no single point of failure or vulnerability), and location-awareness [35].

2.1.2.6 Big Data and Analytics

Big data refers to very large and complex data sets that cannot be processed with traditional data-processing application software. This includes structured, semi-structured, and unstructured data from different sources and in sizes ranging from terabytes to zettabytes. Data volumes collected in manufacturing are constantly growing, reaching more than 1000 exabytes (one exabyte being the equivalent of 1048576 terabytes) [36], largely due to the increased use of IoT devices [37]. In order to gain insights from these data sets (and, in turn, assess and improve manufacturing processes), manufacturers must use advanced analytics techniques such as machine learning, data mining, and statistics [14]. These techniques are considered important enablers for advanced Industry 4.0 applications. After all, the intelligence of manufacturing systems depend on the large amount of data accumulated and the capacity of analyzing said data [38].

2.1.3 5G

Similarly to how the general population has seen an increased number of connected devices (and herewith larger volumes of data), manufacturers will also, with the rise of Industry 4.0, see an increase of connected devices and machines. Such devices can connect (device-to-device or to the internet) either by wire, mainly via Ethernet, or wirelessly via either Wi-Fi or cellular technologies [2]. Wired connections, although fast and reliable, do not scale well with the increase of devices as it makes production line planning more complex [2]. Wireless connection technologies, on the other hand, has thus far been proven to simplify line layouts and save costs for manufacturers. However, today’s primarily used wireless technologies fail to meet the requirements of Industry 4.0, which gives numerous reasons to look for a better connectivity option. Such reasons include, but are not limited to, the following [2]:

- Substantially more data will be transmitted across the manufacturing facilities.
- All areas (even those with many physical barriers) within manufacturing facilities should have good network coverage.
- Remote control of machines and real-time monitoring of facilities require very low latency.
- High reliability should be maintained while adhering to the low latency demands as it is important that little, or no data, is lost during transit.

Compared to other wireless network technologies, the fifth generation of cellular technology, 5G, is capable of addressing this list of demands, making it an enabler of the Industry 4.0 vision [34, 39]. Due to millimeter-wave communication (mmWave), which uses higher frequency bands, 5G will have greater bandwidth, giving higher speeds than its predecessors (at least 10 Gigabit per second compared to 4G which has a speed of 100 Megabit per second). By combining the benefits of mmWave and the deployment of small cell antennas, 5G also enables lower latency and higher reliability [34]. The relative strengths of different wireless network technologies are visualized graphically in the radar chart (Figure 2.2) below, as inspired by Burkacky et al. [4].

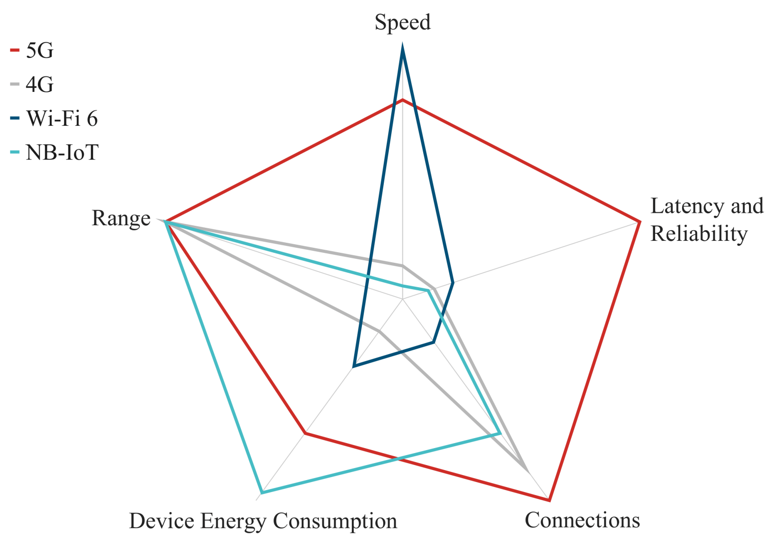

Figure 2.2: Radar chart visualizing the relative strengths of different wireless network technologies.

2.1.4 Challenges

At present, Industry 4.0 is a vision for the future as it involves many aspects and faces many types of challenges, including scientific, technical, economic, social, and political ones [40]. Although research on such challenges is scarce, especially Software Engineering related ones, it is still possible to distinguish common themes in related work.

Firstly, many researchers place a lot of emphasis on the security and privacy aspects of Industry 4.0. Without it, no organization will dare to bring smart factories to fruition [41]. As already mentioned, security issues become increasingly serious when the digital world and the physical world are integrated, which is, as we now know, the very basis of Industry 4.0 [40]. This is exacerbated by the fact that many IoT devices have bad standard security mechanisms [42] and systems used to control and monitor cyber-physical manufacturing processes use standard network protocols that have known security vulnerabilities [43]. As such, there are many challenging problems to solve in terms of how security can be ensured in smart factories.

Secondly – and this is also related to the merging of the physical world and the digital world – more attention must be paid to the system architecture as the boundaries between hardware and software are no longer well defined [44]. How do you design manufacturing systems that are not only completely self-organized but also highly scalable, modular, and interoperable [41, 44]? After all, manufacturing facilities have dynamic and changing environments and smart manufacturing systems should be able to cope with these changing factors [42]. This is especially tricky as Industry 4.0 requires the integration of highly heterogeneous components, that is, components that vary in terms of capabilities (computing power, storage capabilities, and energy requirements) but share memory and tasks [42].

Finally, researchers highlight the concern of managing, recovering, representing, and storing big data generated by many different manufacturing devices, especially when there are strict low latency requirements to be met [44]. According to Gil et al. [45], it is always much easier to create data than to analyze and make sense of it. Big data also introduces enterprise information protection and privacy issues [40], which adds to security aspects that manufacturers must take into account when implementing elements of Industry 4.0.

3

Research Method

This chapter presents the research design of the study or, in other words, the overall strategy utilized to carry out the study and answer the research questions. As such, it describes the type of research that was conducted, data collection methods, the selection and composition of the participants, and, finally, the data analysis process. The chapter also presents some terminology that needs to be defined for the context of this study.

3.1 Qualitative Exploratory Case Study

This section describes the type of research that was conducted: Its components and why it was relevant for this particular study. Overall, the research objectives were classified as exploratory due to their intentions to explore new insights and find problems for future research. A main research objective was to investigate the challenges surrounding an Industry 4.0 use case, which is why it was considered most relevant to carry out a case study. This made it possible to extract realistic insights from individuals in a natural context.

3.1.1 Case Study

Allowing the study to use a real world example – an Industry 4.0 use case that was aligned with the case company's manufacturing goals – as a starting point was believed to motivate and make it easier for the participants to identify challenges that were relevant to the case company. At the end of the day, the goal of the study is to create as realistic insights as possible. The use case was also considered to be representative of Industry 4.0 (it covers most of its possible technologies), allowing for more generalized conclusions for similar Industry 4.0 use cases. A methodology relying on a real world setting, or to some extent, a real world example was needed for the study. Consequently, a case study was conducted which, per definition, is used to investigate a contemporary phenomenon in its natural context [46].

In contrast to other research methodologies such as experiments, surveys, and action research, case studies are less structured processes. The mentioned methodologies require either control, more researcher involvement, or a large population [47]. Case studies, however, require observation of phenomena which means that parameters can change during the course of the study. This can make case studies more flexible in their nature compared to other methodologies [47]. Nonetheless, flexibility does not diminish the importance of planning the study. On the contrary, Runeson et al. [48] stress that planning is crucial to its success. Robson et al. [47] provide fundamental elements of planning a case study: Research questions, theory, the case, objective, methods, and selection strategy. The former four are described in subsequent sections.

3.1.1.1 The Case

In itself, the phenomenon (or case) can be anything and is restricted only to remaining in its natural context for the entire study [48, 46]. A case should be observed by the researchers while it is used or scrutinized by the individuals or entities closely related to it [48].

In Software Engineering, case study cases traditionally take the shape of software development projects or aspects surrounding such projects and processes [48]. In this study, the case was an actual use case – or rather, a conceptualization of a use case – enabled by 5G. More specifically, the use case included deploying kitting automated guided vehicles (AGV) in one of Volvo Group's truck manufacturing facilities. *Kitting* is the delivery of exact quantities of relevant materials and tools to operators within their work area [10]. Normally, AGVs rely on pre-defined routes on the factory floors. Comparatively, the use case aims to deploy AGVs that can receive new plans if needed while simultaneously communicating their current status in real-time. This leads to requirements in terms of high reliability and performance – firstly, because they need to maintain communication given potential obtrusions and, secondly, because real-time communication relies on low latency. A highly reliable and performant means of communication is required to fulfill these requirements, which is why this specific use case has been identified as 5G distinct. It also covers many Industry 4.0 enabling technologies (autonomous robots, IoT, cloud computing, and big data).

3.1.1.2 Case Study Objective

Given the flexibility of case studies, the objective of a case study serves as a high-level focus point and purpose that can evolve throughout the study [48]. The study objective can take the shape of one of several classifications. Robson et al. present four classifications of case study objectives [47]:

- Exploratory: Finding out what is happening, seeking new insights, and generating ideas and hypotheses for new research.

- Descriptive: Portraying a situation or phenomenon.

- Explanatory: Seeking an explanation of a situation or a problem, mostly but not necessary in the form of a causal relationship.

- Improving: Trying to improve a certain aspect of the studied phenomenon.

This study does not seek to identify causal relationships or improvements surrounding the case, nor does it aim to explain the case and its characteristics wholly. Thus, the explanatory, improving, and descriptive classifications were deemed inapplicable. Instead, the study aims to investigate a case in its natural context and formulate problems that could require further investigation. Given this, the study falls under the exploratory research objective classification.

3.1.2 Qualitative Research

In empirical research, there are two different types of data: Quantitative and qualitative. Runeson et al. [48] summarizes the two types of data as follows:

> "Quantitative data involves numbers and classes, while qualitative data involves words, descriptions, pictures, diagrams etc."

A study's research methodology is, to some extent, shaped by the type of data it expects to collect or encounter. Accordingly, research methodologies based on quantitative data are more inclined to be in the shape of so-called fixed methodologies, such as surveys or experiments, where the design is rigorously pre-defined and data is statistically analysed to derive generalized conclusions [48, 49]. Research methodologies based on qualitative data instead deal mostly with collecting data from individuals in a context of interest in order to gain knowledge regarding the situation the individuals are in [49]. Naturally, case studies gravitate more toward qualitative research due to the rich data they generate [48]. Considering these factors, this study is qualitative.

Qualitative data is inherently less precise than quantitative, making it even more important to use triangulation in qualitative research [48]. Triangulation is the means of taking different angles toward a research object to get a more broad picture, enabling the researcher to draw a more precise conclusion [48, 46]. There are four different types of triangulation that a study can take advantage of [50]:

- Data: Using multiple data sources.
- Investigator: Having multiple investigators, or observers, throughout the study.
- Theoretical: Using different theoretical perspectives, hypotheses or viewpoints.
- Methodological: Combining multiple data collection methods.

This study mainly leveraged data and investigator triangulation. The former was achieved by interviewing individuals from different companies. Investigator triangulation was implicitly carried out since two interviewers were always present throughout the course of the study.

3.2 Interviews

Interviews are so-called first-degree data collection methods, wherein the researchers are in direct contact with the subjects and collects data in real-time. In case study research, the aim is to capture data directly from subjects in an area of interest, naturally making interviews a relevant means of data collection [48]. During such interviews, data is collected by asking questions to said subjects based on the research questions. Questions are either open or closed, meaning that they give room for broad answers or limited answers, respectively [48]. The interviews can either be unstructured, semi-structured or fully structured. An unstructured interview lacks predefined questions and instead contains only important topics that the interview should touch on. Its polar opposite – the fully structured interview – contains predetermined questions that the interview should not deviate from. A semi-structured interview is a combination of those two opposites, that is, questions and their order are pre-defined in an interview guide, but interviewers can ignore their order and alter the phrasing of the questions if the interview requires it [47]. The less structured alternatives are more common in case studies due to them being more compatible with the flexible nature of case study research [48, 47].

For this study, a total of ten semi-structured interviews were conducted using an interview guide as the outset. This type of interview was chosen because it allowed for both consistency and flexibility during the interviews (the phrasing and order of the questions were changed based on the role and company of the participants). One participant was interviewed at a time, with one exception when two participants requested to be interviewed simultaneously. Questions were asked based on the premise that they were allowed to elaborate and be open with their answers. In addition, all interviews were conducted with two interviewers present, each asking the same number of questions, which gave the interviewers the opportunity to react if something was missed during a question or discussion.

The following sections describe, in detail, the process of selecting the participants and the structure of the interview guide.

3.2.1 Selecting Participants

In 5G-enabled Industry 4.0 use cases, multiple parties will need to work together to provide different services [51]. Consequently, in order to successfully deploy the Kitting AGV use case in one of the case company's truck manufacturing facilities, multiple suppliers would need to come together to form a partner ecosystem. Partners in such ecosystems work together to deliver products and services from their respective area of expertise to achieve a common goal [52]. In the context of the use case, one partner could provide communication technology (for example, Ericsson) and another could supply compatible equipment (for example, Atlas Copco or HMS). Interview participants were selected from these potential ecosystem partners with the aim of giving the study more than one perspective on challenges that the case company might face and ways to mitigate them. This is aligned with the study's goal of achieving data triangulation as mentioned in Section 3.1.2.

How these parties help to achieve triangulation is presented graphically in Figure 3.1 below.

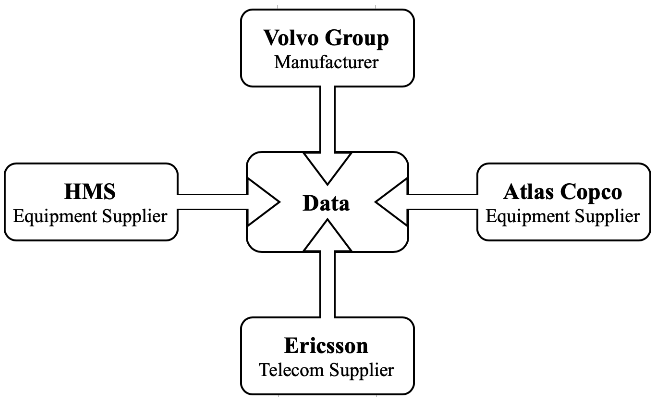

Figure 3.1: Graphical presentation of how the companies involved in this study help to achieve data triangulation.

Sampling was based on two techniques, namely purposive sampling and convenience sampling. The former refers to sampling participants whose experiences are compatible with the goals of the study [53]. In other words, participants were selected only if they had prior knowledge of both Software Engineering and Industry 4.0. This, combined with convenience sampling (the process of selecting participants based on their availability) [49], resulted in the participants shown in Table 3.1 below being interviewed. Note that the names of the interviewees have been replaced by pseudonyms in order to hide their identities. The pseudonyms were chosen without regard to gender for the sake of anonymity.

Table 3.1: Details about the interview participants.

Pseudonym	Role	Organization	Years in role	Years in field
George	Research Engineer	Volvo GTO	3	22
Pam	Enterprise Architect	Volvo GTO	5	15
Morris	IT Architect	Volvo Group IT	4	4
Clint	IT Architect	Volvo Group IT	13	23
Alex	Solutions Architect	Ericsson	4	27
Gunther	Product Manager	Ericsson	1	13
Marnie	Portfolio Manager	Ericsson	3	13
Caroline	IT Manager	Atlas Copco	3	15
Gil	Software Developer	Atlas Copco	3	3
Penny	IT Manager	HMS	9	30

3.2.2 Interview Guide

Acting as a framework, the interview guide (see Appendix A) provided consistency and a structure to, somewhat, adhere to during the interviews. All questions in the guide were based on the research questions, relevant theory, and, most importantly, the case itself. A complete overview of the relationship between the research questions and the interview questions can be seen in Figure 3.2 below.

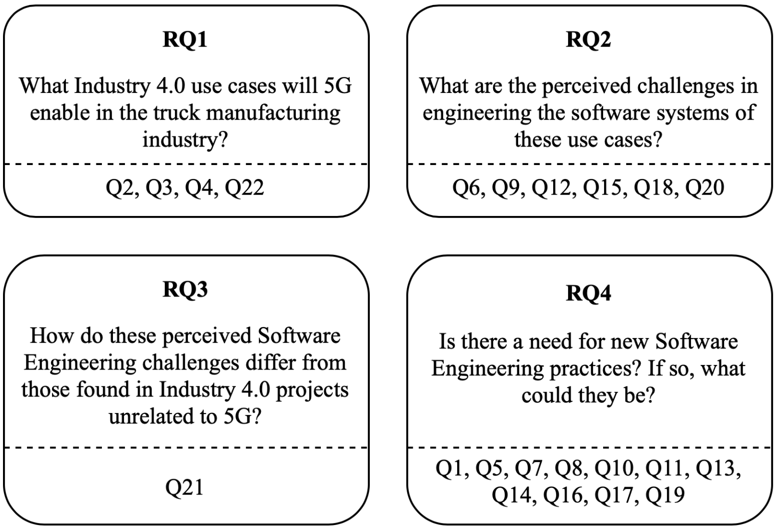

Figure 3.2: The relationship between the research questions and the interview questions in Appendix A.

As a whole, the interview guide follows a sequence similar to the one presented by Robson et al. [47]:

1. Introduction: The researchers introduce themselves and the purpose of the interview, provide confidentiality assurance, and ask for permission to record.

2. Warm-up: Questions asked at the beginning of the interview.

3. Main body of interview: Covers the main purpose of the interview and encompasses all numbered questions in Figure 3.2 above.

4. Cool-off: Straightforward questions at the end to conclude the interview.

5. Closure: A final thank you to the interviewee.

Questions directly related to the research questions and the case are found in the main body of the interview. Structurally, it follows the so-called funnel structure, addressing more broad and open questions in the beginning and progressing toward more specific questions [48]. In summary, this part of the interview involved asking case company employees to explain *how they would bring the Kitting AGV use case into existence* at the case company (in an existing manufacturing facility) given their current Software Engineering practices. The interviewees were asked to describe their approach according to the phases of a software development process

(Requirements, System Design, Implementation, Verification, and Maintenance as defined by Sommerville [54]). In connection with this, they were asked to think of *challenges that they expected to face* during the part of the process they just described. Each phase ended with the interviewee being asked to think of ways in which these challenges could be mitigated, and whether there was anything in their current way of working that needed to be addressed in order to take full advantage of the opportunities presented by the use case in question.

The purpose of the interview and, in turn, the phrasing of the questions differed depending on which company the interviewee in question was employed at (an example of this can be seen in Figure 3.3 below). Questions addressed to case company employees were based on the premise that they were interested in deploying the Kitting AGV use case in one of their manufacturing facilities. Hence, their interviews followed the structure described in the previous paragraph and by the left part of Figure 3.4 below. Given suppliers' experience in helping manufacturers bring similar Industry 4.0 use cases into existence (for example, in 5G pilot projects), they were instead asked to describe challenges they had encountered in similar software development projects and what was required to solve them. This interview structure is visualized by the right part of Figure 3.4 below.

Implementation

Q8 Case Company: How would you perform this phase given the following activities?

Q9 Case Company: What challenges do you expect in this phase?
Supplier Company: What challenges have you encountered in this phase?

Q10 Case Company: What does the company need, or need to do, in order to overcome these challenges?
Supplier Company: How did you go about overcoming these challenges?

Figure 3.3: Excerpt from the interview guide that shows how questions differ depending on which company the participant works at.

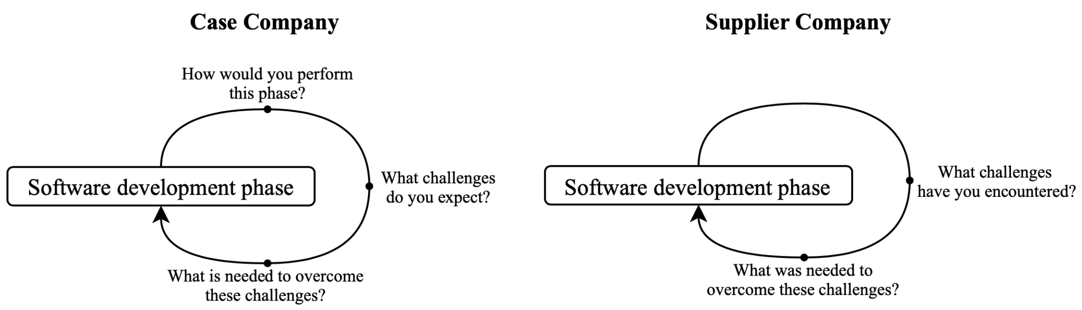

Figure 3.4: The interview structures that were followed when employees from the case company (left) and supplier companies (right) were interviewed.

All theory and terminology related to the topics of discussion in the interview guide, such as Industry 4.0, 5G, and software development phases, were defined for all participants during the interview. The goal was to gain a common understanding of the theory, eliminate confusion, and avoid potential misunderstandings.

3.3 Data Analysis

The subsequent section describes the central step in qualitative research, namely data analysis [55] – the process of inspecting, transforming, and modeling data with the goal of discovering useful information. After all, it is what forms the outcomes of the research. The analysis of qualitative data can have several aims ranging from describing a phenomenon to finding an explanation for it. Taking into account the exploratory nature of this study, the purpose of this process within the framework of this study is to create new insights.

In more detail, this section explains how interview data was prepared for analysis, what methods were used to find major themes in the data, and in what manner those themes were arranged.

3.3.1 Transcription

After the interviews had been conducted, they were transcribed and prepared for analysis. Simply put, transcription involves getting the interviews off the devices on which they were recorded and into a formatted document (in this case, a spreadsheet). Interview dialogues were transcribed in detail, the reason being that it made it possible to examine how speakers managed disagreements and accomplished common understanding [56]. Still, the transcriptions excluded some utterances that were not considered to contribute to the topics of talk, e.g. “um” and “uh”. The following excerpt (Table 3.2) from one of the transcripts shows how the interviewee Pam asks the interviewer (IR) to clarify a question in order to accomplish common understanding.

Table 3.2: An excerpt from the interview with Pam in which she asked for a clarification.

IR:	“How do you imagine truck manufacturing will look like in the future?”
Pam:	“Then you think of manufacturing systems, IT systems and so on, or?”
IR:	“Yes, you could say that. Exactly.”

Words added for clarification, as well as inaudible segments, were noted by use of square brackets. Descriptive information such as features of the context and delivery of utterances, e.g. sarcasm and jokes, falls within this framework of formatting, and Roulston [56] argues that one might indicate this where deemed necessary to "enrich representations of findings." The following excerpt (Table 3.3) shows an example of this.

Table 3.3: An excerpt from the interview with Morris that showcases how the word "JOKINGLY" was added for clarification when the interviewee delivered a joke.

IR:	"Admittedly, you do not work in this way anymore, most people do not."
Morris:	"No, but we do at Volvo." [JOKINGLY]

3.3.2 Coding

Transcription is to be distinguished from coding, which refers to a way of analyzing qualitative data [57]. A code is defined by Saldaña [58] as a word or short phrase that assigns a symbolic meaning or summative attribute to a portion of data (in this case, interview transcripts). Codes are mainly used to categorize similar data units, which in turn makes it easier to find and cluster the segments relating to a particular research question, for example [59]. This helps set the stage for further analysis and drawing conclusions.

Saldaña [58] divides coding into two stages, namely First Cycle Coding and Second Cycle Coding. The former assigns initial codes to the data units, while the former works with the resulting codes themselves.

3.3.2.1 First Cycle Coding

First Cycle Coding happens during the initial coding of data, splitting it into individually coded segments. There are many First Cycle Coding methods, each one with a particular purpose, and these can be compatibly "mixed and matched" as needed [59]. The coding methods chosen for this study were Descriptive Coding, In Vivo Coding, and Emotion Coding. The following coded excerpt (Table 3.4) from George's interview exemplifies the use of these methods.

Table 3.4: An excerpt from the interview with George and its related First Cycle Codes.

	Descriptive Code	**In Vivo/Emotion Code**
"With the history we have, it has worked very well with silos. But what happens here is that there are so many more who are dependent on this, who have requirements for functionality. Or on the implementation bit. And the first difficulty is to identify everyone who may be affected and include them in the requirements."	STAKEHOLDER MANAGEMENT	"SILOS", "IDENTIFY EVERYONE"

Here, the Descriptive Code summarizes the primary topic of the passage in question: Stakeholder Management. Descriptive Codes, usually a word or short phrase (most often a noun), provide an inventory of topics for categorizing [58]. The column on the far right contains In Vivo Codes, which are taken directly from what the interviewee (George) himself said. The purpose of this coding method is to give meaning to the data using the interviewee's own words and, in a way, capture the essence of the passage [58]. Furthermore, the In Vivo Codes were color coded based on the contexts in which they were uttered, more specifically if they were said by the interviewee to express something challenging (shown in red) or a sense of hope or opportunity (shown in green). These color codes symbolize a type of Emotion Coding or, in other words, a method for labeling the emotions expressed by the interviewees [59].

3.3.2.2 Second Cycle Coding

Second Cycle Coding generates categories, themes and concepts, grasps meaning, and builds theory from the First Cycle Codes. Like First Cycle methods, Second Cycle methods can be compatibly "mixed and matched". For this study, Pattern Coding was used in conjunction with Focused Coding and Axial Coding.

Pattern Coding develops major themes from the data by condensing, or summarizing, large amounts of similar First Cycle Codes into a smaller number of analytic units ("meta-codes") [59]. In the context of this study, the In Vivo Codes "Very Old", "Very Long", "Conservative Industry", "Sensitive To Upgrades", and "Million Dollar Project" assigned during First Cycle Coding were considered to paint a picture of manufacturing systems having long life cycles. As such, the aforementioned In Vivo Codes were grouped into one single Pattern Code, namely Long Life Cycles (visualized in Figure 3.5 below).

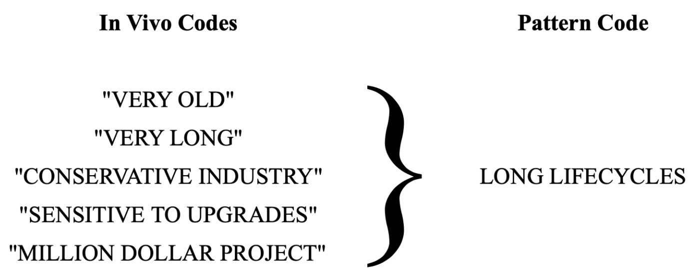

Figure 3.5: Similar In Vivo Codes being grouped into one single Pattern Code.

Although Pattern Coding managed to reduce the number of initial codes, it remained to be determined which resulting Pattern Codes were of the greatest importance. This is where Focused Coding came in useful. The method discerns the most salient categories in the data by searching for the most frequent, or rather, recurring codes [60]. In the context of this study, the method helped determine how major a theme was by counting the interviewees who touched on said theme. Themes that were mentioned only in occasional interviews were omitted. Namey et al. [61] suggests doing so, that is, determining frequency based on the number of individual interviewees who mention a theme (rather than the total number of times it appears in the interview). In addition to identifying interviewees who had touched on a particular theme, attention was paid to the distribution of partner companies: How many of said interviewees came from each company? This information was then used to determine whether the partner companies agreed on major themes.

The last method used during Second Cycle Coding, Axial Coding, relates codes to each other to reveal the central categories of the study. This involved taking major themes developed during Focused Coding, pooling related ones and, lastly, tying them together via an Axial Code. For example, the Pattern Codes Customer Customization, Fewer Manufacturing Operators, Mixed-model Assembly, and Human-robot Collaboration were pooled into the central category Future Manufacturing Concepts (visualized in Figure 3.6 below).

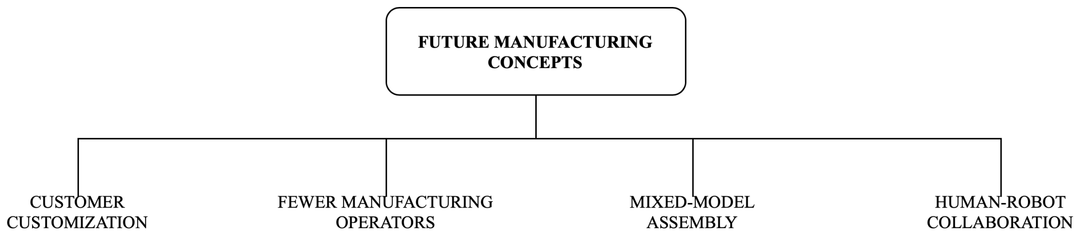

Figure 3.6: Related themes (Pattern Codes) tied together via a central category (Axial Code).

The last thing that was done in this phase of data analysis was to look for possible code structures and arrangements. According to Saldaña [58], it is when such categories of categories are created that theory emerges. An example of such a structure is processes – the influence of one category on another. Saldaña [58] goes on to explain that there are many kinds of processes (concurrency and domino effects, to name but a few), but in this particular study, the processes manifested mainly in the form of so-called networks. This means that the categories interacted in complex ways to suggest interrelationship. Here, it is worth mentioning that the color coding from First Cycle Coding was used in this cycle as well. The purpose of this was to provide a quick overview of how challenges and opportunities were interconnected as well as the ratio between them.

A complete list of the final codes (the pattern codes, their associated axial codes, emotion codes, and frequencies) and how they relate to the results of the study can be found in Appendix B. Note that for practical reasons this list does not cover code structures and arrangements.

3.3.3 Identifying Major Challenges

After coding had been completed and a number of challenges had been identified, the major ones needed to be identified. In other words, it remained to determine which challenges the case company actually perceived as challenging. The purpose of the study was, after all, to identify challenges that the case company perceived itself to face. The fact that the majority of interviewees (6 out of 10) were employed by suppliers made this part of the data analysis particularly important as it also examined the extent to which the company agreed to challenges identified by external parties.

This part of the data analysis was conducted in the form of a questionnaire (see Appendix C) that was sent out to twenty case company employees by email. Of all those who received the questionnaire, a couple had already participated in the interviews while the rest were their colleagues. This group of employees had been compiled at the beginning of the study by the case company itself and consisted of people with varying roles linked to Industry 4.0, 5G, and smart manufacturing. In this way, sampling was based on purposive sampling (see previous Section 3.2.1). In total, fourteen people responded to the questionnaire. Designed using a five-point Likert Scale, the questionnaire asked the participants to specify their level of agreement or disagreement (ranging from “strongly disagree” to “strongly agree”) for a series of statements related to the challenges identified in the earlier stages of the data analysis. The challenges that the majority of respondents agreed with (above 50 %) were ultimately identified as major challenges. The resulting level of agreement for each statement can be seen in detail in Appendix D.

4

Findings

This chapter includes the findings of the study, or, in other words, answers to the study's research questions. As such, this chapter presents 5G-enabled Industry 4.0 use cases identified to bring the most value to the truck manufacturing industry, challenges that the case company may face if they were to bring the use cases into existence, and how these challenges differ from those that the case company would encounter in Industry 4.0 projects unrelated to 5G. Finally, this chapter focuses on the question whether the identified challenges puts the case company in such a position that it needs to introduce new Software Engineering practices as well as what these practices might look like.

4.1 5G-Enabled Industry 4.0 Use Cases

This section presents the 5G-enabled Industry 4.0 use cases identified to bring the most value to the truck manufacturing industry. Through this, it intends to answer the study's first research question, namely:

> *What Industry 4.0 use cases will 5G enable in the truck manufacturing industry?*

Although many valuable Industry 4.0 use cases were mentioned during the interviews, it was clear what use cases all interviewees agreed would contribute the most tangible and concrete value to the truck manufacturing industry: Smart tools and moving robots. Other use cases mentioned were digital twins and augmented reality for operator support. However, these were not discerned as the most salient use cases during Focused Coding, that is, they were mentioned only in occasional interviews.

4.1.1 Smart Tools

For years, manufacturing tools have communicated with manufacturing systems by wire, mainly because contemporary wireless technology has been non-existent or very limited. Gil and Caroline from Atlas Copco stated in their interviews that they have been supplying wired tools to their customers for the past 20 years, but that in recent years they have started delivering wireless tools that communicate via

Wi-Fi. As mentioned in Section 2.1.3, Wi-Fi is an insufficient connectivity option for Industry 4.0. This is confirmed by Caroline (see the excerpt in Table 4.1).

Table 4.1: An excerpt from the interview with Caroline in which she argues that Wi-Fi is insufficient for smart tools.

Caroline:	“The tool communicates directly with the customer’s superordinate system [...], usually via Wi-Fi which works so-so. After all, there is limited signal quality in these factories.”

Tools connected to 5G can maintain a constant and reliable connection to manufacturing systems, which creates valuable opportunities for manufacturers. One of the interviewees explained, for example, that this can enable so-called signal triangulation. This can be used to continuously and accurately locate tools, making the production line more efficient. Gil from Atlas Copco explained, as seen in the excerpt in Table 4.2, that 5G makes it possible for each individual tool to communicate directly with suppliers’ systems instead of having to go through the local manufacturing system first.

Table 4.2: An excerpt from the interview with Gil regarding the possibility of using 5G to receive data from each individual tool.

Gil:	“We receive our data from one point per customer. It is like a pipe. If we have a customer over there, we get all the data from one pipe there. 5G allows us to get 500 pipes from a customer with 500 connected tools.”

By gaining continuous tool status (for example, torque and power), suppliers can more accurately analyze the tools’ performance and health. Manufacturers can thus gain a better understanding of how they use their tools and how they can work more efficiently with them. This was a recurring topic of discussion in Gil’s interview, as seen in the excerpt in Table 4.3.

Table 4.3: An excerpt from the interview with Gil that describes how data from smart tools can be used.

Gil:	“We receive data from factories that describe how the tools behave, what speed they have, and if they produce faults. [With 5G] we would get the same data but we would get much more data. With this you can make extensive analyzes and calculations.”

In summary, wireless and smart tools are considered to be one of the 5G-enabled Industry 4.0 use cases that can bring the most value to the truck manufacturing industry: Combined with big data and analytics, it can help manufacturers better understand their assembly lines and provide clearer plans for achieving the goal of flexibility.

4.1.2 Moving Robots

The full potential of moving robots in manufacturing is held back by what currently connects them to manufacturing systems. Robots connected by wire are strictly constrained to move as far as their cables can reach. Similarly, current wireless robots are restricted by how far they can move from their access points without losing connection. As a result, manufacturers fail to fully achieve high flexibility – one of the main goals of Industry 4.0 and the goal most frequently mentioned by the interviewees. The fact that current connectivity options are insufficient for moving robots was highlighted in the interview with Pam, as seen in the excerpt in Table 4.4.

Table 4.4: An excerpt from the interview with Pam in which she argues that current connectivity options are insufficient for moving robots.

Pam:	"We have problems with things that cannot be connected by cable. It can be things that move, such as trucks, that we need to connect. Here we have used Wi-Fi and there are problems with this technology. There are zones in factories where we simply do not have Wi-Fi coverage."

Moving robots in manufacturing should be able to roam and achieve their tasks without being impeded by objects or, at least, have the capability to be aware of obstacles and avoid them. Case company employee George mentions that moving robots that roam in larger areas need to be constantly connected in order to first, identify obstacles in their path and second, receive a new path from a superordinate system. 5G, he says, can enable such a use case (as seen in the excerpt in Table 4.5) with its high reliability and continuous connection.

Table 4.5: An excerpt from the interview with George that highlights how 5G can enable continuous connection for moving robots.

George	"Robots moving over larger areas must be constantly connected to find out if there are any obstacles on the road further ahead or if they should take another path. I can imagine putting a 5G tag on these to be able to follow them globally in a new way. With continuous connection."

Additionally, many interviewees mentioned the use of fleet management as an essential part in manufacturing systems with moving robots and emphasized that robots should be available in real-time through those systems. All robots should in such a case be virtually accessible in the cloud and with an interface provide the user with advanced controls over the robots. The employees believe that 5G can enable and provide more advanced controls due to the precision that it is capable of delivering.

4.2 Software Engineering Challenges

This section presents the challenges that the case company may face if they were to bring the aforementioned 5G-enabled Industry 4.0 use cases into existence. Through this, it intends to answer the study's second research question, namely:

> *What are the perceived challenges in engineering the software systems of these use cases?*

The main identified challenges can be categorized into the software development phases (Requirements, System Design, Implementation, Verification, and Maintenance) in which they are expected to be met. The purpose of this is to give an almost chronological view of what is potentially to come when an Industry 4.0 development project begins during the 5G era, as well as what the potential causes of failure may be for the project's end product. This categorization of challenges is presented graphically in the fishbone diagram in Figure 4.1 below. In the phases colored gray (Verification and Implementation), no significant challenges were identified.

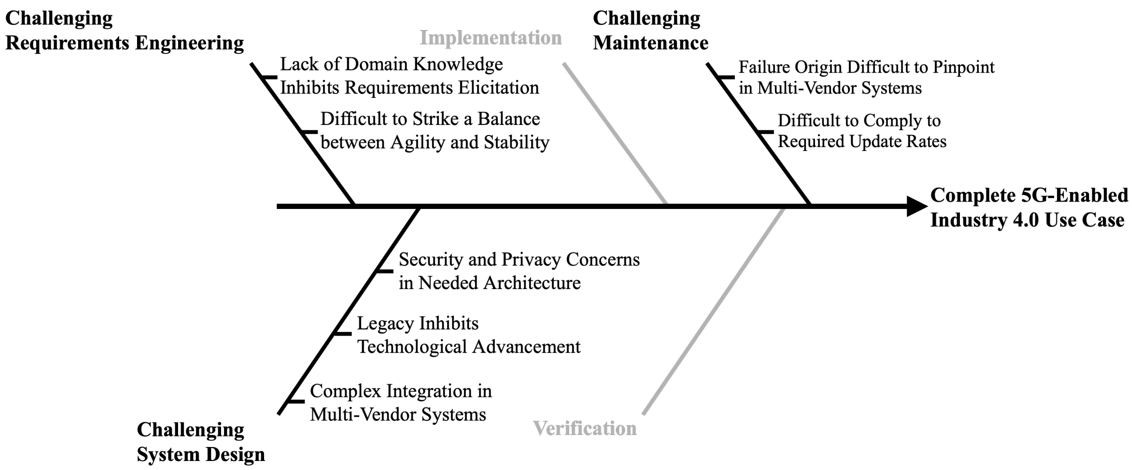

Figure 4.1: Identified challenges or, in other words, potential causes of failures in an Industry 4.0 development project in the 5G era.

4.2.1 Challenging Requirements Engineering

This section presents challenges identified in the requirements phase and what consequences these may have for the entire development process. Overall, a lack of knowledge and maturity regarding 5G-enabled manufacturing use cases has been identified. A need for rigid requirements has also been identified when implementing such use cases, which challenges the case company's current development processes.

4.2.1.1 Lack of Domain Knowledge Inhibits Requirements Elicitation

Many of the challenges that are expected to face the case company in the 5G era, regardless of the development phase, are related to the fact that they will become dependent on their suppliers and partners to a greater extent than before. This was highlighted during the interview with Pam, which can be seen in the excerpt (Table 4.6) below.

Table 4.6: An excerpt from the interview with Pam in which she explains that the case company will become dependent on their suppliers to a greater extent in the 5G era.

Pam:	"We really wanted some kind of spectrum for [5G], otherwise you have to sit in the lap of a mobile network operator. That is new in itself. We do not have that with Wi-Fi or Ethernet – there are no middlemen."

Overall, the consensus among the interviewees seems to be that a potential 5G network in the case company's manufacturing facilities will be provided by a mobile network supplier such as Ericsson. Many of the interviewees believe, for example, that the knowledge required to develop and operate a 5G network simply does not exist in the case company. In addition to this, the case company will be dependent on suppliers such as, among others, Atlas Copco and HMS for machinery and related applications that form the CPSs acting as the core of 5G-enabled Industry 4.0 use cases. After all, the case company makes it clear that their strategy is to buy off the shelf (OTS) whenever possible instead of developing system components themselves (as explained by Morris in the excerpt in Table 4.7 below).

Table 4.7: An excerpt from the interview with Morris in which he explains that the case company aims to buy OTS whenever possible.

Morris:	"We have several different principles at Volvo Group and one of them is that we must buy [system components] instead of developing them ourselves."

However, many of the interviewees, both from the case company and the suppliers, express that no supplier is yet mature when it comes to adopting 5G for manufacturing. This is reflected in the fact that there is currently very little 5G-compatible industrial equipment on the Swedish market. Despite there being 5G testbeds at a number of manufacturing facilities in Sweden (Volvo Construction Equipment in

Eskilstuna, SKF in Gothenburg, and ABB in Västerås, to name but a few), this low degree of maturity leads to many of these testbeds being built around 4G with hitherto limited 5G functionality [62]. As a result, the level of knowledge about 5G for manufacturing – its capabilities, limitations, and business opportunities – remains low among manufacturers. The surveyed employees at the case company seem to agree with this, that is, that the degree of maturity among suppliers is low and that there is a lack of knowledge in their own company. This can be seen in the chart (Figure 4.2) below.

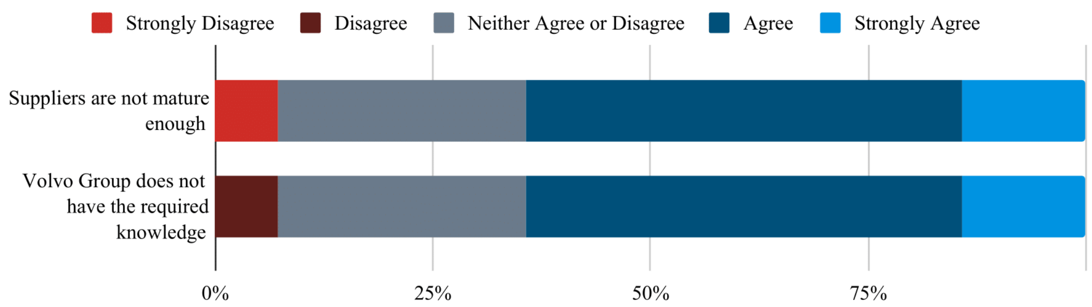

Figure 4.2: 64.3 % of those surveyed do not feel that the case company possesses the required knowledge of 5G-enabled manufacturing. An equal percentage believe that its suppliers are not mature enough to support them in their technological transition.

The lack of domain knowledge may manifest itself in the form of Software Engineering challenges. In the software development community, it is generally accepted that *Requirements Engineering* is the life cycle stage with the greatest influence on the quality of the end product [63]. Identifying stakeholders, gathering facts, and collecting requirements in diverse forms (for example, goals and features) becomes especially challenging when there is a lack of domain knowledge: If manufacturers are unaware of the possibilities and constraints of 5G or have incomplete understanding of their needs and how they can be met, it can result in missing or mistaken requirements [64]. This, in turn, can lead to delayed or interrupted system development projects, or a system that is later judged to be unsatisfactory or unacceptable, has high maintenance costs or undergoes frequent changes [65].

4.2.1.2 Difficult to Strike a Balance between Agility and Stability

Many parts of the case company, at least those that fall within the scope of this study, use Agile practices, which is underlined by both interviews and internal information. Defined as an iterative approach to software development that encourages changing requirements (even late in development), Agile practices have long been appreciated for its many benefits in terms of improved communication, increased quality, and higher productivity [66]. However, it seems that the approach is not applicable to all development projects. In Agile projects, it is challenging to strike a good balance between agility and stability (degree of commitment in relation to flexibility for late changes) [67]. This is especially true for large and complex manufacturing systems [40]. In such systems, there may be architectural aspects that are difficult and costly to change due to the critical role they play in the core services offered by the system [68]. This was confirmed by Alex as seen in the excerpt in Table 4.8 below.

Table 4.8: An excerpt from the interview with Alex that showcases the perceived lack of structure and stability in agile manufacturing projects.

Alex:	"In [agile] software projects, there is far too much flexibility and openness. There is no structure or stability. It is difficult to make later changes in [manufacturing] projects. The system design is relatively large and if it is done wrong, it costs a lot to change."

If several suppliers are involved in a project, which will often be necessary in the 5G era, it will only be more difficult to make changes. This is because such collaborations are often based on contracts that precisely stipulate what is required of the supplier [68]. What is more, suppliers do not belong to the same company or organization and, therefore, do not necessarily share a common business goal. This can easily result in proposed changes not being in line with everyone's interests and priorities [69]. Judging from the chart in Figure 4.3 below, the employees surveyed seem to agree that it is difficult to make requirements changes when many suppliers are involved in a development project. More specifically, there seems to be a great need for stability and rigid requirements (requirements that cannot be changed).

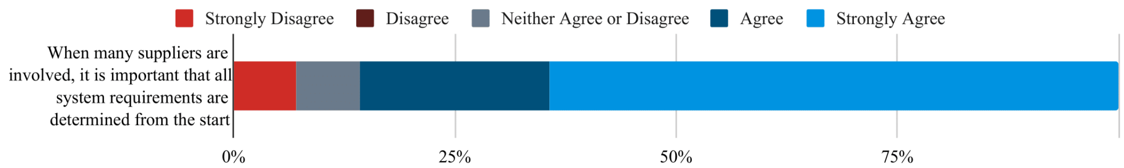

Figure 4.3: 85.7 % of those surveyed believe that when many suppliers are involved in a development project, it is important that all system requirements are determined from the start.

4.2.2 Challenging System Design

This section covers challenges regarding the design of manufacturing systems and how these could be affected with the introduction of 5G. Challenges identified concern security issues in distributed architectures, which will be necessary in a 5G manufacturing system, the company's inevitable legacy, and finally the fact that the more suppliers involved in a project, the more complex the system integration becomes.

4.2.2.1 Security and Privacy Concerns in Needed Architecture

As already established, Industry 4.0 introduces an increased vulnerability to cyberattacks. With the advent of 5G, the security threat is expected to be greater than ever before, as is the concern for privacy [51]. This is a challenge that the majority of those surveyed at the case company expect to face with the deployment of a 5G-enabled Industry 4.0 case, as is made clear by the chart in Figure 4.4 below.

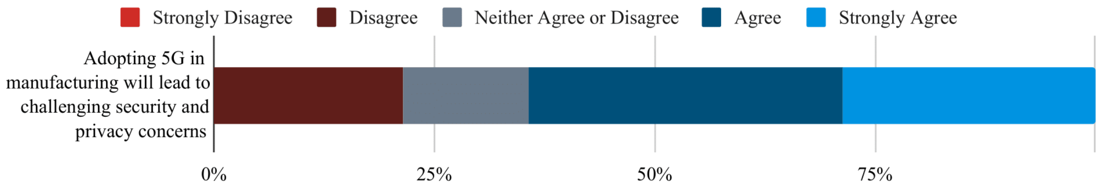

Figure 4.4: 64.3 % of those surveyed believe that adopting 5G in manufacturing will lead to challenging security and privacy concerns.

Security challenges posed by 5G depend not only on the wireless nature of mobile networks but also on the potential technologies that are very important, if not necessary, for 5G. For example, many of the interviewees explain that when 5G is adopted in manufacturing, an edge computing architecture will need to be part of this transition. As already mentioned, 5G will generate huge amounts of data and has to meet strict quality of service requirements, something that traditional cloud computing models are not suitable for. In the excerpt in Table 4.9 below, Morris highlights that edge computing is necessary for 5G.

Table 4.9: An excerpt from the interview with Morris that highlights the need for edge computing in a 5G world.

Morris:	"When talking about architecture and 5G, it is important to mention mobile edge computing. With it you can process [data] locally and send data only when needed. This allows you to get lower latency. Although this type of architecture is advanced, it will help [manufacturing] in the future."

Although edge computing delivers many benefits, it presents critical challenges, especially in terms of security and privacy. Firstly, edge servers are more susceptible to attacks (malware injection attacks and distributed denial-of-service attacks, to name but a few) than cloud servers because they are not as computationally powerful and thus not as good at maintaining strong defense systems [33]. Secondly, the inherent heterogeneity of edge computing systems, that is, different edge servers may be deployed by different suppliers, makes conventional trust and authentication mechanisms inapplicable [35]. Finally, the fact that all assets (network infrastructure, service infrastructure, and user devices) are not controlled by a single actor but by several raises privacy issues. For example, as data is outsourced to third parties where data ownership and control are separated, users face the risks of data loss, data leakage, and illegal data management [51]. The fact that manufacturers such as the case company are worried about the security and privacy issues that may come from sharing assets with external parties in the cloud was made clear during the interview with Gil from Atlas Copco (see the excerpt in Table 4.10 below).

Table 4.10: An excerpt from the interview with Gil that showcases manufacturers security and privacy concerns that may come from sharing assets with external parties in the cloud.

Gil:	"[Manufacturers] are not always so eager to connect to the cloud. Even though they know that we comply with [General Data Protection Regulation], that we mask data, and that everything is as secure as it can be, they still do not want to connect for reasons of principle. It varies between factories and cultures, but it is still something you need to think about. Admittedly, they should be careful when someone is allowed to communicate with their individual tools. It could, quite frankly, be used for sabotage."

In addition to this, each actor must maintain their own assets, by, among other things, updating software. The fact that external parties would not only have access to data from the manufacturing facilities but also need to introduce software to its systems on a regular basis is something that the majority of those surveyed believe could pose a security problem. This can be seen in Figure 4.5 below.

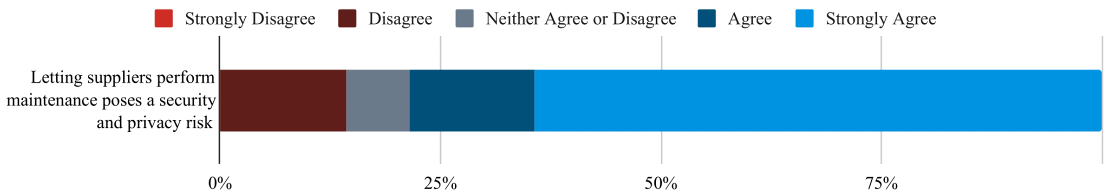

Figure 4.5: 78.6 % of those surveyed believe that letting suppliers into the case company's systems to perform maintenance poses a security risk.

4.2.2.2 Legacy Inhibits Technological Advancement

The case company has manufactured trucks for many decades and have done so using almost the same manufacturing systems throughout the years. In recent years, their roadmap has revolved around achieving the goals of Industry 4.0. However, there seems to be a general agreement among the interviewed case company employees that due to the inevitable presence of legacy, it will be difficult to evolve the current systems to become fully 5G and Industry 4.0 compatible. This is also apparent in the survey responses, with the majority of the survey respondents agreeing that legacy systems constrain technological advancements (see the chart in Figure 4.6).

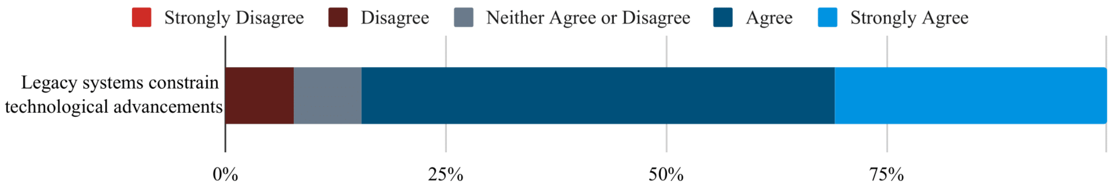

Figure 4.6: 84.6 % of those surveyed believe that legacy systems constrain technological advancements.

Instead of completely transitioning to what Industry 4.0 entails, the case company has, according to case company employee Pam, found a way to be bi-modal, meaning that they get legacy systems to work with new technologies wherever necessary (see the excerpt in Table 4.11). The reasoning behind this is that the case company finds it too expensive to do a full transition and going bi-modal keeps the fundamental functionality unchanged.

Table 4.11: An excerpt from the interview with Pam in which she describes why the case company builds bi-modal systems.

Pam:	"We try to be bi-modal. We have a mindset and a pattern for how we can combine new technology with older technology. It is very difficult to replace systems in factories just like that. It is associated with very high costs. Once you have those systems in place, you run them for quite some time. You learn to live with them and build on top."

By keeping the legacy systems and building on top of them, the case company could put themselves in a position where it is difficult to make technological progress. Even if the first iteration of introducing new technologies into the facilities might work, the case company is putting themselves at risk of hindering the new technology to update properly if it has been too adapted to the legacy systems. This was explained by case company employee Clint as seen in the excerpt in Table 4.12 below.

Table 4.12: An excerpt from the interview with Clint in which he explains that legacy inhibits technological advancement.

Clint:	"I know from experience that it is difficult to transfer legacy systems to new technologies. This often limits the use of the new technology. If you develop a special solution in your legacy that can handle 5G and then something changes in the 5G standard, then your solution may no longer work. Then you can not update to the latest release of the new technology."

According to supplier interviewees, the reluctance of the case company, and similar companies, to let go of its legacy systems is becoming a bottle-neck that inhibits flexibility (as seen in the excerpt in Table 4.13).

Table 4.13: An excerpt from the interview with Caroline in which she argues that legacy systems inhibits manufacturing flexibility.

Caroline:	"What I hear most about right now is flexibility, but how do you fulfill flexibility when you have an old infrastructure? It's not going to happen. Then it becomes a matter of legacy – they live on in the old days. They dream of flexibility but have difficulty moving forward."

4.2.2.3 Complex Integration in Multi-Vendor Systems

Current manufacturing systems will require new devices and system components to fulfill the goals of Industry 4.0. Such new devices and components will not only need to work together with manufacturers' legacy systems (resulting in challenges described in Section 4.2.2.2) but also with heterogeneous devices and components from different suppliers. This creates a great need for interoperability, which was touched on by Penny (see the excerpt in Table 4.14 below).

Table 4.14: An excerpt from the interview with Penny that highlights the importance of interoperability in multi-vendor systems.

Penny:	"The manufacturing industry is an industry that is strongly characterized by a multi-vendor system. A system is built up with system components from several different suppliers. They must work together, which makes interoperability between devices very important."

As 5G is expected to increase the number of suppliers, the importance of interoperability will also increase. If this is not taken into account by everyone involved, it will be difficult to integrate components from different suppliers into a cohesive manufacturing system [70]. The majority of the employees surveyed seem to be worried that this will be the case in the 5G era. When asked whether system integration becomes more complex when many suppliers are involved, the case company employees agree that it does (see the chart in Figure 4.7 below).

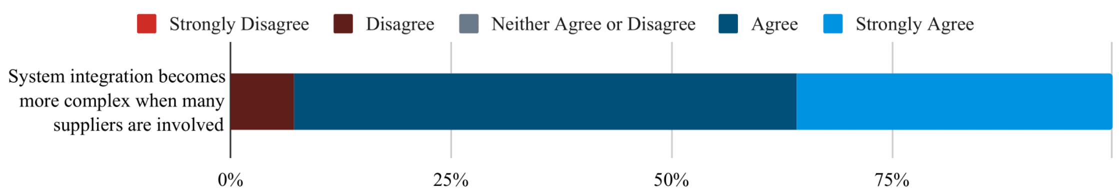

Figure 4.7: 92.8 % of those surveyed believe that system integration becomes more complex when many suppliers are involved.

Negligence of (or a lack of awareness about) interoperability could manifest itself in many different ways. For example, one case company employee touched on the risk of different equipment suppliers partnering with different telecommunications operators and, perhaps, different cloud providers (see the excerpt in Table 4.15). This would, to say the least, put a strain on interoperability.

Table 4.15: An excerpt from the interview with Pam in which she talks about what interoperability challenges 5G could bring.

Pam:	"5G is very new, so to speak. It requires new patterns and new ways of integrating systems. What happens if a new supplier comes into the picture and they happen to cooperate with another telecommunications operator? And a completely different cloud service provider? What do you do then?"

System integration problems like the one mentioned above are exacerbated by the fact that the case company has many system components that are both hard-coded and duplicated. Hence, they are built in such a way that they cannot be modified in a simple and generic way, which, in turn, results in each new integration requiring to be made unique depending on the system component in question. On top of this, the case company's systems suffer from high coupling, which also puts a strain on system integration. All these problems that the case company has with its current system components are raised by Morris (see the excerpt in Table 4.16 below).

Table 4.16: An excerpt from the interview with Morris in which he mentions the case company's extensive use of hard-coded solutions.

Morris:	"Today, many of our technical solutions are hard-coded. We also have a lot of dependencies between applications. There are different variants of applications as well."

4.2.3 Challenging Maintenance

Many of the challenges that are expected to face the case company in the 5G era are, as already established, related to the fact that they will become dependent on their suppliers and partners to a greater extent than before. This also became clear in the maintenance phase, especially in terms of security and privacy (as discussed in Section 4.2.2.1). Another challenge identified in this phase was that it will be more difficult to pinpoint the source of failure in a manufacturing system in which different parts come from different suppliers. In connection with this, many of the interviewees expressed concern about whether this would increase the repair time. This is problematic, mainly for financial reasons: The longer there is a production stoppage, the greater the financial consequences. Pam explained this in her interview (see the excerpt in Table 4.17 below):

Table 4.17: An excerpt from the interview with Pam about the effects that hours of production stoppage has.

Pam:	"If there are many different components and actors involved that integrate with each other, then it becomes a big challenge once [the factory] is at standstill. Who should I call? If something goes wrong in a factory, you only have minutes before you have to get things started and make it work again. Hours of production stoppage often result in very large costs."

Another challenge that was identified and which is also linked to manufacturers doing everything to avoid production stoppage is related to suppliers' maintenance requirements. Since production can be disrupted by extensive and unpredictable maintenance, many manufacturers, such as the case company, use preventive or predictive maintenance. This ensures that equipment remains reliable and available at the lowest cost possible [10]. If these guidelines are not successfully communicated to all suppliers and one of them issues an update or patch requiring it to be addressed within three months, as Ericsson usually does for security reasons, there is a risk that manufacturers may not be able to comply.

A majority of those surveyed agreed with the aforementioned maintenance challenges, that is, it being difficult to pinpoint the source of failure when many suppliers are involved and that it would be challenging to meet suppliers' requirements for system update rates. This can be seen in the chart (Figure 4.8) below.

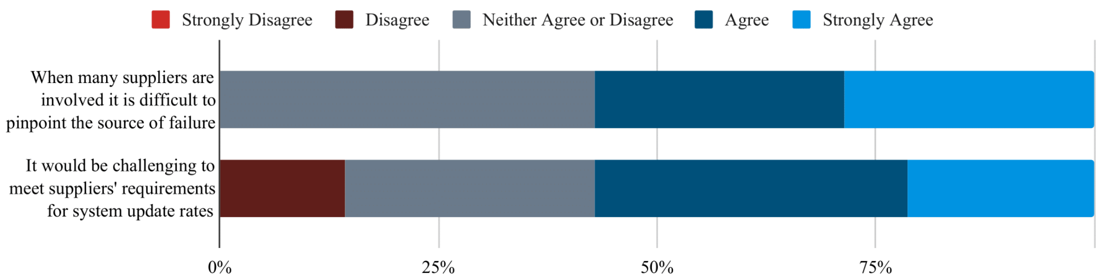

Figure 4.8: 57.2 % of those surveyed believe that it is difficult to pinpoint the source of failure when many suppliers are involved. An equal percentage believe that it would be challenging to meet suppliers' requirements for system update rates.

4.3 Differences from Challenges Unrelated to 5G

This section presents how the aforementioned challenges differ from those that the case company would encounter in Industry 4.0 projects unrelated to 5G. Through this, it intends to answer the study's third research question, namely:

> *How do these perceived Software Engineering challenges differ from those found in Industry 4.0 projects unrelated to 5G?*

Overall, many of the challenges identified by this study are similar to those not related to 5G and found in related work in the sense that they fall into the same categories, namely security and privacy as well as system architecture and integration. However, this study has discovered that 5G will add another layer of complexity to already existing challenges. In terms of security and privacy, manufacturers will, as mentioned in Section 4.2.1.1, become dependent on suppliers and their services to a greater extent than before the 5G era. This, in turn, leads to assets, such as manufacturing data, inherently becoming more accessible to external suppliers. Moreover, Section 4.2.2.1 establishes that 5G requires an edge computing architecture. Besides being advanced and novel, at least from the perspective of the case company, the paradigm poses a new set of security and privacy challenges. In terms of system architecture and integration, more suppliers result in more complex system integration, which creates a greater need for interoperability in the 5G era. Consequences that this is perceived to have for manufacturers are a greater need for more rigid requirements and failure origin being more difficult to pinpoint.

On the other hand, this study has identified challenges that are somewhat unique to the 5G era, that is, they are not necessarily found in related work. For example, the introduction of 5G will not only create a knowledge gap but also create a noticeable difference in knowledge among suppliers. In other words, some suppliers, such as mobile network suppliers, will have cutting-edge expertise when it comes to 5G, while others will not possess any expertise. This means that companies will be dependent on each other's maturity levels (not only at the technological level but also at the business level) in order to make technological progress themselves. Pam explained this in her interview (see the excerpt in Table 4.18 below):

Table 4.18: An excerpt from the interview with Pam in which she mentions that the case company is dependent on their suppliers' degree of maturity.

Pam:	"I think it will take a couple of years before you can have [the use case] in production and feel that it is robust. However, it depends on how the suppliers' degree of maturity develops. We are very dependent on [their degree of maturity]."

A couple of other challenges were identified which, although not raised by many interviewees or agreed on by many survey respondents, are still worth highlighting because they are so unique to 5G. To begin with, there seems to be a great deal of skepticism about 5G. For example, some interviewees reported that blue-collar workers are sceptical about the technological transition that 5G entails. This is problematic because it is the blue-collar workers who will use the technology and sometimes be in close proximity to it (for example, human-robot collaboration). In the excerpt in Table 4.19 below, George describes the way in which this skepticism has been expressed.

Table 4.19: An excerpt from the interview with George regarding blue-collar workers' skepticism about 5G.

George:	"I think that Sweden itself is quite tolerant. However, we made an attempt in a factory here in Sweden, where we had a robot that helped an operator and partly took over his tasks, and it was sabotaged several times at night."

Moreover, the use of 5G is increasing during a time of international uncertainty and mistrust of some foreign countries [71]. This leads to the Swedish government having opinions about which 5G frequency bands may be used, which data may be allowed to leave the country, and which foreign suppliers Swedish manufacturers may cooperate with [72]. Such regulations could potentially have an inhibiting effect on manufacturers' technological progress. What is more, the durability of 5G-enabled manufacturing solutions could also be limited if such regulations are changed, or rather, tightened. Manufacturers and their suppliers have not had to comply with similar regulations before, as was made clear by Alex (see the excerpt in Table 4.20).

Table 4.20: An excerpt from the interview with Alex in which he explains that manufacturers are unfamiliar with the type of regulations that now exist for 5G.

Alex:	"All of a sudden, there are statutory restrictions to take into account. For example, Chinese 5G equipment is now banned in Sweden. Such restrictions have never existed before."

4.4 New Practices

This section focuses on the question whether the challenges identified in this study puts the case company in such a position that it needs to introduce new Software Engineering practices in order to take full advantage of the opportunities presented by 5G-enabled Industry 4.0 use cases. It also presents what these practices might look like. Through this, it intends to answer the study's fourth and final research question, namely:

> *Is there a need for new Software Engineering practices? If so, what could they be?*

As explained in the previous section, many of the challenges identified by this study are similar to those not related to 5G and found in related work. This gives reason to believe that the challenges in question are not unique enough to require new solutions. As such, the case company does not necessarily need new Software Engineering practices per se. Instead, they need to be wary about the aforementioned challenges and develop guidelines for navigating Industry 4.0 projects in the 5G era – multi-vendor projects that have strict requirements on system robustness, interoperability, and security. In some cases, this may mean that the company should modify its current practices.

4.4.1 Hybrid Development Approach

Industry 4.0 projects in the 5G era should aim for less agility (for reasons mentioned in Section 4.2.1.2) and instead incorporate characteristics of traditional plan-driven development processes, at least at early project stages, to better achieve system robustness. This involves defining requirements before designing the manufacturing system, which, in turn, ensures high predictability. The fact that manufacturers should adopt a more plan-driven process was something that Alex agreed with (see the excerpt in Table 4.21 below).

Table 4.21: An excerpt from the interview with Alex in which he argues that a plan-driven process could benefit Industry 4.0 projects in the 5G era.

Alex:	"I think you have to work a little bit according to the waterfall model when you make certain parts of large systems. Otherwise there will be far too much flexibility and openness. There will be no structure."

Nevertheless, the case company should incorporate the agile principle of cross-functional teams as it can mitigate the lack of domain knowledge obstructing the process of Requirements Elicitation (see 4.2.1.1): By improving the communication between the business and the engineering roles, the requirements can be identified, communicated, and agreed upon more efficiently [67]. In addition to this, cross-functionality is necessary for Industry 4.0 to say the least: It helps to generate knowledge, improve communication, increase collaboration, and stimulate innovation [73]. Research suggests that a hybrid process (combined characteristics from both agile and plan-driven processes) is beneficial for large-scale projects as it helps to eliminate requirements uncertainties early on, subsequently leading to an increased project success rate [74]. One such hybrid approach is the "hybrid by phases", meaning that the phase of the project determines which development process to use [74]. For example, the case company could adopt the Requirements Engineering phase found in plan-driven processes and combine that with a development phase that adheres to Agile principles.

4.4.2 Introduce Industry 4.0 Reference Architecture

As has been mentioned many times already, the key to success in the 5G era is multi-vendor interoperability. This can only be achieved through coordinated standardization actions [75]. The industry as a whole, rather than individual manufacturers, must introduce a standardized way of integrating different suppliers' heterogeneous devices into manufacturers' legacy systems. Some of the issues that are currently confusing the manufacturing industry and that require standards are the co-existence of different wireless protocols and systems as well as the interoperability between wired and wireless communication systems [76].

Individual manufacturers, however, cannot and must not stand idly by while these standards are definitively determined. Instead, this study suggests that manufacturers should take initiatives that can facilitate interoperability within the own organization. More specifically, manufacturers should adopt an Industry 4.0 reference architecture (for example, The Reference Architectural Model Industrie 4.0 or RAMI 4.0 for short [77]) that transcends the boundaries of a single smart factory and shows the entire organization how to approach the issue of Industry 4.0 in a structured manner. A reference architecture is especially important to have in an organization as large as the case company because it ensures that everyone has a common understanding of Industry 4.0 technologies. This was emphasized by Alex (see the excerpt in Table 4.22 below).

Table 4.22: An excerpt from the interview with Alex in which he emphasizes the importance of having a Industry 4.0 reference architecture.

Alex:	"I think you have to put your [reference architecture] first when building complex systems in which there are a lot of people involved."

4.4.3 Security by Design

On the issue of one of the most critical aspects of the 5G era, security and privacy (see Section 4.2.2.1), there needs to be a shift in attitude among manufacturers. Rather than being seen as a system add-on or enhancement, security and privacy should act as an outset for both the design and development of manufacturing systems. As such, this study proposes the "security by design" approach, that is, the act of designing systems to be foundationally secure. Prior to the design phase, this could include identifying potential security threats to the system and addressing them with design decisions [78]. The "security by design" approach was also mentioned by Penny (see the excerpt in Table 4.23 below).

Table 4.23: An excerpt from the interview with Penny in which she highlights the importance of security by design.

Penny:	"Security is a very important part [of the design]. There is talk of security by design instead of security enhancements."

In terms of privacy, Industry 4.0 entails inevitable sharing of assets between suppliers. As mentioned in Section 4.2.2.1, manufacturers appear to be skeptical about sharing manufacturing data with external parties, making it difficult for their suppliers to access the resources needed for certain use cases (for example, smart tools). In order take full advantage of the opportunities presented by 5G-enabled use cases, manufacturers should strive to overcome their skepticism by building trust with their suppliers (especially if the suppliers in question comply to privacy regulations such as the General Data Protection Regulation).

5

Discussion

This chapter discusses the findings of the study – what consequences they have for the manufacturing industry and Software Engineering research as well as how valid they are. In other words, this chapter presents how manufacturers can benefit from this study, the ways in which it calls for further research, and, finally, threats to its validity.

5.1 Implication for Practice

Industry 4.0 will make truck manufacturing more flexible and agile, but needs 5G in order to enable all its promises. The findings of this study can guide truck manufacturers, and hopefully manufacturers in general, who have thoughts of implementing elements of Industry 4.0 in a 5G era, but who are unsure of what this entails.

By presenting Industry 4.0 use cases that 5G is seen to enable in the truck manufacturing industry and the possibilities that come with said use cases, this study can support manufacturers who are in the process of exploring what use cases can generate the most value for them. This, in turn, can help manufacturers decide how to allocate their resources and what use cases to incorporate into their technology roadmap.

Furthermore, this study gives an idea of what challenges manufacturers may face during the implementation of 5G-enabled Industry 4.0 use cases. Initially, the case company was overwhelmed by 5G and expected that the introduction of the new wireless technology in an Industry 4.0 context would require a major shift in the organization. This study, on the other hand, has identified that the challenges that the company may face in the 5G era do not differ significantly from challenges found in Industry 4.0 projects unrelated to 5G (many fall into the same categories). Admittedly, 5G will increase the complexity of already existing Industry 4.0 challenges, but often this is due to to factors that can be addressed by the manufacturers themselves: Lack of knowledge, experience, trust, and suitable business models. In other words, manufacturers will need to garner knowledge about 5G (for example, by doing pilot projects), make an effort to establish trust with their suppliers, and create clear and common business goals – not only within the organization but also together with suppliers.

The companies that participated in this study all agreed on the major challenges, which means that the supplier companies have experienced these challenges during collaborations with other manufacturers, not just truck manufacturers. This suggests that the results of the study are generalizable, that is, that they are valuable to manufacturers other than the case company.

Finally, this study presents Software Engineering practices that manufacturers should seek to adopt in order to mitigate the aforementioned challenges and take full advantage of the opportunities presented by 5G-enabled Industry 4.0 use cases. Though not necessarily new Software Engineering practices per se, these suggestions can serve as guidelines for adopting parts of Industry 4.0 in the 5G era as painlessly as possible. Many of the guidelines were explicitly mentioned by the case company interviewees, making them, to some extent, aware of their options for addressing the challenges at hand. Even if this study does not provide manufacturers with completely new knowledge, it still serves as a collection of guidelines in a tangible, compiled, and structured medium.

5.2 Implication for Research

Although the role of Software Engineering is indisputable in Industry 4.0, research on it is scarce (especially in the context of 5G). This study helps fill that research gap by, among other things, identifying the key Software Engineering challenges that a manufacturer is expected to face during the implementation of an Industry 4.0 use case in the 5G era. What is more, the challenges have in themselves the potential to form the basis for future Software Engineering research. For example, researchers can examine said challenges in more detail, that is, their technological aspects, full scope, and potential consequences. Alas, the breadth of this study did not allow for an in-depth look at the challenges.

Other ways in which this study helps to fill the research gap are by presenting a number of Software Engineering practices, or rather, guidelines that manufacturers should adhere to in order to mitigate the aforementioned challenges. Future research should examine, in a real world setting, whether the proposed guidelines actually address the challenges they are supposed to address. For example, a researcher could investigate whether a hybrid software development approach helps manufacturers strike the necessary balance between agility and stability, to what extent an Industry 4.0 reference architecture facilitates interoperability and common understanding within an organization, and if the security by design approach in fact makes manufacturing systems more secure. Like the proposal for future research in the above paragraph, this did not fall within the scope of this study.

Finally, this study has identified a need for, as well as a lack of, research in the field of Industry 4.0 partner ecosystems – entities that will, as already mentioned throughout this study, only get bigger in the 5G era. Before manufacturers can find themselves entangled in complex partner ecosystems along with suppliers who do not necessarily share the same business goals or trust each other, future research should identify best practices for communicating, enabling trust, and collaborating in such ecosystems. According to many of the interviewees in this study, this is the key to a successful implementation of Industry 4.0. One question that could be investigated, for example, is whether the results from research on general software ecosystems can be successfully applied in an Industry 4.0 context.

5.3 Validity

This section discusses the validity of the study, that is, how trustworthy its findings are, in what ways it addressed validity threats, and what it could have done better in terms of validity. This section is structured based on the four aspects of validity described by Runeson et al. [48]: Construct validity, internal validity, external validity, and reliability.

5.3.1 Construct Validity

Construct validity is related to whether the study investigates what it intends to or, in other words, whether the chosen methodology is appropriate for answering the research questions at hand. In the context of this study, this relates to whether the qualitative exploratory case study approach was appropriate. A threat to construct validity, in this case, was that the interviewees could misunderstand the questions they were asked to answer. This threat was addressed by reformulating the interview questions based on the role and company of each interviewee and providing explanations of important terminology. Another threat to construct validity was that the Kitting AGV use case, which was used as a starting point in the interviews to motivate and make it easier for the participants to identify challenges that were relevant to the case company, limited the interviewees' insights by giving a relatively narrow picture of 5G in Industry 4.0. This threat was mitigated by choosing a use case that manages to cover many Industry 4.0 technologies.

5.3.2 Internal Validity

Internal validity is of concern when a cause-effect relationship is investigated and a third factor affects that relationship. One such factor in this study is participant bias, wherein the supplier companies have an incentive to present their products and services in a positive light. Thus, they might have been reluctant to mention any challenges during the interviews. Despite this, the companies that participated in this study all agreed on the major challenges, making this validity threat less of a concern.

This study identified the major challenges presented in Section 4.2 through the use of a questionnaire sent out to case company employees. By placing the prioritization in the hands of those who are most likely to be directly affected by the challenges in question, this part of the data analysis addresses an internal validity threat related to research bias.

5.3.3 External Validity

External validity is concerned with how generalizable the study findings are or, rather, how interesting the findings are to individuals outside the study itself. In the context of this study, other individuals may refer to truck manufacturers (or manufacturers in general) other than the case company. There is reason to believe that the challenges stated by the interviewees are specific to the case company only. Alas, examining the extent to which the case company's practices and manufacturing systems were unique did not fall within the scope of this study. The fact that the challenges may be specific to the case company may lead to a domino effect on the proposed guidelines designed to address the challenges in question in that they may suit the case company but not necessarily other manufacturers.

In an attempt to address the external validity threat and increase the generalizability of this study, a use case that manages to cover many Industry 4.0 technologies and that is relevant to other manufacturers was used. Another choice made to increase the generalizability was to allow several different suppliers to participate in the study. The fact that the suppliers in question have collaborated with different types of manufacturers made it possible to identify challenges that are relevant not only for truck manufacturers but manufacturers in general.

5.3.4 Reliability

Reliability is concerned with how dependent the analysis is on the specific researchers, that is, how reproducible the findings of the study are. In order to address this aspect of validity, it is necessary that the researchers are transparent regarding their means to derive their findings. For example, the interview guide used in this study (see Appendix A) should, ideally, generate similar results if participants with similar roles as the ones in Table 3.1 are interviewed. Still, the validity threat is still present due to the risk of discrepancies in the data as a result of the semi-structured interviews leaving room for discussions unique to every participant.

6
Conclusion

The role of Software Engineering is indisputable in Industry 4.0, which made it necessary to investigate whether manufacturers need to change their current Software Engineering practices in order to successfully implement elements of Industry 4.0 in the 5G era.

Through a series of interviews, it was possible to identify challenges that a truck manufacturer may face during the implementation of an Industry 4.0 use case in the 5G era given their current Software Engineering practices. Overall, Industry 4.0 projects in the 5G era will have strict requirements on system robustness, interoperability, and security. This will reportedly be challenging for the truck manufacturer in question to achieve in view of their current practices and technologies. Such projects will also, to a greater extent than before, rely heavily on partnerships with suppliers. This will result in more complex system integration and maintenance, while the current lack of domain knowledge and trust among partners will hamper the success of potential Industry 4.0 use cases.

In connection with this, this study was able to discern Industry 4.0 use cases that 5G is seen to enable in the truck manufacturing industry and the possibilities that come with them. After all, the truck manufacturer in question was contemplating what use cases would generate the most value. Although many use cases were mentioned during the interviews, it was clear what use cases all interviewees agreed would contribute the most tangible and concrete value to the truck manufacturing industry: Smart tools and moving robots.

Using literature, this study concluded that the aforementioned challenges do not differ significantly from challenges found in Industry 4.0 projects unrelated to 5G, although 5G will increase the complexity of already existing Industry 4.0 challenges. In other words, not many of the challenges identified in this study were unique enough to require further research and new solutions. Still, this study managed to compile Software Engineering guidelines that may help the truck manufacturer, and hopefully manufacturers in general, mitigate some of the aforementioned challenges. In summary, these guidelines suggest that manufacturers should strive for less agility and incorporate characteristics of traditional plan-driven development processes to better achieve system robustness, introduce a Industry 4.0 reference architecture to facilitate interoperability and common understanding within the organization, and adopt a "security by design" approach to make manufacturing systems more secure.

Research on Software Engineering in Industry 4.0 is scarce (especially in the context of 5G) and this study helps fill that research gap while simultaneously calling for further research. More specifically, future research should examine whether the proposed guidelines actually address the challenges they are supposed to address. It should also identify best practices for communicating, enabling trust, and collaborating in Industry 4.0 partner ecosystems in the 5G era.

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Appendices

A

Interview Guide

Interview Guide

1 Introduction

1. Present ourselves and the thesis subject.
2. Present the interview goals.
3. Tell the interviewee that the data will be anonymized.
4. Ask the interviewee for their approval to record the interview for later transcription.
5. Tell the interviewee to ask us to clarify a term or definition if needed.

2 Introductory questions

1. What is your role in the company? Briefly describe your responsibilities.
2. How long have you been in this role?
3. How many years have you worked in this particular industry (truck manufacturing)?

3 Investigative questions

Q1 Case Company: Briefly describe the software development practices used in your department.

Q2 Case Company: How do you envision manufacturing technology to look in the future?

Case Company: *Introduce Industry 4.0 and 5G.*

Q3 What use cases do you think 5G could enable in the truck manufacturing industry?

Case Company: *Introduce Volvo Trucks Industry 4.0 use case (Kitting AGV).*

Q4 Case Company: Given the use case presented, where does software play a role?
Partner Company: Given these use cases, where does software play a role?

Define Software Engineering as a field (using the steps of a software development process).

Case Company: *Ask the interviewee to tell us how they would bring the Kitting AGV use case into existence at the company in an existing factory. Remind them to take company software development practices into consideration and follow the software development steps below.*

Partner Company: *Ask the interviewee to describe the challenges they have encountered during the implementation of a 5G-enabled Industry 4.0 use case. Remind them to follow the software development steps below.*

Requirements

Q5 Case Company: How would you perform this phase given the following activities?

- Feasibility study
- Requirements elicitation
- Requirements analysis
- Requirements validation
- Requirements management

Q6 Case Company: What challenges do you expect in this phase?
Partner Company: What challenges have you encountered in this phase?

Q7 Case Company: What does the company need, or need to do, in order to overcome these challenges?
Partner Company: How did you go about overcoming these challenges?

Design

Q8 Case Company: How would you perform this phase given the following activities?

- Architectural design
- Interface design
- Component design
- Database design

Q9 Case Company: What challenges do you expect in this phase?
Partner Company: What challenges have you encountered in this phase?

Q10 Case Company: What does the company need, or need to do, in order to overcome these challenges?
Partner Company: How did you go about overcoming these challenges?

Implementation

Q11 Case Company: How would you perform this phase?

Q12 Case Company: What challenges do you expect in this phase?
Partner Company: What challenges have you encountered in this phase?

Q13 Case Company: What does the company need, or need to do, in order to overcome these challenges?
Partner Company: How did you go about overcoming these challenges?

Verification

Q14 Case Company: How would you perform this phase given the following activities?

- Development testing
- System testing
- Acceptance testing

Q15 Case Company: What challenges do you expect in this phase?
Partner Company: What challenges have you encountered in this phase?

Q16 Case Company: What does the company need, or need to do, in order to overcome these challenges?
Partner Company: How did you go about overcoming these challenges?

Maintenance

Q17 Case Company: How would you perform this phase given the following activities?

- Fault repairs
- Environmental adaptation
- Functionality addition

Q18 Case Company: What challenges do you expect in this phase?
Partner Company: What challenges have you encountered in this phase?

Q19 Case Company: What does the company need, or need to do, in order to overcome these challenges?
Partner Company: How did you go about overcoming these challenges?

General

Q20 Case Company: Is the required knowledge (for every phase mentioned) accessible?

Q21 Would you say that the mentioned challenges differ from those found in Industry 4.0 projects unrelated to 5G? If so, how?

Q22 Case Company: Based on all your answers in this interview, make an estimate of how long it will take before the use case is a reality at the company. Please motivate.
Partner Company: How long has it normally taken to implement use cases together with the customer?

4 Wrap-up questions

1. Is there anything we forgot to ask you that you would like to add?
2. Do you recommend anyone else we should talk to?

Thank the interviewee for their time.

B

Codes

Axial Codes	Frequency (Case Company)	Frequency (Supplier)	Pattern Code	Research Question	Finding	Excluded
SCEPTICISM	2		BLUE-COLLAR SCEPTICISM	RQ2		Majority in questionnaire disagreed with this statement.
	4		CURRENT SYSTEMS ARE BIG INVESTMENTS	RQ2		Majority in questionnaire disagreed with this statement.
	3	1	WAIT FOR SOMEONE ELSE TO TRY IT OUT	RQ2		Majority in questionnaire disagreed with this statement.
	1	3	TECHNOLOGICALLY CONSERVATIVE FIELD	RQ2		Majority in questionnaire disagreed with this statement.
	2	1	DIFFICULT TO ACHIEVE ROBUSTNESS	RQ2		Majority in questionnaire disagreed with this statement.
MATURITY LEVEL	3	3	NO ONE IS MATURE	RQ2	Lack of Domain Knowledge Inhibits Requirements Elicitation	
	2	3	NEW AREA	RQ2	Lack of Domain Knowledge Inhibits Requirements Elicitation	
	2	3	LACK OF EXPERIENCE	RQ2	Lack of Domain Knowledge Inhibits Requirements Elicitation	
FUTURE MANUFACTURING CONCEPTS	2	1	AUTOMATION	RQ1	Moving Robots	
	3	3	WIRELESS	RQ1	Moving Robots, Smart Tools	
	3	1	HUMAN-ROBOT COLLABORATION	RQ1	Moving Robots	
	3	4	FLEXIBILITY	RQ1	Moving Robots, Smart Tools	
	1	1	ELIMINATION OF CABLES	RQ1	Moving Robots, Smart Tools	
	4	6	EDGE COMPUTING	RQ1, RQ2, RQ4	Security and Privacy Concerns in Needed Architecture, Smart Tools, Security by Design	
	2	3	LEVERAGE DATA	RQ1	Smart Tools	
		2	POSITIONING	RQ1	Smart Tools	
	1	1	PROCESS OPTIMIZATION	RQ1	Smart Tools	
	3	2	FLEET MANAGEMENT	RQ1	Moving Robots	
	2	2	OPEN A CLOSED ENVIRONMENT TO THE INTERNET	RQ2	Security and Privacy Concerns in Needed Architecture	
SOFTWARE ENGINEERING PRACTICES	3		MANY DEPENDENCIES	RQ2, RQ4	Complex Integration in Multi-Vendor Systems, Introduce Industry 4.0 Reference Architecture	
	2		VARIANTS OF THE SAME APPLICATION	RQ2	Legacy Inhibits Technological Advancement	
	2	2	LONG SYSTEM LIFE CYCLES	RQ2	Legacy Inhibits Technological Advancement	
	2		LACK OF WHITE AND BLUE-COLLAR PERSONNEL COLLABORATION	RQ2		Majority in questionnaire disagreed with this statement.
	1	2	AGILE LEADS TO NO STRUCTURE	RQ2, RQ4	Difficult to Strike a Balance between Agility and Stability, Hybrid Development Approach	
	3		RELY ON OTS SOLUTIONS	RQ2, RQ3, RQ4	*Permeates virtually the entire result because it is related to the code MANY NEW SUPPLIERS.*	
	3	1	BI-MODAL	RQ2	Legacy Inhibits Technological Advancement	
	2	2	AGILE	RQ2, RQ4	Difficult to Strike a Balance between Agility and Stability, Hybrid Development Approach	
USE CASES	4	4	SMART TOOLS	RQ1	Smart Tools	
	4	3	MOVING ROBOTS	RQ1	Moving Robots	
	3	1	UNREACHABLE AREAS	RQ1	Moving Robots, Smart Tools	
	2		AUGMENTED REALITY	RQ1		Decided to focus on the two use cases that had the highest frequency.
		1	DIGITAL TWINS	RQ1		Decided to focus on the two use cases that had the highest frequency.
	2	1	OPERATOR SUPPORT	RQ1		Decided to focus on the two use cases that had the highest frequency.
SYSTEM DESIGN	1	1	INTEGRATION COMPLEX WHEN MANY ARE INVOLVED	RQ2, RQ4	Complex Integration in Multi-Vendor Systems, Introduce Industry 4.0 Reference Architecture	
	2	3	NEED TO BE DECIDED FROM THE START	RQ2, RQ4	Difficult to Strike a Balance between Agility and Stability, Hybrid Development Approach	
	3	1	INTEGRATION IS SLOW	RQ2	Legacy Inhibits Technological Advancement	
	3	4	INEVITABLE LEGACY	RQ2	Legacy Inhibits Technological Advancement	
	2	1	CO-EXISTING TELECOMMUNICATION	RQ4	Introduce Industry 4.0 Reference Architecture	
	2	1	NEED FOR DISTRIBUTED ARCHITECTURE	RQ2, RQ4	Security and Privacy Concerns in Needed Architecture, Security by Design	
REGULATIONS		1	DATA AND NATIONAL SECURITY (LEK)	RQ3	Unique to 5G	
		1	AVOID FOREIGN EQUIPMENT	RQ3	Unique to 5G	
MAINTENANCE	2	2	DIFFICULT TO PINPOINT SOURCE OF FAILURE	RQ2	Failure Origin Difficult to Pinpoint in Multi-Vendor Systems	
	3	1	LEGACY HARD TO UPGRADE	RQ2	Legacy Inhibits Technological Advancement	
	1	2	THIRD-PARTY INVOLVEMENT IS A SECURITY ISSUE	RQ2	Security and Privacy Concerns in Needed Architecture	
	2	2	MAINTENACE PERIOD	RQ2	Difficult to Comply to Required Update Rates	
	2		ON-SITE SUPPORT	RQ2		Majority in questionnaire disagreed with this statement.
	3	2	PRODUCTION STOPPAGE, HUGE COSTS	RQ2	Difficult to Comply to Required Update Rates, Failure Origin Difficult to Pinpoint in Multi-Vendor Systems	

PARTNER ECOSYSTEM	3	1	UNESTABLISHED BUSINESS MODEL	RQ2, RQ4	Difficult to Strike a Balance between Agility and Stability, Introduce Industry 4.0 Reference Architecture	
	3	1	MANY NEW PROVIDERS	RQ2, RQ3, RQ4	*Permeates virtually the entire result.*	
	3	2	LACK OF STANDARDS FOR INTEROPERABILITY	RQ2, RQ4	Complex Integration in Multi-Vendor Systems, Introduce Industry 4.0 Reference Architecture	
ENVIRONMENT	3		OBSTACLES	RQ1	Moving Robots	
	2		INFLEXIBLE DUE TO CABLES	RQ1	Moving Robots	

C

Questionnaire

Challenges Facing the Truck Manufacturing Industry in the 5G Era

The thesis "Perceived Software Engineering Challenges Facing the Truck Manufacturing Industry in the 5G Era" (carried out in partnership with Volvo Group and Ericsson) aims to answer the following research questions:

1. What Industry 4.0 use cases will 5G enable in the truck manufacturing industry?
2. What are the perceived challenges in engineering the software systems of these use cases?
3. How do these perceived Software Engineering challenges differ from those found in Industry 4.0 projects unrelated to 5G?
4. Is there a need for new Software Engineering practices? If so, what could they be?

In this survey, you will be asked to specify your level of agreement or disagreement for a series of statements related to 5G, Industry 4.0, and manufacturing. Each statement is a challenge that Volvo Group may face if they were to adopt 5G to enable Industry 4.0 use cases in their manufacturing facilities. NOTE: If you feel that you do not know how to respond to a statement, feel free to skip it.

For further questions, please contact either zdjelar@student.chalmers.se or ayko@student.chalmers.se

Stakeholders

Challenges in this section are related to Volvo Group's internal and external stakeholders.

1. Volvo Group's vendors are not mature enough when it comes to 5G-enabled manufacturing use cases.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

2. Volvo Group's blue-collar workers are sceptical about the technical transition that 5G entails.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

3. There is a lack of white and blue-collar personnel collaboration at Volvo Group.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

4. When many vendors are involved, it is important that all system requirements are determined from the start.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

System Architecture

Challenges in this section are related to the architecture of Volvo Group's manufacturing systems.

5. Adopting 5G in manufacturing will lead to challenging security and privacy concerns.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

6. Volvo Group's legacy systems constrain technological advancements.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

7. System integration becomes more complex when many vendors are involved.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

Maintenance

Challenges in this section are related to the maintenance of Volvo Group's manufacturing systems.

8. It is difficult to pinpoint the source of failure when many vendors are involved.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

9. It would be challenging to meet vendors' requirements for system update rates (for example, 3 months).

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

10. Letting vendors into Volvo Group's systems to perform maintenance poses a security and privacy risk.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

11. During an extensive system upgrade, vendors should be on site.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

Change Management

Challenges in this section are related to Volvo Group's processes surrounding the adoption of new technologies.

12. Volvo Group's current manufacturing systems are big investments, making it less of a priority to adopt new 5G enabled ones.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

13. I fear that 5G-enabled manufacturing systems will not be as robust as current ones.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

14. Volvo Group should wait for another company to pilot and validate 5G in manufacturing before investing in it themselves.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

15. Volvo Group does not have the required knowledge of 5G-enabled manufacturing use cases.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

16. The truck manufacturing industry is conservative (technologically).

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

D

Questionnaire Results

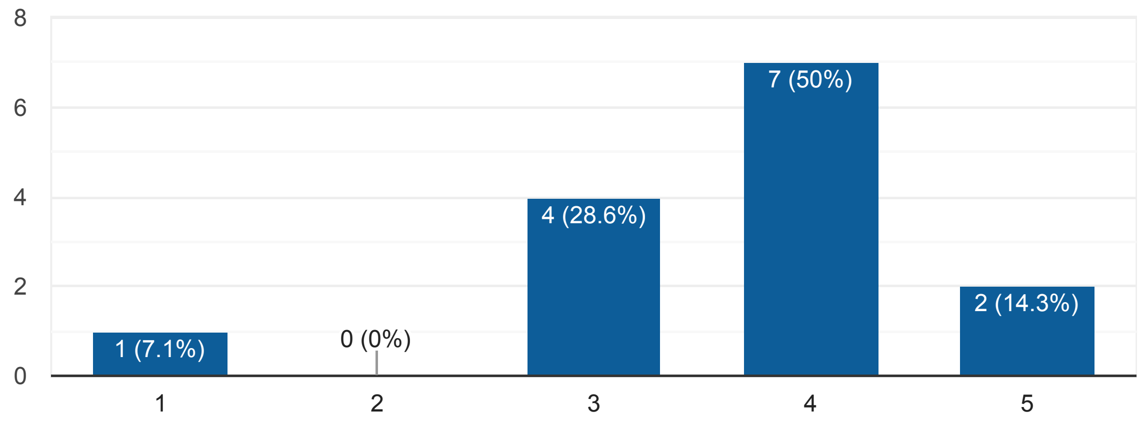
Challenges Facing the Truck Manufacturing Industry in the 5G Era

15 responses

Stakeholders

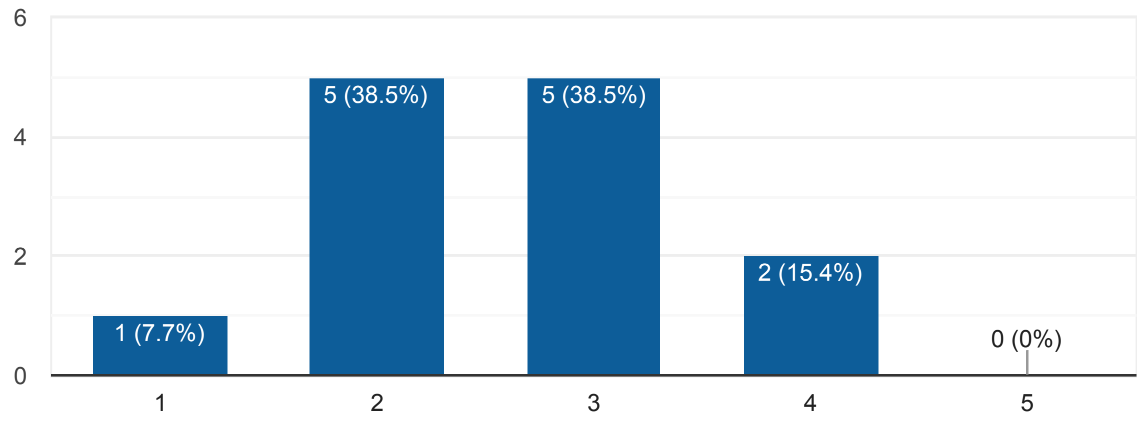
Volvo Group's vendors are not mature enough when it comes to 5G-enabled manufacturing use cases.

14 responses



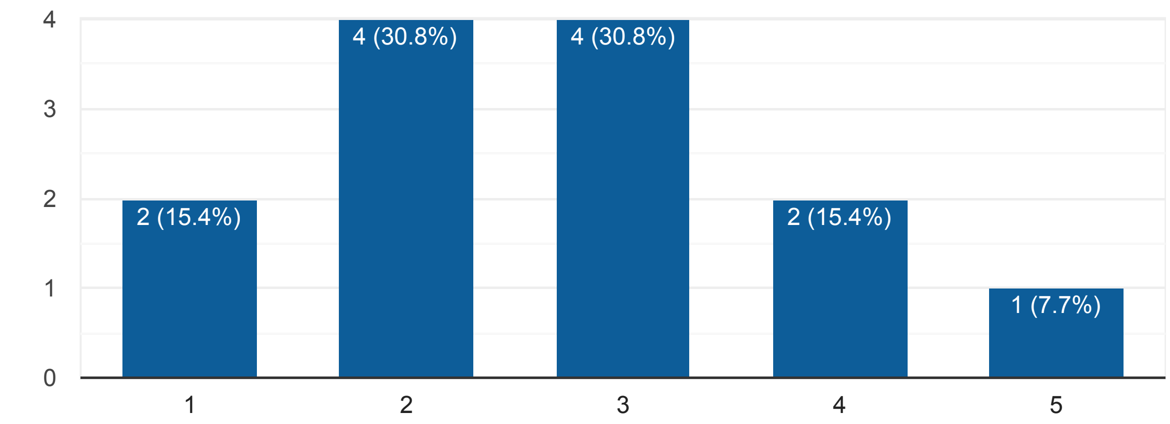
Volvo Group's blue-collar workers are sceptical about the technical transition that 5G entails.

13 responses



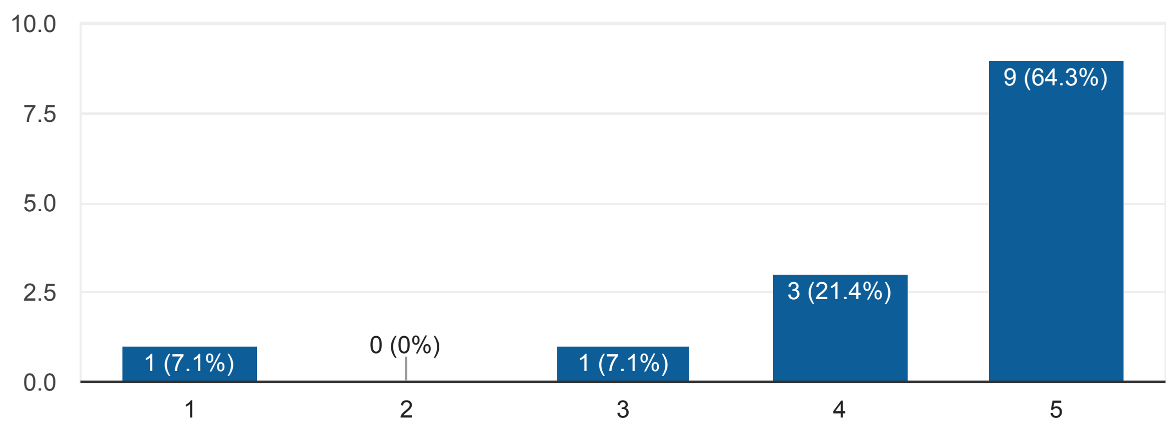
There is a lack of white and blue-collar personnel collaboration at Volvo Group.

13 responses



When many vendors are involved, it is important that all system requirements are determined from the start.

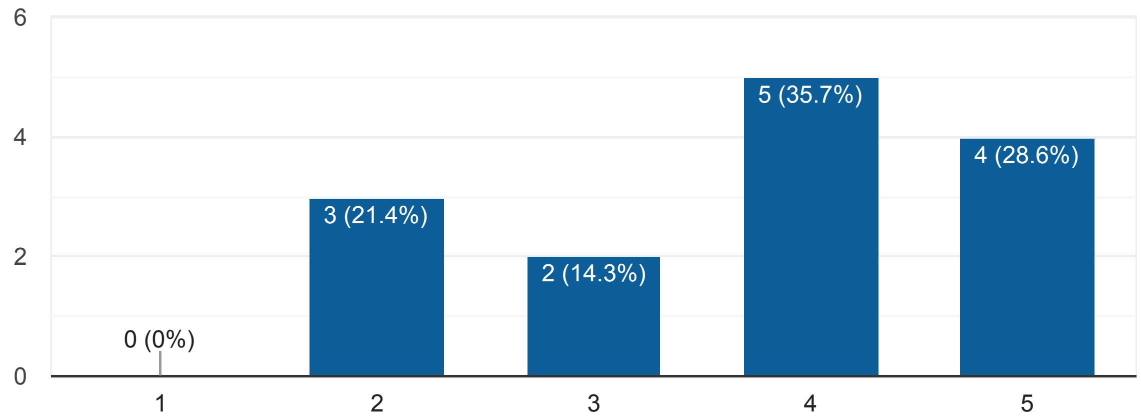
14 responses



System Architecture

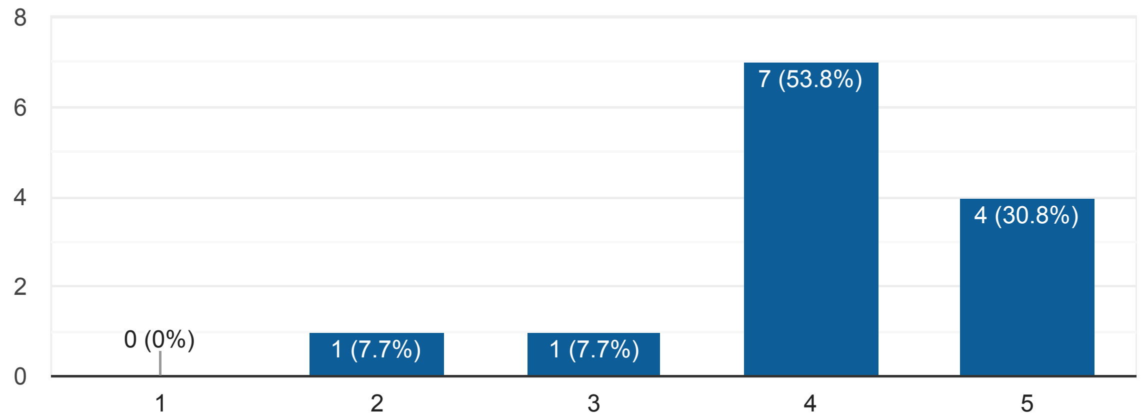
Adopting 5G in manufacturing will lead to challenging security and privacy concerns.

14 responses



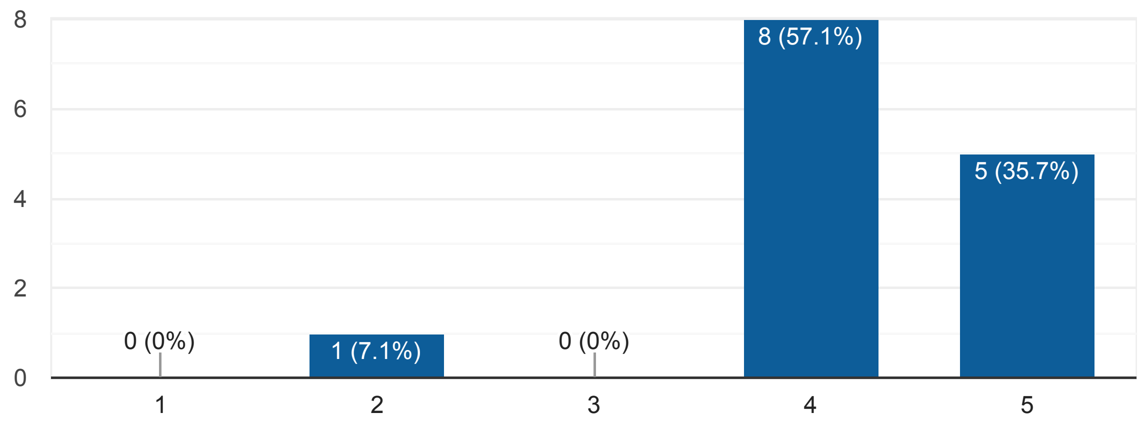
Volvo Group's legacy systems constrain technological advancements.

13 responses



System integration becomes more complex when many vendors are involved.

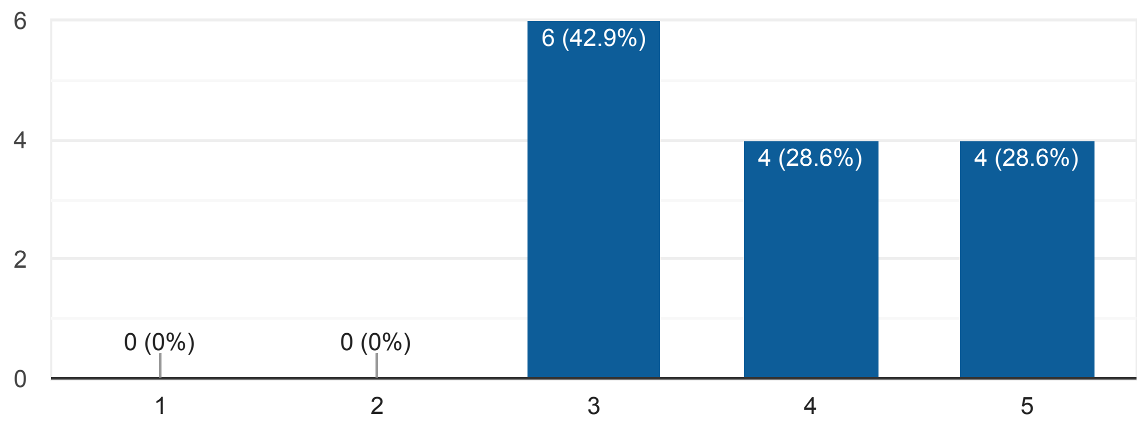
14 responses



Maintenance

It is difficult to pinpoint the source of failure when many vendors are involved.

14 responses



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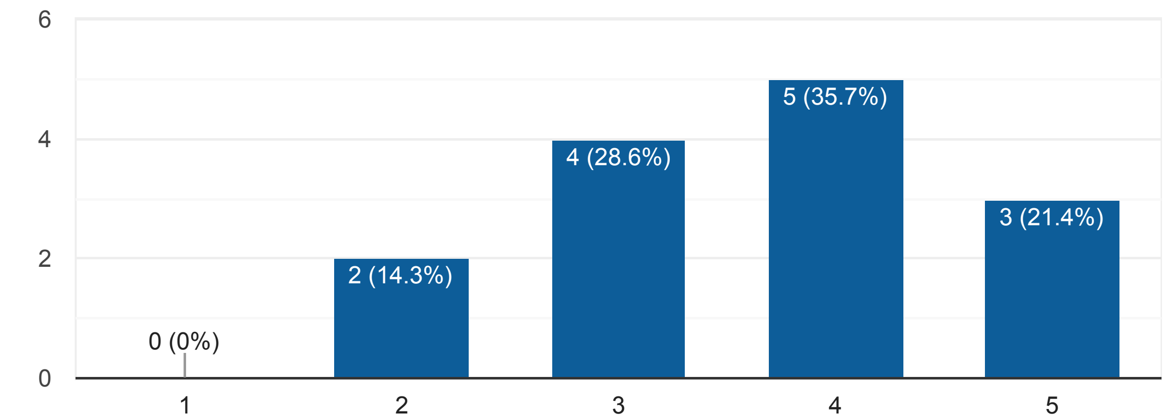
14 responses



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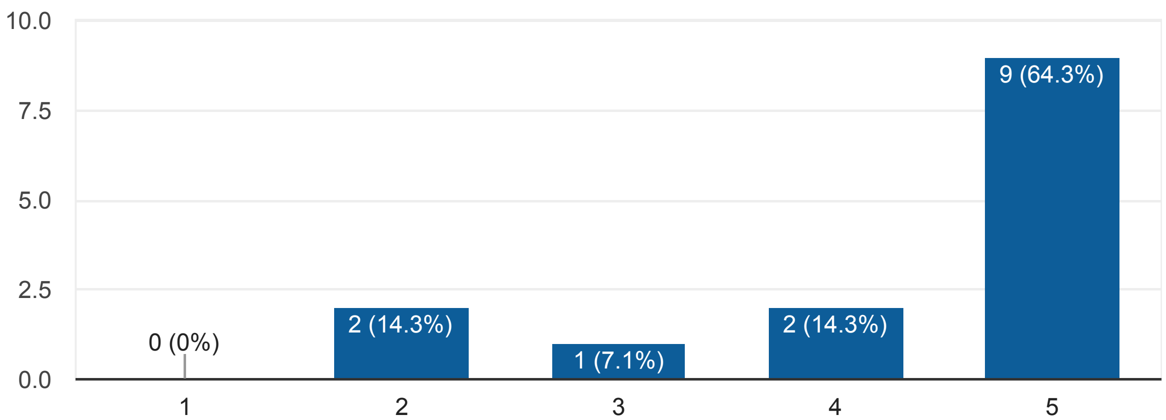
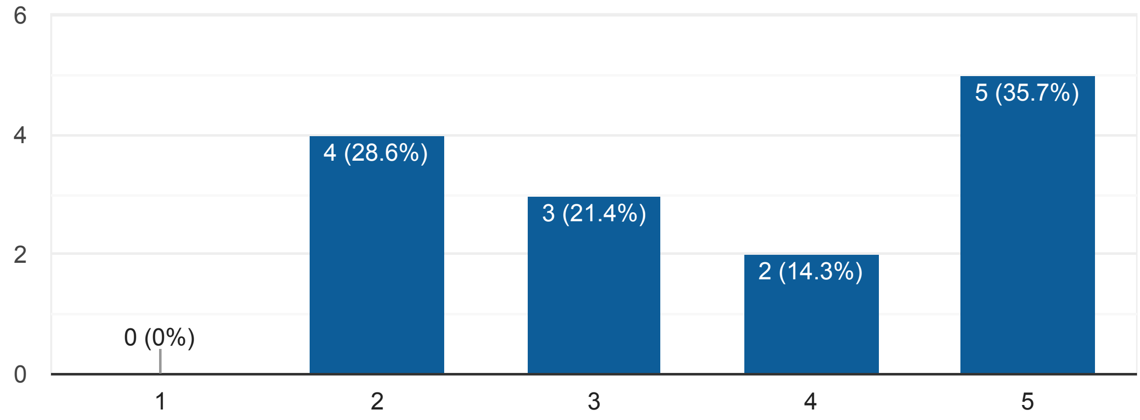
14 responses



During an extensive system upgrade, vendors should be on site.

14 responses



Change Management

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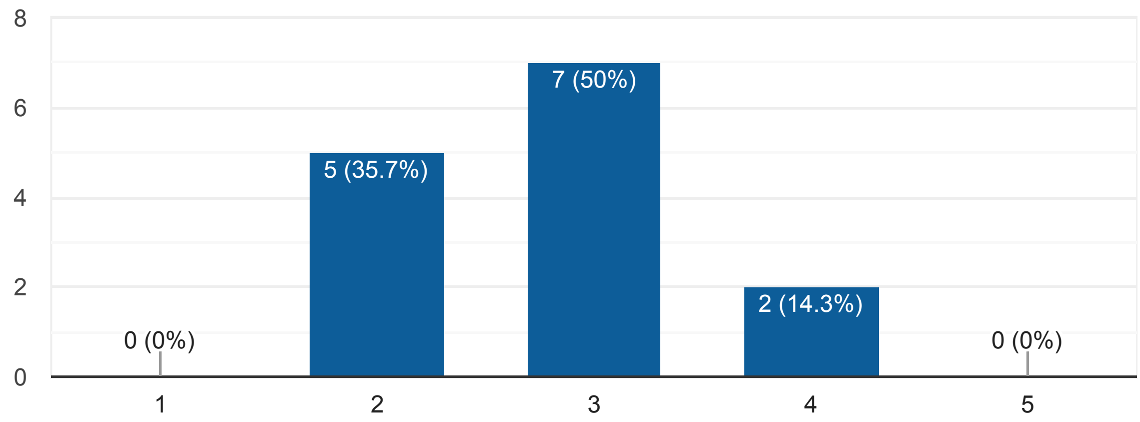
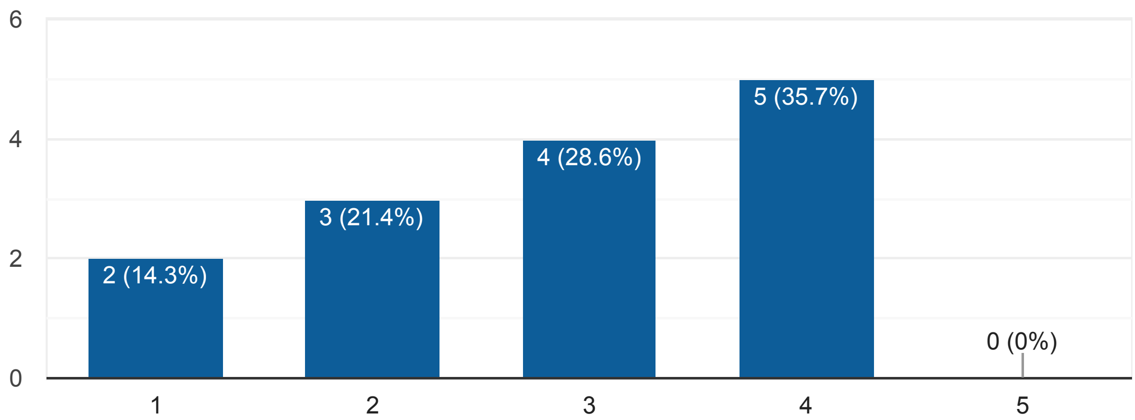
14 responses



I fear that 5G-enabled manufacturing systems will not be as robust as current ones.

14 responses



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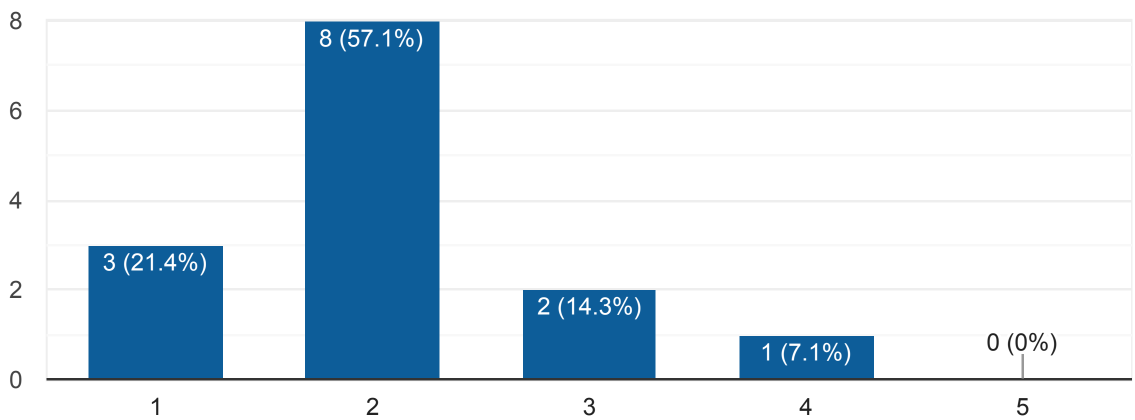
14 responses



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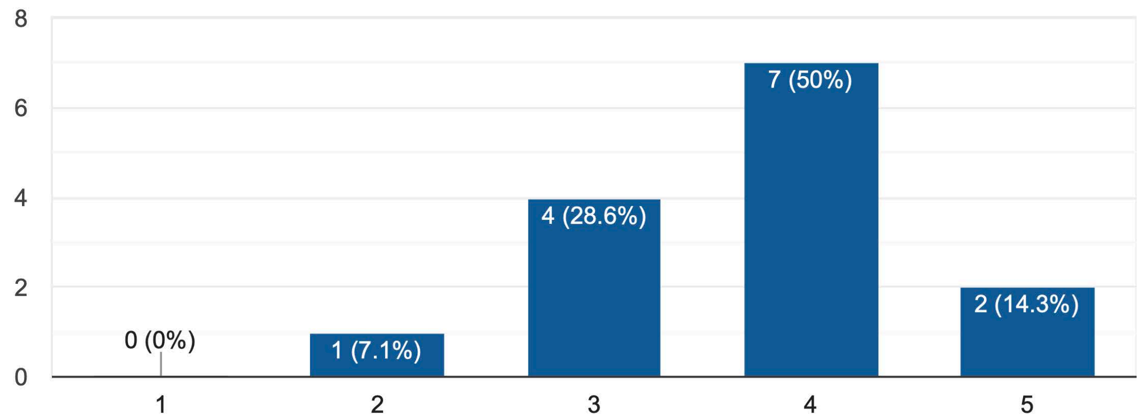
14 responses



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14 responses