INVESTIGATING INDUSTRY 4.0 READINESS IN THE SWEDISH MANUFACTURING SECTOR

Victor Rådinger and Hampus Samuelsson

Graduate School
Master Degree Project in Innovation and Industrial Management
Supervisor: Sven Lindmark

UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

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School of Business, Economics and Law, University of Gothenburg
Institute of Innovation and Entrepreneurship
Vasagatan 1, P.O. Box 600, SE 405 30 Gothenburg, Sweden

Contact: victorradinger@gmail.com, hamsam0709@gmail.com

ABSTRACT

Industry 4.0 is the fourth, most recent industrial revolution, and refers to the integration of the digital and the physical world in a manufacturing environment. Since first introduced in 2011, Industry 4.0 has gained significant academic and industrial attention. Due to the novelty of the concept, however, there are many areas that are yet to be properly covered in the Industry 4.0 literature. One area on which numerous calls for additional research have been made is Industry 4.0 readiness, which refers to the assessment of a company's degree of readiness for a full-scale adoption of Industry 4.0 and its surrounding technologies.

In order to respond to these calls for additional research, this study evaluates the Industry 4.0 readiness of a company in the Swedish manufacturing sector using a qualitative approach. The evaluation is based on a recently developed analytical framework which focuses on eight enabling technologies of Industry 4.0. In order to gain a more holistic understanding of the company's Industry 4.0 readiness, a range of organizational barriers are also examined.

The empirical findings reveal a varying degree of presence of the enabling technologies at the investigated company, consequently resulting in a degree of Industry 4.0 readiness of 63.2 %. An alternative degree of readiness is also calculated, taking into consideration the relative importance of the enabling technologies for the company. Finally, lack of an Industry 4.0 strategy, the existence of competency traps, limited financial support, and lack of internal collaborations are identified as the major organizational barriers to an increased Industry 4.0 readiness. By addressing these, it is argued that the company can facilitate their overall work with Industry 4.0 and thereby increase their readiness for a full-scale adoption of Industry 4.0.

Keywords: *Industry 4.0, Readiness, Technology, Barriers*

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Victor Rådinger

Hampus Samuelsson

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LIST OF ABBREVIATIONS

AI – ARTIFICIAL INTELLIGENCE

AR – AUGMENTED REALITY

CMfg – CLOUD MANUFACTURING

CPS – CYBER-PHYSICAL SYSTEMS

ERP – ENTERPRISE RESOURCE PLANNING

I4.0 – INDUSTRY 4.0

ICT – INFORMATION AND COMMUNICATIONS TECHNOLOGY

IoT – INTERNET OF THINGS

M2M – MACHINE-TO-MACHINE

ML – MACHINE LEARNING

NIST – NATIONAL INSTITUTE OF STANDARDS & TECHNOLOGY

OEM – ORIGINAL EQUIPMENT MANUFACTURER

RFID – RADIO FREQUENCY IDENTIFICATION

SAE – SOCIETY OF AUTOMOTIVE ENGINEERS

WSN – WIRELESS SENSOR NETWORK

1. INTRODUCTION

1.1 THE FOUR INDUSTRIAL REVOLUTIONS

Looking back at the evolution of industrial manufacturing systems over the past centuries, their development can be seen as a path through four main stages – the four industrial revolutions (Rojko, 2017). The fourth, most recent industrial revolution is commonly known as *Industry 4.0*, and is hereafter referred to as *I4.0*. While adopting the I4.0 concept and its surrounding technologies is becoming increasingly important for manufacturing companies' survival (Drath & Horch, 2014; Lee, Kao & Yang, 2014), it is critical to make sure they are actually ready before initiating this process (Pacchini, Lucato, Facchini & Mummolo, 2019). Therefore, this study will investigate the topic of I4.0 readiness. However, in order to understand where the I4.0 concept originates from, a brief review of the first three industrial revolutions is necessary.

The first industrial revolution began in eighteenth-century Britain and lasted until late nineteenth century, at which point it had reached a relatively widescale spread in Western Europe and in the United States (Stearns, 2012). Being driven by the advent of steam engines, waterpower and mechanization, Ghobakhloo (2018) describes the first industrial revolution as entailing a shift from manual work to mechanical manufacturing. This transition marked the beginning of a new organization of work known as the factory system, with significant productivity gains being one of its main advantages (Wahl, 2015).

The second industrial revolution took place between late nineteenth and mid-twentieth century (Stearns, 2012). According to Horváth and Szabó (2019), it was triggered by electrification and driven by the division of labor, consequently giving rise to the moving assembly line and enabling mass production. The second industrial revolution brought with it an intensified and more widespread international impact, providing an opportunity for economies outside the Western world to catch up to the already established industrial powers (Stearns, 2012). However, sustaining its domination was the continuation and even enhancement of Western industrial strength, leading to new rounds of innovation and the rise of the United States and Germany as industrial global leaders.

The third industrial revolution took off in mid-twentieth century and marks the time during which half of the world became effectively industrialized, resulting in significant increases in international trade and advanced technological development (Stearns, 2012). Specifically, Rojko (2017) describes the third industrial revolution as characterized by digitalization, where the application of microelectronics and information technologies allowed for greater levels of automated production. Consequently, a wide variety of products could be manufactured on flexible production lines which were both more efficient and less vulnerable to disruptions than before (Horváth & Szabó, 2019).

While the third industrial revolution in one sense can be seen as still being in progress today (Horváth & Szabó, 2019), the general conception is that we in recent years have entered a new, fourth revolutionary industrial change – I4.0 (Müller, Buliga, & Voigt, 2018). I4.0 has gained significant attention in the last decade, both in the academic and the industrial world (Dilberoglu, Gharehpapagh, Yaman & Dolen, 2017; Rojko, 2017). Due to its novelty, however, there is still much uncertainty surrounding the concept, and many important questions are yet to be answered (Piccarozzi, Aquilani & Gatti, 2018).

1.2 INDUSTRY 4.0

At the time of writing, searching on "Industry 4.0" on Google generates an impressive 496 million hits. Indeed, the concept has gained a substantial amount of attention since first introduced by the German government at the 2011 Hannover Fair (Rojko, 2017). "Industrie 4.0" was launched as a strategic initiative to secure Germany's position as a global leader in industrial manufacturing (Xu, Xu & Li, 2018), and as rapid technological advancements and increasing globalization have turned international competition more fierce than ever before, other nations have followed (Dalenogare, Benitez, Ayala & Frank, 2018). "Advanced Manufacturing Partnership" in the United States, "Towards Industry 4.0" in Brazil, and "Made-in-China 2025" in China are a few examples of government-led efforts around the world to disseminate the concept of I4.0. In Sweden, the Government has developed "Smart industri" – a strategy aimed at strengthening the industrial sector's global competitiveness (Government Offices of Sweden, Ministry of Enterprise and Innovation, 2016). Here, I4.0 is a main area of focus, critical for stimulating the development, spread and use of the technologies with the greatest potential to lead the industrial sector's development.

Evidently, I4.0 has generated much interest and seems to be widely recognized as the future of industrial manufacturing. Despite its popularity, however, the concept still lacks a generally accepted definition (Schneider, 2018). In a literature review investigating 68 papers published on the topic of I4.0, Piccarozzi et al. (2018) find that more than half of the sample papers do not include any definition of the concept altogether. Among the papers that do define I4.0, a considerable share of these offer not only one, but several definitions, thus illustrating the lack of consensus as to what I4.0 actually is. Before moving on, a clear description of I4.0 is therefore needed.

In broad terms, I4.0 can be described as the integration of the digital and the physical world (Annunziata & Biller, 2015). By linking together people, machines, equipment and products in a communicating, intelligent network, I4.0 allows for real-time production planning along with dynamic self-optimization (Sanders, Elangeswaran & Wulfsberg, 2016). Companies adopting the concept and its surrounding technologies will be built on flexible and adaptable business structures (Prause, Atari & Tvaronavičienė, 2017), thereby better able to cope with the current challenges of shorter product life cycles, highly customized products, and stiff global competition (Weyer, Schmitt, Ohmer & Gorecky, 2015). Additionally, industrial manufacturing systems adapted to I4.0 will perform more efficiently than ever before, consequently resulting in lower overall production costs and a more efficient use of natural resources and energy (Manavalan & Jayakrishna, 2019; Rojko, 2017).

1.3 PROBLEM DISCUSSION

While it is widely accepted that I4.0 offers far-reaching opportunities, it is critical to make sure the company is ready before actually initiating its implementation (Machado et al., 2019). A first important step is therefore to assess the company's digital readiness in terms of its technologies and capabilities. Digital *readiness*, or I4.0 readiness as it is referred to in the context of I4.0, should be separated from I4.0 *maturity*, which represents the progress already made by the company in implementing I4.0 (Pacchini et al., 2019). Because readiness precedes the maturing process, readiness can be defined as indicating whether the company is ready to start the actual implementation of I4.0 (Schumacher, Erol & Sihn, 2016).

The distinction between readiness and maturity might seem rather clear. However, as emphasized by Pacchini et al. (2019), many studies claiming to evaluate companies' readiness for implementing I4.0 do not actually measure their readiness. Although "readiness" is included in the models they use for evaluation, these models generally treat readiness and maturity as synonyms (Schumacher et al., 2016). By leaving the difference between the two undefined, they fail to measure what they claim to measure – the degree of readiness, and readiness only, for implementing I4.0 (Pacchini et al., 2019). Consequently, companies' I4.0 readiness has been identified as an important research gap to explore further (Botha, 2018; Castelo-Branco, Cruz-Jesus & Oliveira, 2019; Machado et al., 2019). This is especially true considering the importance of I4.0 for any manufacturing company interested in long-term survival (Drath &

Horch, 2014). In order to maintain their competitiveness, these companies simply have to be prepared for implementing I4.0 and its surrounding technologies (Lee et al., 2014).

As an attempt to address this research gap, Pacchini et al. (2019) have developed a model for measuring I4.0 readiness. However, because their model is tested on only one company, the authors call for further testing in order to validate its use. As a response to this call for further research, this study will use said model to assess the degree of I4.0 readiness of a Swedish manufacturing company. Admittedly, attempts to assess I4.0 readiness have been made in Sweden before. For example, Machado et al. (2019) recently performed a study in which the I4.0 readiness of a set of Swedish manufacturing companies was investigated. However, as their study is based on a quantitative approach, the authors call for additional research where the evaluation of I4.0 readiness adopts a qualitative, more in-depth approach. As such, this study's ambition of thoroughly assessing the I4.0 readiness of a Swedish manufacturing company should be considered highly relevant in relation to the current state of the I4.0 literature.

1.4 RESEARCH QUESTIONS AND PURPOSE

In light of the discussion above, the main research question which this study will address is:

- *What is the degree of I4.0 readiness of a Swedish manufacturing company?*

Additionally, although companies are becoming increasingly interested in applying new technologies to ensure their long-term competitiveness, there are a number of factors which could hinder a successful adoption of I4.0 (Horváth & Szabó, 2019). Only a few studies have empirically examined the barriers to the digital transformation which is I4.0 (Machado et al., 2019), and a relatively large share of these studies are limited to the technological side (Horváth & Szabó, 2019). However, implementing and integrating a variety of advanced technologies is much more than a technological task (Larkin, 2016; Basl, 2017). Therefore, it should be considered highly interesting to apply a more holistic approach and investigate a wider range of inhibiting factors in order to understand the I4.0 phenomenon as a whole. Therefore, two additional research questions which this study will address are:

- *What are the major organizational barriers to an increased I4.0 readiness at the company?*
- *How can the company increase its I4.0 readiness?*

By addressing these three research questions in total, this study aims to fulfill the purpose of responding to the numerous calls for more empirical research on the area of I4.0 in general

(Horváth & Szabó; Ivanov, Dolgui & Sokolov, 2019), as well as those for further research on I4.0 readiness specifically (Botha, 2018; Pacchini et al., 2019; Castelo-Branco et al., 2019; Machado et al., 2019). Furthermore, this study contributes to both theory and practice. On the theoretical side, it will help assess the viability of a model developed to measure the I4.0 readiness of manufacturing companies, which has not been thoroughly studied in the past. On the practical side, it will help increase the investigated company's understanding of their current situation, and shed light on the barriers which companies might experience in preparing for the implementation of I4.0, as well as how they can increase their I4.0 readiness.

1.5 DELIMITATIONS

While a widescale adoption throughout the entire value chain is necessary in order be able to reap the full benefits of I4.0 (Rojko, 2017), this study will focus on I4.0 readiness only *within* a specific company. As such, whether or not the other actors in the company's value chain are equally ready for implementing I4.0 will not be taken into consideration here. This means that this study will not be able to fully tell what benefits the company analyzed in this study can expect from implementing I4.0. Even though the company itself might have a relatively high degree of I4.0 readiness, other actors within its value chain might not. Since convincing these other actors to implement I4.0 can be a major challenge (Mohamed, 2018), this is something the reader should keep in mind.

Furthermore, as the company on which this study was conducted is part of a multinational organization with hundreds of facilities spread out across the world, assessing the I4.0 readiness of the entire organization has not been possible. Therefore, the scope of this study has been narrowed down to the organization's subsidiary in Sweden. Specifically, considering that I4.0 focuses on improving a company's manufacturing processes, a specific factory of the investigated company located in Western Sweden has been the main subject of research. However, it should still be noted that although the central focus has been on investigating factory-level factors, areas concerning the company and even the organization as a whole have also been discussed with the interviewees in order to gain a more holistic view of the company and its readiness for I4.0.

1.6 DISPOSITION

This paper is divided into six chapters: Introduction, Analytical Framework, Methodology, Empirical Findings, Analysis and Discussion, and Conclusions. Following is a brief description of the content of each chapter.

The first chapter serves as a way to introduce the reader to the research topic, discuss the more specific problem area, and motivate the importance of this study. The research questions which this study aims to address are also presented, as well as the research purpose. Finally, decisions that have been made regarding the scope of the study are explained.

In the second chapter, the current literature on I4.0 readiness is reviewed. The analytical framework used in this study to assess I4.0 readiness is discussed, focusing on the eight technologies which have been identified as enabling the implementation of I4.0. The chapter concludes with the major organizational barriers to an increased I4.0 readiness identified in the literature.

The third chapter outlines the research strategy, research design and the research methods used for this study. Regarding the research methods, the processes of conducting a systematic literature review as well as collecting and analyzing empirical data is presented, thereby explaining how the analytical framework used in this study was applied to the investigated company. Lastly, a discussion on research quality is provided.

In the fourth chapter, empirical findings gathered from a collection of interviews are presented. An introduction to the investigated company is followed by a detailed description of their work with I4.0 and its enabling technologies. The final part of the chapter presents the major organizational barriers, as expressed by the interviewees.

The fifth chapter provides an extensive analysis and discussion of the empirical findings, leading to an assessment of the investigated company's degree of I4.0 readiness. An alternative degree of readiness is then calculated, taking into consideration the relative importance of the eight enabling technologies. The degree of I4.0 readiness for the company is then discussed, as well as their readiness seen from an organizational perspective.

In the sixth and final chapter, conclusions are drawn. Specifically, answers to the research questions are provided, contributions to theory and practice are presented, and the limitations of this study are discussed along with suggestions for future research.

2. ANALYTICAL FRAMEWORK

This chapter is divided into three main sections. The first section discusses some of the relatively few existing studies on I4.0 readiness, particularly focusing on those including a Swedish perspective. The second section presents the analytical framework used in this study. As the framework is based on eight enabling technologies of I4.0, the focus of this section is on describing these technologies and the purpose they serve in an I4.0 context. The third and final section reviews the major organizational barriers to an increased I4.0 readiness, based on what factors are most frequently discussed in the I4.0 literature.

2.1 I4.0 READINESS

Whereas readiness can be described as the state of being prepared to accomplish a specific task, maturity refers to the development already made in accomplishing this task (Pacchini et al., 2019). In the context of I4.0, readiness thus refers to the degree to which a company is ready to start the implementation of I4.0, and maturity to the progress already made in this regard. As already emphasized, this distinction is important. For example, Schumacher et al. (2016) highlight the importance of assessing readiness before engaging in the maturity process, and Botha (2018) argues that I4.0 maturity can only be achieved once a company has been consistently operating in a digital environment for a considerable time. Due to the novelty of the I4.0 concept, maturity should not be expected of many companies. Rather, what is more interesting to look at today is their degree of *readiness* for implementing I4.0.

There are several possible reasons as to why there is no established method for measuring I4.0 readiness. For example, because the I4.0 concept is still in its emerging phase, there is no commonly agreed upon definition of the term yet (Schneider, 2018). This makes it difficult to know what I4.0 actually entails, and thus complicates the assessment of a company's readiness for its implementation (Castelo-Branco et al., 2019). However, a few attempts have been made to assess I4.0 readiness before. The methods used for some of these assessments and the results they have generated are discussed below, particularly focusing on the Swedish manufacturing sector and eventually leading to a review of the specific framework which will be used in this study.

2.1.1 MEASURING I4.0 READINESS

One of the most recent studies on I4.0 readiness was conducted by Machado et al. (2019). The researchers measured the readiness of a number of Swedish manufacturing companies through a self-check tool called “Industry 4.0 readiness online self-check for businesses,” which was developed by the IW Consult and FIR at RWTH Aachen University in Germany. Although the questionnaire considers a wide variety of aspects, such as strategy, operations and employees, the companies involved in the study found that it did not cover the different topics properly. Additionally, some of the terminology was considered confusing and the questions too reliant on the experiences and insights of the people filling out the survey.

Nevertheless, readiness was measured and the results showed that Swedish manufacturing companies have a rather low degree of I4.0 readiness overall. This means they have only taken initial steps toward digitalization and are not fully ready for the implementation of I4.0. According to Machado et al. (2019), these results are in line with previous studies conducted in Germany, who have also found rather low levels of I4.0 readiness. Additionally, a correlation was identified between company size and degree of readiness, where larger companies showed a higher degree of readiness for I4.0, albeit still not being fully ready.

In terms of measuring I4.0 readiness, Castelo-Branco et al. (2019) have taken a wider approach and evaluated the degree of readiness across a number of EU countries. Using data published by Eurostat on the Information and Communications Technology (ICT) usage and digitization in these countries, the researchers assessed I4.0 readiness based on two main dimensions: I4.0 Infrastructure and Big Data Maturity. I4.0 Infrastructure refers to a digital infrastructure which encompasses all the information, communication and connectivity technologies that are changing the way companies operate. Big Data Maturity, in turn, is defined as the ability to process the information generated by the infrastructure, thereby reflecting the analytical capabilities of a country’s manufacturing sector. Together, Castelo-Branco et al. (2019) argue, these two dimensions provide a good indication of the ability to adopt I4.0.

The results indicate large disparities between countries. As for Sweden, the country displays a relatively high level of I4.0 Infrastructure, but a relatively low level of Big Data Maturity, thereby placing them in the same cluster as countries such as Spain, Denmark and Germany. Within this cluster, Denmark and Sweden demonstrate the biggest similarities, both deviating considerably from the other countries in terms of the two dimensions. Specifically, they showcase higher levels of both I4.0 Infrastructure and Big Data Maturity than the other countries in their cluster, although still trailing behind the majority of the other countries overall in terms of Big Data Maturity.

While Castelo-Branco et al. (2019) consider I4.0 Infrastructure and Big Data Maturity to be useful indicators on whether or not a country is ready to implement I4.0, they also admit that the two dimensions might not cover all relevant factors characterizing a country's I4.0 readiness. This limitation is a trade-off between depth and width of the analysis, since fewer countries become available the more factors included. The fact that Castelo-Branco et al. (2019) evaluate I4.0 readiness based on merely two dimensions thus means they prioritize analytical width. Consequently, the researchers suggest that future studies investigate a wider range of factors in order to gain a deeper understanding of I4.0 readiness.

There have been additional studies conducted on I4.0 readiness than the ones described above, such as Basl (2017), Botha (2018) and Rajnai and Kocsis (2018). However, without discussing them all in detail, it can generally be said that assessments of I4.0 readiness seem to fall short in terms of analytical depth. Both the simpler and the more complex models are typically based on quantitative methods for collecting data (Basl, 2017). Company-level evaluations specifically are often based on self-assessments, where surveys are made available online to the participating companies. Therefore, it seems as if most studies on I4.0 readiness only scratch the surface and thus are not able to identify the underlying reasons as to why a company might have a low or high degree of readiness. In other words, there seems to be a need for a model which allows for a deeper investigation of companies' I4.0 readiness. As an attempt to address this need, Pacchini et al. (2019) have developed a model which is based on a *qualitative* approach for assessing I4.0 readiness. Specifically, the model focuses on evaluating a number of key enabling technologies for I4.0. In the following section, this model will be further discussed.

2.2 ENABLING TECHNOLOGIES

The model developed by Pacchini et al. (2019) for measuring the degree of I4.0 readiness is based on the concept's most relevant enabling technologies. Through an extensive literature review, the researchers identified the seven most cited technologies in the I4.0 literature, which they argue need to be in place in order to enable a successful implementation of I4.0. To confirm the adequacy of these technologies as I4.0 enablers, they were discussed with four experts on the subject. The experts unanimously agreed with the selection of the seven technologies, and added an eight technology also considered to be highly relevant.

The eight enabling technologies of I4.0 are: Big data, Internet of Things (IoT), Cloud computing, Cyber-Physical Systems (CPS), Additive manufacturing, Autonomous robots, Augmented Reality (AR), and Artificial Intelligence (AI). In order to better understand these technologies, a comprehensive review of each technology was conducted by the authors of this study. In the following sections, the results of these reviews are presented.

2.2.1 BIG DATA

Big data refers to the fast-growing amounts of data constantly being generated from a wide variety of sources, enabled by the rapid development of better and more informative sensing technologies (Reis & Gins, 2017). While earlier definitions of big data separate the term into three dimensions, the currently most accepted definitions typically include two additional ones (Coda et al., 2018; Shams & Solima, 2019). Together these make up the "5Vs" of big data:

- *Volume* – Big data involves massive amounts of data. To put it in perspective, every second the amount of data generated on the Internet is bigger than the storage capacity of the entire Internet 20 years ago (Ferraris, Mazzoleni, Devalle & Couturier, 2019).
- *Velocity* – Data is being generated at a continuously higher pace (Coda et al., 2018), and for many applications the speed of data creation is more important than the actual volume (McAfee & Brynjolfsson, 2012). This is because real-time information allows companies to be more flexible in responding to changes in the business environment.
- *Variety* – Big data involves a wide variety of data types from multiple sources (McAfee & Brynjolfsson, 2012). Data comes in both structured, semi-structured and unstructured forms, which puts increasing pressure on companies to make sense of all their data and turn it into useful information (Yan, Meng, Lu & Li, 2017).
- *Veracity* – Veracity refers to the authenticity of the data (Shams & Solima, 2019). It is of crucial importance to make sure the data generated is authentic in order to gain reliable data-based insights and understand the real value of the data.
- *Value* – By collecting large amounts of different types of data in real time, and by understanding how the data can be most effectively utilized, companies can increase the value of their data (Wessel, 2016). While most companies used to collect data mainly to target advertising better, they have now discovered that it can serve many additional purposes, some of which will generate entire new streams of revenue (Bean, 2017).

In the context of I4.0, the ability to process large quantities of various forms of data is critical (Coda et al., 2018). I4.0 relies heavily upon the usage of the information and insights gained from efficiently collecting and analyzing data (Preeti & Prasad, 2018). The amount of data is not necessarily what is most important, but that companies have the right data and understand how it can support their strategic decision-making (Wessel, 2016). Simply put, the fourth industrial revolution would be unimaginable without it.

2.2.2 INTERNET OF THINS (IoT)

Internet of Things (IoT) comprises a collection of digital technologies seeking to integrate physical systems with the digital world through the Internet (Chou, 2019). Two main IoT technologies are radio frequency identification (RFID) and wireless sensor networks (WSNs) (Lee & Lee, 2015). RFID utilizes radio waves to easily identify and track physical objects (Zhong & Ge, 2018). It consists of a tag and a reader. The tag is a microchip attached to an antenna with a housing, and stores a unique electronic product code. The reader then triggers the transmission of data by generating a signal to which the tag responds. WSN refers to a network of sensor-equipped devices used to monitor and track the status of objects in terms of their location, movements, temperature, and more (Ben-Daya, Hassini & Bahroun, 2019; Lee & Lee, 2015).

Together with additional technologies such as middleware, cloud computing and IoT applications software, RFID and WSN enable the interaction between physical objects and their surrounding environment (Witkowski, 2017). By continuously picking up signals from various sensors, they provide up-to-date information which they then communicate across the value chain (Lee & Lee, 2015; Manavalan & Jayakrishna, 2019). Based on this information, the objects can respond to a variety of requirements, production situations, and unexpected events in real time and without any human involvement (Chou, 2019).

IoT is one of the most fundamental technologies of I4.0 (Ben-Daya et al., 2019; Jiafu et al., 2016). An IoT-enabled business environment provides many benefits, such as smoother automation and higher levels of tracking and monitoring (Zhong & Ge, 2018). Through IoT, traditional manufacturing companies' physical resources are transformed into so-called smart manufacturing objects. Digital counterparts are created for the objects, which allows them to interconnect and interact with each other, thereby enabling decentralized decision-making (Chou, 2019). The result is a much more responsive and flexible production system, capable of both mass production and mass customization.

2.2.3 CLOUD COMPUTING

In 2010, The National Institute of Standards & Technology (NIST) released their definition of cloud computing which since has been widely cited. NIST describes cloud computing as "a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (for example, networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service-provider interaction" (Mell & Grance, 2010 pp.50). The cloud model has five main characteristics; on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service. Additionally, the cloud should consist of three service models; Cloud SaaS (Software as a Service), Cloud PaaS (Platform as a Service), and Cloud IaaS (Infrastructure as a Service).

Although NIST's definition of cloud computing has gained significant attention, it should be noted that it was released before the concept of I4.0 was introduced in 2011. Nevertheless, reviewing the literature on cloud computing's impact on manufacturing companies shows that the technology is highly relevant for I4.0 (Zhong, Xu, Klotz & Newman, 2017; Jiafu et al., 2016). In order to improve manufacturing environments, Cloud Manufacturing (CMfg) has been proposed as an interesting use of the cloud computing technology. CMfg involves on-demand IT-resources provided by cloud computing, such as server, storage, network and software. Additionally, manufacturing resources, capabilities, and whole manufacturing life cycle applications are provided to the users (Zhang et al., 2014). This approach is shifting manufacturing from being production-oriented to service-oriented, and just like in a regular cloud, any person, institute or company can participate in, and contribute with their resources and knowledge to, the CMfg service platform (Alcácer & Cruz-Machado, 2019).

Cloud computing and CMfg are essential for I4.0 since they allow for scalable, flexible and cost-effective solutions (Alcácer & Cruz-Machado, 2019). One of the key advantages of CMfg is the ability to virtualize manufacturing resources, capabilities and capacities, which make them available for the operators at all times. As a result, the operators are able to manage and operate the cloud platform, as well as utilize cloud services to fulfill consumer demands (Siderska & Mubarok, 2018).

2.2.4 CYBER-PHYSICAL SYSTEMS (CPS)

According to Lee, Bagheri and Kao (2014, pp.18), Cyber-Physical Systems (CPS) can be described as a collection of "transformative technologies for managing interconnected systems between its physical assets and computations capabilities." CPS can be seen as consisting of two main functional components (Frontoni, Loncarski, Pierdicca, Bernardini & Sasso, 2018). First is the advanced connectivity, which ensures real-time data acquisition from the physical world and feedback of information from the cyberspace. Second is the intelligent data management, analytics and computational capability, which constructs the cyberspace. To facilitate the understanding of this complex but highly important technology for I4.0, CPS can be seen as the merger of "cyber," as in electronic systems, with "physical" things, where the cyber component enables the interaction between physical components and their surrounding environment through the creation of virtual copies (Alcácer & Cruz-Machado, 2019).

A five-level CPS structure proposed by Lee et al. (2014), called the "5C" architecture, presents a step-by-step guideline for developing and deploying a CPS for manufacturing applications. The five levels are: connection, conversion, cyber, cognition, and configure (hence the name *5C* architecture). Simply put, these levels show applications and techniques which could be seen as guidelines for manufacturing companies. For example, "connection" emphasizes the importance of considering how to gather and manage data, while "configuration" refers to the feedback provided from the cyber space to the physical space.

CPS represents one of the latest significant ICTs, and has the potential of revolutionizing traditional warehouses by transforming them into smart, integrated factories (Frontoni et al., 2018). CPS allows for production systems to be self-configuring, self-maintaining and self-organized, resulting in improvements in both productivity and efficiency in manufacturing (Lee et al., 2014; Alcácer & Cruz-Machado, 2019). Consequently, CPS plays a critical role in the context of I4.0.

2.2.5 ADDITIVE MANUFACTURING

Additive manufacturing, also known as 3D printing, is a form of manufacturing where three-dimensional objects are built by adding layer after layer of a certain material (Rayna & Striukova, 2016). This differs from the more traditional method of subtractive manufacturing, where objects are carved out of blocks of raw material, or moulding, where a molten material is injected into a mould. What is also different about additive manufacturing is that a *digital* model of the object to be printed must be created. This is typically done with some modelling software or by using online services provided by one of the numerous 3D printing platforms available. 3D scanners can also be used to create a model of an already existing object.

I4.0 heavily relies on mass customization, which traditional manufacturing methods are not capable of delivering (Dilberoglu et al., 2017). Additive manufacturing, in contrast, offers the ability to produce small batches of a wide variety of objects with advanced attributes – quickly and at a low cost, without compromising performance (Chun, Kim & Lee, 2019). In some cases, performance might even be improved, for example as a result of weight savings (Larkin, 2016). As such, additive manufacturing supports factories with high efficiency and the ability of fabricating high-quality, customized products (Dilberoglu et al., 2017). Additional advantages include reduced waste and energy consumption, as well as positive societal impacts in terms of moving people away from being used strictly as labor force to jobs where they are involved in areas of management, design and analysis (Gao et al., 2015).

While offering many benefits, additive manufacturing also has its limitations (Dilberoglu et al., 2017). However, as new technological advancements are expected to eliminate most of these, an increasingly wider adoption of additive manufacturing is expected moving forward. One recent development, for example, is the possibility of integrating products' electronic components in their fabrication. This is highly relevant in the context of I4.0, since the core of the concept is the integration of the digital and physical (Annunziata & Biller, 2015).

2.2.6 AUTONOMOUS ROBOTS

An autonomous robot is a type of automation equipment combining a wide range of advanced technologies such as machinery, electronics, computers, and sensors (Wu, Liu & Wu, 2018). Through programming, the robots are provided with instructions which they then execute independently. It is in this way the robots become *autonomous*, meaning they are capable of performing tasks under constantly changing conditions and without the need of human involvement (Alcácer & Cruz-Machado, 2019). The robots are also intelligent in the sense that they can learn from their interactions with the surrounding environment, and based on this decide for themselves what they need to do (Li, Hou & Wu, 2017).

In terms of applications, autonomous robots can be classified into industrial robots and service robots (Wu et al., 2018), with the former being the category most interesting in the context of I4.0. Industrial robots are commonly used in processes such as product development, material handling, manufacturing and assembly (Fragapane, Peron, Sgarbossa, Strandhagen & Ivanov, 2020; Alcácer & Cruz-Machado, 2019). By working together and complementing each other with different capabilities, these robots enable the conversion of traditional production lines into flexible, efficient production networks, in which several production lines are interconnected in an automatic and dynamic fashion. This collaborative concept can be extended to also include the cooperation between robots and human beings (Koch et al., 2017).

Here, robots designed to interact with people serve as robotic co-workers to assist the human workers in a wide variety of ways.

Since I4.0 is characterized by a dependence on automation and interconnection of systems, which ultimately stems from the need for more efficient and customizable processes, autonomous robots become an important tool (Gonzalez, Alves, Viana, Carvalho & Basilio, 2018). Indeed, to reach the flexibility required today, incorporating robots into the production system is essential (Pedersen et al., 2016). The robots are adaptive and self-regulating, and thereby able to make their own, decentralized decisions (Alcácer & Cruz-Machado, 2019). In turn, this results in a wider product variation and lower production costs, which are central ambitions of the I4.0 concept. Additionally, by connecting the robots remotely to the company's computer systems, they become part of an entire production network where connections are created both within and between workstations (Fragapane et al., 2020).

2.2.7 AUGMENTED REALITY (AR)

While many technologies play an important part in the context of I4.0, Augmented Reality (AR) is the only one which has improved interaction between machines and humans as its main focus (Egger & Masood, 2020). By adding digital content to the real world, AR allows humans to see and hear things they otherwise would not (Qeshmy, Makdisi, Ribeiro Da Silva, & Angelis, 2019). As such, the AR technology provides support to the people working within an intelligent manufacturing environment, bridging the gap between the physical world and the digital one (Egger & Masood, 2020).

An AR system is typically divided into five main components (Egger & Masood, 2020):

- The *sensor system* obtains information from the physical environment.
- The *visualization technology* displays digital information in the context of the real environment.
- The *tracking system* enables digital information and objects to be placed accurately within the physical world.
- The *user interface* enables two-way communication between the system and the user.
- The *processing unit* is the software responsible for running the AR system.

Based on these five components, the AR process can be divided into two basic steps: (1) determining what is happening in reality, and (2) visualizing the processed data (Qeshmy et al., 2019). In this simple way, human workers can access the digital world through a layer of information positioned on top of the physical world (Eggers & Masood, 2020), with hands-free viewing of information and real-time user guidance as a result (Blanco-Novoa, Fernandez-Carames, Fraga-Lamas, & Vilar-Montesinos, 2018).

Despite being generally accepted as a technology driving the development of the I4.0 concept, recent research shows that the application of AR is challenging (Egger & Masood, 2020). If successfully implemented, however, there are many potential benefits awaiting. In the assembly processes, which is where the technology is most widely applied, decreased mental working loads and a heavily reduced number of errors are among the biggest advantages, consequently resulting in significant productivity gains (Blanco-Novoa et al., 2018).

2.2.8 ARTIFICIAL INTELLIGENCE (AI)

Artificial Intelligence (AI) is a technology which stimulates behavioral processes of humans, such as thinking, reasoning and planning, and applying them to machines or systems (Li et al., 2017). Given a fast, changing and dynamic manufacturing environment, machines infused with AI will have the ability to learn and adapt to changes and provide solutions for all circumstances (Wuest, Weimer, Irgens & Thoben, 2016). AI will enhance the quality, flexibility, productivity, and speed in different aspects of manufacturing.

Within the AI field, Machine Learning (ML) is a niche which has a significant impact on manufacturing (Wuest et al., 2016). ML allows computers to make reliable, repeatable decisions when exposed to new data without requiring programming beforehand. Computers can find highly complex and non-linear patterns in data, and transform raw data into models which can be applied in areas such as prediction and detection. As a result of large increases of complex and unstructured data in the business world today, applications of ML techniques have surged in recent years.

Although the benefits of AI look promising, there are issues in terms of a lack of adoption among companies especially in the manufacturing industry (Lee, Singh & Azamfar, 2019). One of the major issues is the absence of industrial successes to convince companies to deploy the technology in their businesses. Nevertheless, incorporating AI in an I4.0 context has many benefits in itself, as well as the potential to increase the value generated from the other enabling technologies. For example, by combining AI and ML with autonomous robots, the robots can understand and recognize patterns within different sets of data, learn from their past experiences, and improve future performance.

2.2.9 INTEGRATING THE ENABLING TECHNOLOGIES

Being described as "...an integrated set of intelligent production systems and advanced information technologies that are based on sets of integrated software systems" (Pacchini et al., 2019, pp. 1), it is clear that I4.0 relies heavily on its enabling technologies. By allowing for data to be generated and shared in real time between the physical components of the company's manufacturing system, all enabling technologies play an important part in realizing the central idea of I4.0 – connecting the physical world with the digital (Machado et al., 2019).

The integration of the I4.0-enabling technologies is two-fold, relying on a combined vertical and horizontal integration (Alcácer & Cruz-Machado, 2019). Vertical integration entails transforming the manufacturing process from being an automated hierarchical pyramid to a collection of distributed and decentralized architectures. Horizontal integration, in turn, allows for new kinds of value to be created by increasing the degree of collaboration, both between humans and machines and machine-to-machine (M2M).

Implementing the enabling technologies is a big commitment for any company (Rojko, 2017). It can therefore be expected that most companies will introduce the technologies gradually and by building on their already existing technological infrastructure in order to not jeopardize the stability of their production. However, in order to reach their full potential, the technologies should be implemented in parallel, meaning that companies interested in adopting I4.0 must be prepared to implement *all* the enabling technologies (Alcácer & Cruz-Machado, 2019). Consequently, when measuring the degree of I4.0 readiness, Pacchini et al. (2019) emphasize the importance of making a *collective* assessment as to how far the company is in implementing each technology.

2.3 MAJOR ORGANIZATIONAL BARRIERS

Although the enabling technologies play a vital role in being ready for I4.0, there are other aspects that are important as well. Specifically, since the adoption of I4.0 is a big decision which entails a great transformation in terms of how the company conducts its business, organizational aspects become critical (Mohelska & Sokolova, 2018). This section discusses the major organizational barriers to an increased I4.0 readiness, which will serve as a foundation for the second and third research question of this study. The four categories of barriers reviewed below are the ones which the authors of this study found to be the most frequently discussed in the I4.0 literature.

2.3.1 FINANCIAL CAPACITY

Choosing to invest in I4.0 is a big commitment, not least because it requires significant financial capital (Mohamed, 2018). Therefore, it does not come as a surprise that economic aspects often cause companies to hesitate to adopt I4.0 (Horváth & Szabó, 2019). Faced with the opportunity to allocate their resources to other causes, many of which can generate a higher payback in the short term, companies might be tempted to prioritize these and thus refrain from investing in I4.0, which is much more of a long-term investment (Botha, 2018). This tendency is reinforced by the fact that I4.0 is a relatively new concept – because many companies are still unfamiliar with the term, and because there are few real-life examples of companies that have undergone the transition to I4.0, investing in I4.0 might simply be perceived as too big of a risk (Basl, 2017). Uncertainties about the economic benefits can thus make it difficult to justify the significant investments required (Machado et al., 2019).

Sometimes the challenge is not to decide where to allocate your money, but not having the financial resources required to begin with. Limited access to capital has been reported as a common obstacle in regard to I4.0 (Lichtblau et al., 2015). As such, although I4.0 seems to be accepted as the future of industrial manufacturing, it is simply not feasible for many companies to go through with an investment of that size (Horváth & Szabó, 2019). Making sure that the company has the financial capacity required to be able to adopt I4.0 is therefore a precondition that needs to be fulfilled.

2.3.2 STRATEGY AND LEADERSHIP

According to Basl (2017), having a clear strategy for how the company will adopt I4.0 is fundamental. Implementing the enabling technologies without knowing how they can improve the current business, or even generate new business models, is fruitless. However, before an appropriate strategy can be developed, the company needs to understand its current readiness for I4.0 (Kane, Palmer, Phillips, Kiron & Buckley, 2018). Here, a thorough investigation of the company's current status is required in order to reach a fair assessment. What is also critical is to make sure that everyone who will be involved in the change all share a uniform interpretation of the I4.0 concept, as the lack of a common understanding will affect the entire process (Horváth & Szabó, 2019). Once a shared interpretation has been established and the current readiness assessed, the company can then start developing a strategy for I4.0.

Closely related to strategy is leadership, which becomes an important feature both at the upper and lower levels of the organization (Basl, 2017). While the transition toward I4.0 might be seen as a technological task, the true challenge is to incorporate the benefits of I4.0 into the company's current business strategy and to lead the change (Kane et al., 2018). However, while great leadership is a critical success factor, it is something most companies struggle with. Nevertheless, companies looking to adopt I4.0 need to make sure they have open-minded leaders who provide vision and purpose, and who empower employees to think differently and work across boundaries. Pushing down decision-making to increase individual responsibility and accountability is also important, as well as encouraging employees to step up and assume their roles as digital leaders (Horváth & Szabó, 2019).

In the new manufacturing environment that I4.0 enables, companies are required to respond and act faster than they ever have before (Kane et al. 2018). The problem is that current business structures typically do not allow for quick decision-making, and communication does not flow as smoothly as it could in many of today's inflexible organizations. However, since creating a strategy and leading the process will require many steps and much iteration, an agile approach needs to be adopted (Basl, 2017). Furthermore, while a company might reach a certain level of readiness by itself, higher levels of readiness demands other actors in the value chain to engage accordingly (Machado et al., 2019). Most I4.0 technologies require systems integration both inside and outside the company. The company therefore needs to make sure that the actors in their value chain collectively align their strategies and integrate their technologies (Horváth & Szabó, 2019). Working closely with social partners and the academic community could also be important, as it allows the company to discover new ways of working with I4.0 (Kagermann, Wahlster, & Helbig, 2013).

2.3.3 ORGANIZATION AND CULTURE

One of the most significant challenges associated with I4.0 is that of developing an appropriate organizational culture (Kane et al., 2018; Lichtblau et al., 2015). As digital businesses move quickly and are exposed to constant ambiguity and change, it is of critical importance to experiment and iterate, and to learn from the experiences. Adopting I4.0 involves major changes, and because many of these changes are characterized by considerable uncertainty, companies cannot expect to have everything under control (Machado et al., 2019). However, being driven by a fear of failure, many companies lack the courage to face the ambiguity that characterizes the transition to I4.0. Developing an organizational culture which encourages experimentation and embraces uncertainty is thus fundamental. Enabling this experimental, iterative culture are flexible business processes and structures which support fast flows of information (Horváth & Szabó, 2019). These processes and structures should allow for both intra- and inter-organizational collaboration (Kane et al., 2018), where cross-functional teams within the organization work together and where the company also cooperates with its suppliers and customers (Kagermann et al., 2013).

Some companies mistakenly argue that behavior which has led to success in the past will also lead to success in the future, thus denying the need to change altogether (Kane et al., 2018). This type of reasoning is known as "competency traps," and is typically more common in established companies. Avoiding competency traps is essential for achieving the kind of digital transformation which leads to long-term success. However, the risk of abandoning old and outdated ways of thinking is that tension might build among employees who may have more of a traditional mindset. As such, competency traps can also exist at the individual level, which is something that companies must be prepared to address. Sometimes "unlearning" is required in order to break away from old models and outdated ways of thinking. Everyone involved in the transition to I4.0 needs to share the same open and acceptive mindset, and frequently communicate in a common language (Machado et al., 2019).

2.3.4 HUMAN RESOURCES

Being a relatively new concept, it can be difficult to find the right people with the right knowledge to help with the transition to I4.0 (Horváth & Szabó, 2019). I4.0 is dependent on automation and the interconnection of systems, and when automated processes and machines make up for an increasingly larger share of the production capacity, workers have to adapt (Gonzalez et al., 2018). This is a problem since the capabilities and skills required of the workers in an I4.0 context are different from those they normally have (Horváth & Szabó, 2019). Therefore, one of the major barriers of I4.0 is the lack of skilled-enough workers. The company needs to find experts within each enabling technology who know not only how to operate the technologies themselves, but also how to integrate them so that they can work seamlessly together. Additionally, increased efforts on training to help existing employees develop the necessary competencies and technological know-how is critical.

In a dynamic, digital environment, it is easy for people to become reactive rather than proactive (Botha, 2018). What this means is that the employees might end up focusing on correcting inefficiencies to improve what is currently being done, rather than chasing new trends. This can be an issue as I4.0 calls for a collaborative, explorative and entrepreneurial mindset from the employees (Kane et al., 2018). Additionally, employees might feel threatened by the changes brought by I4.0 (Horváth & Szabó, 2019). Being afraid of losing their jobs or not possessing the necessary skills might cause employees to start resisting, and loss of jobs and motivation among the employees might disrupt the social environment within the company. Therefore, effective human resource management becomes another important area for companies looking to adopt I4.0 (Hecklau, Galeitzke, Flachs & Kohl, 2016).

3. METHODOLOGY

This chapter is divided into four main sections. The first section discusses the qualitative research strategy on which this study is based. The second section describes the research design employed, which is a case study, and outlines the criteria used for selecting the company to investigate in this study. The third section discusses the research methods used for gathering data, consisting of a combined secondary and primary data collection process. Finally, the fourth section discusses research quality based on five different research quality criteria.

3.1 RESEARCH STRATEGY

As clarified in Section 1.4, the purpose of this study is to respond to the numerous calls for additional research on manufacturing companies' I4.0 readiness. Because many of these calls specifically suggest adopting an in-depth approach in order to gain a deep understanding of the digital state of the company, a qualitative research strategy was deemed the most fitting for this study. The appropriateness of a qualitative research strategy is further reinforced by the research questions at hand, since detailed answers to these questions require a thorough evaluation of the investigated company's I4.0 readiness.

While qualitative research strategies typically focus on the generation of new theory (Bryman & Bell, 2015), one of the main objectives of this study is to test an already developed model for measuring the degree of I4.0 readiness. As such, this study can be seen as partly taking a deductive approach, meaning it seeks to test existing theory (Saunders, Lewis, & Thornhill, 2012). It should be noted, however, that the model currently has been tested only in a small scale and is therefore very much still in its nascent stages. Therefore, assessing its viability and providing suggestions for further improvements does not only entail testing the model, but also helping develop the model and thereby generate new theory.

Generating new theory is especially relevant for the second and third research question, which go beyond simply measuring I4.0 readiness. More specifically, they seek to describe the investigated company's major organizational barriers to an increased I4.0 readiness, as well as the ways in which the company can overcome these barriers to increase their readiness. Because the investigation of these topics is not based on any particular theory, generating new theory is a main concern.

In sum, the research strategy used for this study is of a qualitative nature, incorporating elements of both a deductive and inductive approach, which is sometimes referred to as an abductive approach (Bryman & Bell, 2015). This means the study seeks to both test existing theory and generate new theory. However, the main focus is on generating new theory.

3.2 RESEARCH DESIGN

The research design employed in this study is a case study, essentially meaning that results have been generated from studying a specific case (Bryman & Bell, 2015). Here, the case refers to a company within the Swedish manufacturing sector. Findings from the interviews conducted with employees at the company have been compared and contrasted in order to identify interesting similarities and differences. This was considered important as the qualitative research strategy seeks to obtain deep insights and understandings, which typically requires different sets of data to be analyzed in relation to each other (Bryman & Bell, 2015).

The initial objective of this study was to conduct a multiple-case study to gain a wider picture of the I4.0 readiness in the Swedish manufacturing sector as a whole. However, COVID-19 which will be further discussed below has severely affected the willingness of companies to participate in this study, and thus required a change in research design to a single case study. When searching for an appropriate company to perform this study on, a series of criteria was used. In order to be considered, the company had to: (i) operate in the Swedish manufacturing sector, (ii) operate either as an original equipment manufacturer (OEM) or a Tier 1 supplier to an OEM, and (iii) be classified as a highly technological company.

In order to be considered as operating in the Swedish manufacturing sector, at least one factory in Sweden was required. Regarding the second criterion, an OEM is a company which produces some original equipment but also designs, markets, and assembles the final product. A Tier 1 supplier, in turn, is a company which supplies parts or systems directly to an OEM. Finally, to be classified as highly technological, the company had to incorporate advance technology in their production process. The reason as to why the company had to be considered highly technological is because these kinds of companies are more likely to be interested in adopting I4.0 (Piccarozzi et al., 2018), and therefore are more relevant to investigate in terms of their I4.0 readiness.

3.3 RESEARCH METHODS

The research methods used in this study for gathering data are based on a combined secondary and primary data collection process. Collecting secondary data entailed conducting both a pre-study and a systematic literature review in order to identify a relevant research topic and ensure thoroughness in finding relevant literature on this topic. Primary data was gathered through a total of three semi-structured interviews at the investigated company. As for the analysis of the generated results, thematic analysis was the research method of choice. In this section, these method choices will be described more in detail.

3.3.1 SECONDARY DATA COLLECTION

3.3.1.1 PRE-STUDY

A first step in conducting research is finding a relevant topic and then reviewing the existing literature on that topic in order to identify potential gaps or inconsistencies which can be addressed through additional research (Bryman & Bell, 2015). Accordingly, the starting point of this study was the decision of focusing on I4.0 as a general area of research, and exploring the current literature on the topic. Scanning the I4.0 literature revealed a lack of empirical research, but failed to identify a more specific knowledge gap. Therefore, a number of I4.0 experts were reached out to in order to discuss potential research questions, consequently resulting in two separate meetings being held with two researchers both currently working at a technology university in Gothenburg.

The two meetings were 70 and 45 minutes long, respectively. The meetings, in combination with additional scanning of literature, resulted in a decision to focus this study on evaluating I4.0 readiness. Following this decision was the actual systematic literature review, where current research on the selected topic was carefully scrutinized in order to gain a deeper understanding of the subject and identify key issues.

3.3.1.2 SYSTEMATIC LITERATURE REVIEW

The process of conducting the systematic literature review was based on a framework developed by Templier and Paré (2015). This framework, consisting of six general stages, is presented in Figure 3.1.

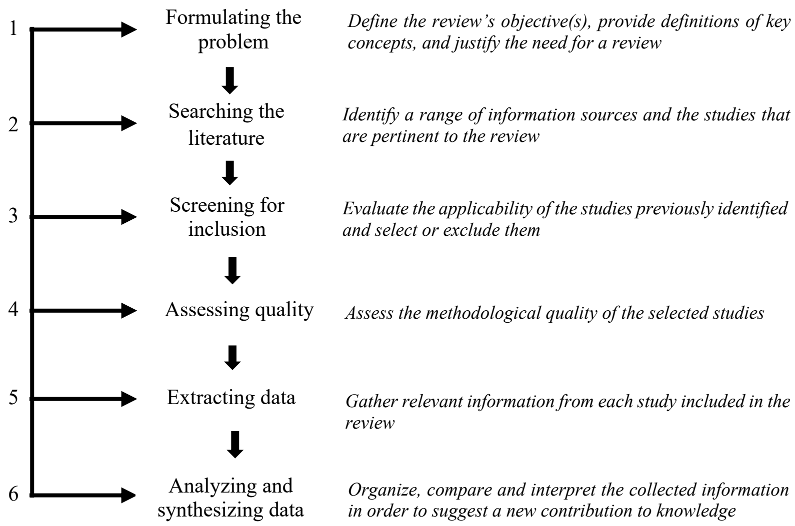

FIGURE 3.1: *GENERAL PROCEDURE FOR CONDUCTING LITERATURE REVIEWS*

The six stages in Figure 3.1 served as valuable guidelines to make sure the studies included in the literature review were relevant, credible, and contributed to an increased understanding of the studied subject. Additionally, it was considered important that these studies also would be able to lay a solid theoretical foundation for the gathering of primary data and the following analysis. As such, these were identified as the objectives of the literature review (stage 1).

In searching for literature and screening studies for inclusion (stage 2 and stage 3), a number key terms and inclusion/exclusion criteria were used (see Table 3.1). The choice of key terms was based on the research questions and purpose of this study, and the inclusion/exclusion criteria were then derived from these key terms. Several different databases were used, which is recommended in order to minimize any potential biases and obtain a more complete set of literature (Xiao & Watson, 2019). The majority of these are databases to which access is provided by the Gothenburg University Library, such as ScienceDirect, Business Source Premier (BSP), and Emerald Insight. Additionally, some literature was accessed through Google Scholar. The literature search was complemented by a backward search, in which references of selected studies were examined in order to find additional relevant work.

Key Terms	Inclusion Criteria	Exclusion Criteria
• Industry 4.0 (I4.0) • Industry 4.0 (I4.0) readiness • Digital readiness • Technology - *Big data* - *Internet of Things (IoT)* - *Cloud computing* - *Cyber-Physical Systems (CPS)* - *Additive manufacturing* - *Autonomous robots* - *Augmented Reality (AR)* - *Artificial Intelligence (AI)* • Barriers/challenges • Organization	• Studies addressing the issue of digital/ I4.0 readiness • Studies discussing technologies central to the I4.0 concept • Studies focusing on the early (pre-implementation) stages of the I4.0 process • Studies analyzing the barriers to an increased I4.0 readiness	• Studies solely addressing the issue of digital/I4.0 maturity • Studies discussing technologies not central to the I4.0 concept • Studies focusing on the latter stages (post-implementation) of the I4.0 process • Studies analyzing the barriers to the implementation of I4.0

TABLE 3.1: *KEY TERMS, INCLUSION CRITERIA, AND EXCLUSION CRITERIA*

Publications found through the literature search were checked for quality (stage 4), mainly by looking at whether or not they had been peer-reviewed, as well as their number of citations. Because non peer-reviewed and rarely cited work generally showcase a relatively low level of quality (Xiao & Watson, 2019), peer-reviewed studies with a relatively large number of citations were favored.

The final steps of conducting the systematic literature review entailed extracting only the most relevant data from the selected studies (stage 5), as well as contrasting and reporting the findings (stage 6). The outcome of this process is presented in Chapter 2.

3.3.2 PRIMARY DATA COLLECTION

3.3.2.1 SAMPLING

The period of time during which this study was conducted has been characterized by severe external circumstances which have caused major disorder in the business world. As a result, the priorities of most companies has significantly shifted from what they normally are. Specifically, COVID-19 has made most companies turn their focus toward survival, consequently resulting in a strictly limited number of available case companies. Therefore, in order to find a company to investigate in this study, a convenience sampling method was used, meaning the company was selected based on its availability and interest in participating in the study (Bryman & Bell, 2015). More specifically, considering the initial difficulties experienced in finding companies willing to partake in this study, the decision was made to reach out to as many companies as possible fulfilling the criteria outlined above, both via mail and a professional networking site. Out of the few ones replying back and stating an interest in learning more about the research, the company which eventually was included in this study was deemed the best suited one. This was due to two main factors: (i) the possibility of interviewing several employees involved in the company's work with I4.0 or some specific technologies related to the concept, and (ii) the company's genuine interest in having its I4.0 readiness evaluated.

Being a non-probability sampling method, convenience sampling has its shortcomings (Bryman & Bell, 2015). For example, by basing the selection of case company mainly on its availability and interest, the risk of not being able to properly answer the research questions and thereby fulfill this study's purpose is increased. However, given the severe external circumstances, convenience sampling was considered the best solution. Measures were also taken to ensure the appropriateness of the company being investigated, such as the use of different criteria. Additionally, through a dialogue with the contact person at the company, during which the purpose of this study and expectations from potential interviews were carefully explained, it was possible to identify the individuals working at the company with the most extensive and relevant knowledge of their work with I4.0. This resulted in three semi-structured interviews being held with three different employees. Information about the interviewees and the interviews are available in Table 3.2.

Interviewee	Position at the Company	Area of Expertise	Duration of Interview	Date and Location
Interviewee A	Business Unit Manager	Product Management Project Management Product Development International Sales	60 minutes	20/4-20, Online
Interviewee B	Operations Manager	Business Development Business Strategy Internal Automation and Digitalization	130 minutes	24/4-20, Online
Interviewee C	Information System Manager	Digital Infrastructure Information Systems Digital Management	70 minutes	29/4-20, Online

TABLE 3.2: *INTERVIEWEE/INTERVIEW INFORMATION*

3.3.2.2 INTERVIEW GUIDE

An interview guide was constructed prior to the interviews. An interview guide is a memory list of areas to be discussed during interviews used to help the interviewer make sure all topics are properly covered (Bryman & Bell, 2015). The interview guide, which is available in Appendix 1, starts off with a few opening questions. These are not intended to provide any answers to the research questions per se, but serve as an easy start to the interview and a way for the interviewee to get comfortable. More specifically, they focus on the interviewee's background and current position, as well as the company's general experiences of working with I4.0, which are questions not requiring too much thinking.

Following the opening questions are two sets of key questions. The first set of key questions refers to the enabling technologies of I4.0. Although the same interview guide was used in all interviews, the technologies discussed the most varied depending on the interviewees' specific areas of expertise. This was made possible due to the background research conducted on each interviewee's role and responsibilities, and made sure each technology was discussed with someone who possessed the relevant knowledge. This being said, most technologies were still discussed with all interviewees, at least to some extent, in order to gain more than one perspective on each technology.

The second set of key questions relates to the major organizational barriers of I4.0. While the questions on the enabling technologies are rather specific in nature, this second set of key questions allows the interviewees to speak more freely about the inhibiting factors to an increased I4.0 readiness. Additionally, in contrast to the opening questions which focus mainly on the interviewees' specific roles within the company and their personal perceptions of the I4.0 concept, this second set of key questions takes a more holistic, organizational perspective.

Finally, included in the interview guide are also a few closing questions. These allow the interviewees to highlight some important aspects which they forgot or did not get the chance to bring up earlier during the interview. It should be noted that this is merely an interview *guide*. As such, depending on the answers given by the interviewees, all questions were not asked in every interview, and not in the same exact order. Additionally, follow-up questions were sometimes asked which were exclusive to the different interviews.

The interview guide was shared with the interviewees in advance to provide them the opportunity to familiarize themselves with the topics to be covered. It was also reasoned that this would create a more comfortable setting for the interviewees during the actual interview, as they would already be aware of what type of areas were to be discussed.

3.3.2.3 SEMI-STRUCTURED INTERVIEWS

The interviews conducted were of a semi-structured nature. This means they all shared the same basic structure, but still allowed for some freedom in terms of what specific questions were asked and in what ways the interviewees could reply to them (Bryman & Bell, 2015). This trade-off between focus and flexibility was deemed desirable for this study, as it was considered important to allow the interviewees to answer most questions rather freely in order to generate interesting insights, but still keep some structure to be able to contrast and compare the results from the different interviews.

Regarding the interview process specifically, the interviews were opened by briefly recapping the purpose of the study and the layout of the interview. Because the main research question of this study requires rather in-depth discussions on the enabling technologies of I4.0, it was considered important to start the interviews in a lighter way. Therefore, before covering the more complex topics, the initial questions were rather straightforward. Gradually, the interviews transitioned into more detailed discussions on the enabling technologies, while going back to more open questions on the barriers to an increased I4.0 readiness toward the end. This way of structuring an interview is referred to as an *hourglass sequence* (Narayan, 1999), where general questions open the interview, followed by more specific ones, and then back to wider questions. This was considered an appropriate technique in order to create a dynamic process, thereby preventing the interviewees from losing their focus or interest.

All interviews were audio-recorded and later transcribed, after permission was granted by the interviewees. Recording the interviews was deemed important as it captures not only *what* the interviewees say, but also the *way* in which they say it (Bryman & Bell, 2015). It also allows the interviewers to be fully present during the interviews and not distracted from having to take notes. The potential risk of recording interviews is that the interviewees might hesitate to share insightful information and become self-conscious or worried about their words being preserved. This risk was mitigated by reassuring the interviewees that all recordings would be deleted after the completion of the study.

Regarding the level of detail in the transcripts, the decision was made to transcribe the interviews word for word. This is because if all aspects of the interviews are to be subject to analysis, it is necessary that a complete account of all exchanges is available (Bryman & Bell, 2015). Additionally, words that might seem irrelevant or excessive could actually prove to be important for the bigger context (Patel & Davidsson, 2011). Thus, by keeping a high level of detail in the transcripts, the risk of missing out on interesting insights was minimized.

3.3.3 DATA ANALYSIS

3.3.3.1 EVALUATING I4.0 READINESS

The analytical framework which this study is based on is inspired by a structure developed by the Society of Automotive Engineers (SAE), called SAE J4000. The SAE J4000 considers six elements for the implementation of lean manufacturing, and for each element there are a number of components evaluated. Each component has four statements, or levels, which indicate to what extent a specific component of a particular element is present in the company being analyzed.

In line with the SAE J4000, the model developed by Pacchini et al. (2019) to assess a company's I4.0 readiness is based on eight enabling technologies (elements). Each technology is then broken down into six different prerequisites (components), making the total number of prerequisites evaluated 48. For example, the six prerequisites for the enabling technology of big data are: (i) the company should have infrastructure for digital systems; (ii) the company should have all its reliable data/information organized and maintained in a secure digital system; (iii) the company should have a high speed and capacity wireless network; (iv) the company should have personnel empowered to collect and analyze data; (v) the company should treat big data at the strategic level; and (vi) the company should know the problems to solve with the data obtained.

The presence of each prerequisite is determined using four levels of adoption. The levels are as follows: Level 0 (L0) – the prerequisite is not present in the analyzed company; Level 1 (L1) – the prerequisite exists but is incompletely implemented; Level 2 (L2) – the prerequisite exists and is almost fully implemented; and Level 3 (L3) – the prerequisite is fully implemented. For a complete list of all prerequisites and adoption levels for each enabling technology, see Appendix 2. However, continuing the example of big data, the first prerequisite for this technology is "the company should have infrastructure for digital systems." The four levels of adoption for this prerequisite are:

- L0 – The company has no infrastructure for digital systems.
- L1 – The company has a small infrastructure for digital systems.
- L2 – The company has a medium infrastructure for digital systems.
- L3 – The company has a complete infrastructure for digital systems.

Each level is associated with a certain amount of points, where L0 = 0 points, L1 = 1 point, L2 = 2 points, and L3 = 3 points. Consequently, the degree of readiness for fully adopting a given technology (g_n) can be calculated by dividing the total points generated from its six prerequisites by the maximum number of points available:

$$g_n = \frac{\Sigma\ points\ obtained\ as\ a\ result\ of\ evaluation\ of\ prerequisites\ of\ technology\ n}{Maximum\ points\ possible}$$

For clarification purposes, consider the following example. Technology 1 consists of six prerequisites with the following adoption levels: prerequisite 1 (L1); prerequisite 2 (L2); prerequisite 3 (L1); prerequisite 4 (L3); prerequisite 5 (L0); and prerequisite 6 (L2). The degree of readiness for Technology 1 (g_1) can in this case be determined as follows:

$$g_1 = \frac{1+2+1+3+0+2}{3+3+3+3+3+3} = \frac{9}{18} = 0.50\ or\ 50\ \%$$

This calculation shows that the company has a degree of readiness of 50 % for Technology 1, equal to 0.50 out of a maximum of 1.00 (which would require the company to reach L3 in all prerequisites of that technology).

As all eight enabling technologies are considered to be of the same importance in the context of I4.0, their respective contribution to the company's I4.0 readiness is also considered equal. Therefore, the company's overall degree of I4.0 readiness can be calculated by averaging the score across all the eight enabling technologies. The final outcome of this assessment will thus be a number between 0 and 1, or alternatively a percentage rate between 0 and 100, which indicates the company's level of preparedness for a full-scale implementation of I4.0.

While the model itself is rather straightforward, some questions arose throughout the research process regarding its application and different components. In order to make sure the model was used in a correct way, a continuous dialogue with its developers, Pacchini et al. (2019), was therefore established. For example, as one prerequisite to one of the enabling technologies was missing from the file of the model available online, a complete version of the model was sent by Pacchini et al. (2019) to the authors of this study. Additionally, uncertainties regarding the process of assigning specific adoption levels to the different technological prerequisites were addressed through discussions with the model's developers. This ensured that the model was properly applied to the company investigated in this study.

3.3.3.2 THEMATIC ANALYSIS

In order to determine the case company's degree of readiness for each enabling technology and consequently also for I4.0, as well as to identify the organizational barriers to an increased I4.0 readiness, thematic analysis was used. This was considered an appropriate method as the aim of this study is to learn about how the company works with I4.0 from a set of qualitative data and through the perspectives of different people – exactly the kind of context in which thematic analysis is normally used (Bryman & Bell, 2015). Thematic analysis also allows for a high degree of flexibility in interpreting the data, and facilitates the comparison of different sets of data by sorting them into themes.

In regard to how the thematic analysis was conducted, the first step of the process included coding the data. Predetermined codes were used for the main research question, meaning each enabling technology was given an individual code. After all interviews had been coded, each technology was then analyzed individually. This entailed processing everything discussed about each technology across all interviews, and consequently assigning adoption levels to its prerequisites. For the second and third research question, emerging codes were used. This means that codes concerning the major organizational barriers to an increased I4.0 readiness emerged directly from the data. After a list of potential codes had been constructed, the next phase of the process involved assigning each code a specific color, and then highlighting sections of the interview transcripts according to these. Color coding was used to get an overview of how frequently the different codes appeared in the interviews, and thus an indication of which codes were too vague to be included in the analysis (Bryman & Bell, 2015). Consequently, some of the codes were discarded, leaving the remaining ones to be compared and combined into a number of themes in the following phase. As a final step, all codes and themes were reviewed in order to make sure they were representative of the data, as well as useful in answering the research questions.

3.4 RESEARCH QUALITY

In quantitative research, validity and reliability are typically used to assess research quality (Bryman & Bell, 2015). However, as validity and reliability can be difficult to apply in a qualitative context, Lincoln and Guba (1985) suggest the use of two alternative criteria to evaluate the quality of qualitative research: *trustworthiness* and *authenticity*. Trustworthiness, in turn, consists of four subcriteria: *credibility*, *transferability*, *dependability*, and *confirmability*. Based on these criteria, the following subsections will discuss the research quality of this study.

3.4.1 CREDIBILITY

Credibility refers to the confidence in the truth of the findings (Connelly, 2016), which can be ensured by carrying out the study in accordance with good practice and having the findings verified by the participants in the study (Bryman & Bell, 2015). To attain a high level of credibility, this study has been conducted by following the typical procedures of qualitative research, including making sure the people interviewed had highly relevant and complementing knowledge of the company's experiences of working with I4.0, constructing an interview guide which formed the basis of all interviews, and transcribing all interviews after they had been conducted. Additionally, areas to be discussed during the interviews were shared with the interviewees in advance, and control questions were asked whenever something was considered unclear in order to reduce the risk of misinterpretations.

3.4.2 TRANSFERABILITY

Transferability reflects the extent to which the findings of the study can be applied to other settings (Bryman & Bell, 2015). Because qualitative research typically is not performed with the intention to extrapolate the results to other contexts, the question of generalizability is not of the same importance as it is in quantitative research (Lincoln & Guba, 1985). Rather than generalizable results, a thick description was preferred for this study, which was achieved by focusing on the unique perspectives of each interviewee. Therefore, the way in which the transferability of this study has been strengthen is by clearly describing the process through which this study was conducted, including the selection of case company and interviewees, as well as the ways in which data was collected and analyzed. This allows the reader to make his or her own assessment of the generalizability of the results.

3.4.3 DEPENDABILITY

Dependability refers to whether the outcome of a study would be the same if conducted again (Saunders et al., 2012). Because external conditions continuously change over time, and thus are difficult to replicate (Bryman & Bell, 2015), it is highly unlikely that the results generated from this study would be identical if conducted again. However, by carefully describing and motivating the research methods used, thereby keeping a high level of transparency throughout the entire research process, attempts have been made to strengthen the dependability of this study. Providing detailed records of all phases of the process will make it easier to replicate the study for anyone interested. For example, a clear description of the databases, key terms, and inclusion and exclusion criteria used in the systematic literature review facilitates an objective, transparent, and replicable search process (Baumeister & Prinstein, 2013).

3.4.4 CONFIRMABILITY

Confirmability is concerned with eliminating the researchers' personal values and opinions from the research process (Bryman & Bell, 2015). Because qualitative research always involves a certain degree of subjective judgement, there is a risk that researcher biases will affect the generation and interpretation of the findings. For example, thematic analysis is a relatively subjective method for analyzing data, which means that the analysis relies on the judgement of the researchers and that the risk of misinterpretations thereby is increased (Patel & Davidson, 2011). One way in which this risk was mitigated was by avoiding any leading questions during the interviews, another was to transcribe the interviews word for word. Additionally, data was coded individually at first and then collectively discussed in order to reach a fair final assessment. Finally, confirmability was also strengthened by making sure the empirical findings were presented in the same way as expressed by the interviewees.

3.4.5 AUTHENTICITY

Authenticity reflects the ability of the researchers to convey the complete perspectives and realities of the study's participants in a fair manner (Connelly, 2016). While the other four criteria discussed above all have their respective counterpart in quantitative research, there is no quantitative equivalent to the criterion of authenticity. Authenticity thus represents the relative advantage of qualitative research – the ability to fully portray the deeper meaning of a phenomenon to increase the reader's understanding. In order to secure the authenticity of this study, it was made sure that the people interviewed had relevant yet different insights into the company's experiences of working with I4.0. Their different perspectives complemented each other well, which allowed for a more nuanced, complete description of the company. Additionally, the semi-structured approach to the interviews allowed the interviewees to steer the conversation in the direction considered most interesting, thereby giving them the opportunity to fully express their personal views and opinions.

4. EMPIRICAL FINDINGS

This chapter is divided into three main sections. The first section provides a general description of the investigated company, including information on the larger organization which the company is part of, and the specific factory examined in this study. The second section describes the company's work with I4.0, focusing mainly on their experiences with the enabling technologies. Finally, the third section presents the major organizational barriers which the company experiences in relation to their work with I4.0.

4.1 COMPANY BACKGROUND

The organization which the case company is a part of is a global leader in motion and control technologies. It was founded over 100 years ago in the United States and employs approximately 55,000 people worldwide. Over the years, the company has made a significant amount of acquisitions, which has contributed to a global dispersion and a decentralized organizational structure. Today, it operates in almost 50 countries across six continents, and in Sweden specifically, the organization has been active for almost 40 years and employs about 900 workers.

The organization currently has four manufacturing facilities in operation in Sweden, all located in the western part of the country, with the specific facility analyzed in this study located in the Gothenburg Area. The factory, which employs approximately 200 people, has a turnover of roughly $100M per year and provides smart solutions mainly to OEMs within the fields of agriculture, refuse, forestry, material handling, construction, and special machinery. The products that are manufactured and sold to these customers are typically of low volume and high complexity, consequently meaning that the amount of mass production is limited. Specifically, production is kept at a component level and later assembled to match the individual requirements of each customer.

The factory is modeled according to a "value flow principle," consisting of three main stages: processing, assembling, and testing. The factory receives raw materials which are processed into components. The components are later assembled into final products, and then tested for quality and functionality. In order to ensure a smooth flow of products, this way of organizing the factory requires materials to be in place at the right time at each stage. Hence, the factory has a material handling function which is responsible for both external and internal logistics, as well as the planning of inventory at the different stages.

On a general level, the case company can be described as highly technological and innovative, as confirmed by the interviewees. However, as emphasized by Interviewee A, despite constantly working toward increased digitalization, the company is usually not first when it comes to adopting completely new technologies. Rather, they prefer to wait for a supplier, customer or competitor to make the first move and try the technology, and then adopt it themselves once its application has been tested and its potential confirmed. One reason as to why the company has this approach to new technology is connected to the decentralized organizational structure. Although the decentralized structure has its advantages, Interviewee B argues that it makes it difficult to achieve the kind of large-scale mobilization of resources that typically is required in order to understand a new technology and how it can be best incorporated into the production. As will be evident from the remainder of this chapter, the organizational structure of the case company is also affecting its work with I4.0.

4.2 I4.0 AT THE INVESTIGATED COMPANY

When asked to describe what I4.0 means to them, a relatively uniform interpretation of the concept was provided by the interviewees. Interviewee A sees I4.0 mainly as a way of reducing idle time and the number of errors, as well as to minimize the risk of having the wrong materials at the different stages of the production process. Additionally, by facilitating the identification of bottlenecks through the use of data analytics, I4.0 can help increase productivity. Interviewee B, in turn, describes I4.0 as a "painting palette of different tools and concepts which aim to increase digitalization… and improve the productivity and profitability of the factory." Finally, Interviewee C sees I4.0 as a way to simplify, automate, standardize, and ultimately improve the quality of their products. Additionally, he argues that the technologies of I4.0 have the potential to create value in most stages of the production process, such as material handling, assembly, and test procedures.

Although the interviewees share relatively similar perceptions of the concept, they admit that there has not been any explicit discussions regarding I4.0 at the company. Rather, a general awareness of the importance of increasing their digitalization and automatization has emerged over the last few years, resulting in discussions on how to develop their factories and continue grow the business in Sweden. Eventually, this has led to conversations regarding some of the more specific technologies included in the I4.0 concept. Nevertheless, there is no explicit strategy for the implementation of I4.0 at the company. The focus has rather been to build on their previous work with lean manufacturing, which is something that lies at the core of the company. As Interviewee B describes it, because the company has invested a significant amount of time and resources in lean over the past few years, I4.0 is not something that will replace their work with lean, but is rather seen as an evolution of the work they have already done.

In addition to not talking explicitly about I4.0 or having a specific I4.0 strategy, the company has not made a proper evaluation of their current state in terms of I4.0 readiness. While it is mentioned that they evaluate different technologies in different contexts before implementing them, there has not been any collective assessments made in regard to I4.0. Interviewee C questions the value of making this kind of formal evaluation. As things continuously change, he is uncertain about the importance of making a thorough assessment and then building a strategy based on this. Rather, he argues that it is better to successively take small steps.

Similar to Interviewee C's uncertainty regarding the relevancy of making an exhaustive I4.0 evaluation, Interviewee B questions the value of some of the eight I4.0-enabling technologies for the company. For example, their high-complexity, low-volume production implies that some of the technologies focusing mainly on increasing productivity might not be as relevant as those enabling higher degrees of customization. Consequently, there are considerable differences in the way the company is working with these different technologies. Hence, the next two sections will focus on the technologies which the company is working with the most and working with the least, respectively.

4.2.1 THE MOST PROMINENT TECHNOLOGIES

One of the most prominent technologies at the case company is *big data*. However, because big data is mainly being managed at the central corporate level, it is a technology which the people at the investigated company is only working with to a limited extent. The organization has a central division which collects large amounts of data generated from various sources, and then decides how to process the data before eventually being forwarded to their different organizational units, such as the investigated company. As for the kind of data that is directly managed at the company level, Interviewee C explains that it mainly relates to the machines within the factory. Specifically, by connecting their Enterprise Resource Planning (ERP)-system to their machines, they are able to collect information about their customer orders and the current status of the machines, and then use this information to decide on an optimal sequence of production.

Another kind of data directly managed at the company level relates to the smart products that are manufactured at the factory and sold to their customers. The data generated by the products are sent back to the company and can then be used for a variety purposes, such as condition monitoring, location and tracking, remote diagnostics, and other kinds of reports. Interviewee A claims that since they design and produce the smart products themselves, they are able to make better analyses than their customers from the data generated by these products. This has been identified as an opportunity to create additional value and thereby extend their customer offerings. However, not all customers understand the value of the data generated from their products, which is why some of them are not interested in paying extra for this additional service. As for the ones that do understand the value of the data, questions often arise in terms of who owns it. Many of the company's big OEM customers consider their data "holy," and are thus reluctant to share it with external partners. Nevertheless, a fair share of the company's customers both understands the value of data and is willing to pay extra for the additional services, and as more customers are expected to recognize the benefits of these extended offerings in the future, more data is expected to be managed at the company level moving forward.

Much of the data being processed at the company is generated from various *IoT* devices which are built into all their smart products and machines. According to Interviewee A, IoT is a prioritized area in the organization as a whole, and has been for several years. As such, he believes they have come relatively far in terms of adopting IoT at the investigated company. This is especially true for the products they manufacture and sell to their customers, as they are equipped with sensors and barcodes which contain product-specific information. This information is stored in a database and can be accessed by, for example, scanning the code on the specific product. Furthermore, information about the status of the products is available remotely by having the products connected to the Internet. In this way, the products can continuously communicate with the company's information system by automatically sending signals, which is possible through the use of antennas and different kinds of gateways, such as bluetooth modules, modems of various speeds, and the company's own developed application.

Looking specifically at how IoT is incorporated within the factory, the technology here is not as developed. Materials arriving on a daily basis are indeed equipped with sensors and barcodes so that they can be tracked and monitored as they move from one station to another. However, materials are not scanned automatically, but manually. As a result, scanning materials is one of the most time-consuming activities for the factory workers. Additionally, because the workers sometimes forget to scan the materials they pick, this system causes issues in terms of inventory level misinformation. In the future, Interviewee B sees the potential of changing to a more advanced system which incorporates RFID into the material handling function for higher levels of automatic scanning.

Another application of the IoT technology is the usage of different software to collect data on the processing machines within the factory. This data can then be used to identify when a machine requires maintenance or when any other kind of improvement work is necessary. Additionally, the processing machines are equipped with electronic codes which make it possible to control them remotely. Although this can be beneficial in several different ways, Interviewee B admits that there is an uncertainty as to how to best utilize these codes. This uncertainty also applies to the way IoT is incorporated in the processing function at the factory in general. Specifically, while most key components of the technology is in place, there is a lack of integration between them. As such, although the company has made significant investments in IoT over the last few years, there is still more to be done.

As is clear from the discussions above, large amounts of data are constantly being generated from a wide variety of sources, which are then stored and managed both at a central corporate level and company level. To support this work, the company uses *cloud computing*. Interviewee C explains that this has not always been the case, mainly because the company has been worried about potential security issues of storing sensitive information in clouds. However, as the technology has developed and been increasingly adopted by other actors in the industry in recent years, the company has started taking advantage of this technology as well.

As for how the technology is utilized at the investigated company, different clouds are used for different purposes. Externally, the company has several clouds to which their customers and suppliers can connect. These external clouds are planned to be developed further. For example, the company is looking to build a separate network within their production which will allow their suppliers to directly connect to the machines in the factory and hence detect whenever any preventative maintenance is required. Here, Interviewee C emphasizes the importance of making a thorough assessment as to what kind of data is stored in this network so that sensitive data is not made available to their suppliers.

For the more sensitive data, the company has their own internal cloud which they are careful about not providing any external partners access to. Because this cloud is intended to be used only within the company, they have taken measures to ensure that the employees know how to manage the data in a safe manner. For example, the company requires their employees to go through different forms of training every year to learn about safe data management and cyber security. As such, this has been a prioritized area within the company.

A central part of cloud computing for the company is the standardization and integration of their different systems and functions. Here, the company's ERP-system plays a fundamental role. However, despite not lacking in terms of functionality, Interviewee C admits that their ERP-system is relatively old and therefore might need to be replaced or updated. This is mainly due to the difficulties of integrating new technologies to the system and finding people with relevant competence. Additionally, because the same ERP-system is used in all organizational units across Europe, upgrading to a new system would be an expensive and time-consuming task. Nevertheless, as Interviewee C argues that they have relatively fast, safe, and high-capacity internal networks, he is positive regarding the company's work with cloud computing moving forward.

4.2.2 THE LEAST PROMINENT TECHNOLOGIES

One of the least prominent technologies at the company is *CPS*. Interviewee B explains that the technology potentially could be used to create virtual representations of their factory, and use these to test out different layout changes. However, because the factory is relatively small in terms of its size, layout changes do not occur particularly often. Therefore, the CPS technology might not to be as relevant to the company as it might be for other companies within the industry with larger manufacturing facilities. Additionally, creating these virtual environments is rather expensive, which further raises questions regarding whether or not it actually is worthwhile for the company to go through with investing in CPS.

Despite questioning the relevancy of CPS, the company recently started a collaboration with a local university concerning digital twins. More specifically, they work on a project which involves 3D-scanning a part of their factory in order to be able to experiment with different potential layout changes. While it is uncertain if this project will actually come to any valuable use for the company, Interviewee B emphasizes that it is necessary for the production engineers to partake in these types of collaborations and keep exploring new technologies. As such, he sees this project not mainly as a way to improve the factory, but rather as a way to encourage experimentation and curiosity.

To further spur creative thinking, the company recently invested in a smaller *autonomous robot*. Since there is a lack of cases within the organization as to how these types of robots can be used, this investment was made by the company mainly to familiarize themselves with the technology and learn more about its potential areas of application. However, Interviewee B argues that this has been difficult, not necessarily due to a lack of technical knowledge of how the robots work, but rather because they are having trouble seeing how the robots can be incorporated into their high-complexity, low-volume production process. Furthermore, as an autonomous robot is expensive and, according to Interviewee B, will only reduce the required human manpower marginally, there are uncertainties regarding the payback of this kind of investment. Additionally, since the robots from time to time will require maintenance work, technicians will need to be readily available, thereby demanding even more resources to be dedicated to the robots.

A few years ago, the company actually worked closely with an external consultant agency to increase the degree of automation in their assembly through the use of autonomous robots. However, although these robots should be able to provide value in an automated assembly process, the project was eventually cancelled. The reason was that the company's products come in too many varieties, and because of their high complexity, they require millimeter precision and thus leave no margin for errors. Since the robots involved in the project were not considered capable of handling this combination of variety and complexity, the company decided not to continue with the project nor incorporate the robots in the factory.

In order to gain a new, fresh perspective on potential ways of incorporating autonomous robots in their production process, the company recently started working on another project, this time with a local university. With this project, combined with additional experimentation with the robot recently invested in, Interviewee B hopes to find valuable uses of the technology. He considers the production engineers well educated and eager to develop the technology, and emphasizes the importance of allowing it to take time, especially considering the lack of good examples within the organization to draw inspiration from.

Aside from looking at autonomous robots, which potentially could replace human workers, the company has focused heavily on developing solutions which will help support their factory workers in their manual labor. One technology with great potential here, especially in the assembly process, is *AR*. However, although the company has started looking into AR, they currently use another system in their assembly function to support the workers, called digital instructions. These digital instructions support the workers by providing step-by-step guidelines for what components to install, where, and how. Furthermore, smart tools are connected to these instructions to give an exact torque when tightening screws, thus minimizing the risk of human errors. This is considered highly important as the high pressure inside the valves of many of the products requires an exact degree of tightness.

Prior to developing the digital instructions, the workers had to learn assembling manuals which in some cases were up to 100 pages long. With the digital instructions, the learning time is reduced significantly, and by learning the system, workers can easily switch between different assembly lines if production stops and extra help is needed. Considering all these benefits, Interviewee C claims that the vast majority of the workers are satisfied with the system, and therefore sees no urgent need of investing in AR, which most likely would replace the digital instructions.

There is a slight disagreement between Interviewee B and C in terms of where the AR technology could create most value within the factory. Interviewee B explains that they have been looking into the application of AR in the assembly line at the factory, where productivity can be increased by not having the workers stop what they are doing and look up instructions on a screen, but have the instructions displayed directly in front of them through a pair of AR-goggles. In contrast, Interviewee C sees little room for value-adding in the assembly line. He argues that it will only create small increases in productivity, which do not justify the cost of the investment. Rather, he sees a future potential for AR when making 3D-scans of the factory and testing new layouts. With the help of AR, he argues, it will be possible to simulate and move around machines, equipment and other objects, and then walk around the factory with a pair of AR-goggles in order to get an idea of the result.

Another technology which the company recently started looking into is *additive manufacturing*. Interviewee B reasons that because their customers do not really care about the specific way in which the products are manufactured, as long as quality is not compromised, the company could in theory switch to more additive manufacturing without having to worry about any customer objections. At the same time, he explains that the complexity of the products demand very specific manufacturing methods which the additive technology might not be able to perform. Therefore, the company is not planning to adopt the technology on a wider scale anytime soon, but rather when the next generation of products is introduced, as these products are expected to be manufactured in a way that is better suited for additive manufacturing. As of today, however, the processing machines that are currently used are considered far more cost efficient than a number of 3D printers would be, even if they were capable of manufacturing the company’s highly complex products.

Nevertheless, Interviewee B still sees some specific areas of application for additive manufacturing in the near future. Specifically, he argues that it could be interesting to invest in the technology in a smaller scale in order to print some spare parts which are produced only in very low volumes. Because the lead time for some of these spare parts can be up to ten weeks, having a 3D printer capable of manufacturing them in a matter days would be highly valuable to the company. Interviewee B also explains that they are currently working with some plastic printers to produce fixtures and prototypes. However, as these printers are used only to a very limited extent today, he sees potential for the additive manufacturing technology to be incorporated on a larger scale also in this regard.

Finally, regarding the I4.0-enabling technology *AI*, Interviewee A explains that their work with this technology has been limited. Going back to the beginning of this chapter, it was explained that the company typically prefers waiting for other actors to make the first move before adopting any new technologies. According to Interviewee A, this is one of the main reasons as to why they have not yet seriously considered adopting AI. At the same time, he argues that as the technology eventually develops and sees a more widescale adoption in the industry, they are likely going to start looking into it more.

In terms of potential application areas for AI, Interviewee B sees the biggest potential for the technology in the material handling function, where it can be used to optimize the internal logistics and planning of material. Today, these activities are controlled by rather rudimentary systems and algorithms. Since having the right materials at the right place and time is critical for the entire production process, using AI for a more efficient and reliable material handling is considered highly interesting for the company moving forward. Therefore, AI is a technology which the company will need to look into sooner rather than later. However, as Interviewee B describes AI as more or less an "off-the-shelf software," he is not concerned about having to source the technology, learn how it works, and incorporate it into the factory.

4.3 MAJOR ORGANIZATIONAL BARRIERS

4.3.1 FINANCIAL CAPACITY

Regarding the investigated company's financial capacity to invest in I4.0, Interviewee C claims that they are rather strictly controlled from a central corporate level. Specifically, they are expected to deliver a certain result each year, and while they have a relatively high degree of freedom in terms of *how* to reach this result, they still need to make sure that they actually reach it. As such, the allocation of resources becomes a critical question and, consequently, the space for investing in new technologies somewhat limited. Interviewee B recalls his manager once saying, “there is no cash tree,” meaning if the company wants opportunities to experiment with different technologies, they have to create and make sure to pursue these opportunities themselves. Therefore, maintaining an open dialogue at the company regarding how they can best organize their resources is considered a key, as is continuously finding ways to create the space in which new technologies can be experimented with.

Because priorities always have to be made in terms of where to allocate their resources, Interviewee A admits that while investments have been made in some technologies, others have not been given the same attention. Regarding the least prioritized technologies, Interviewee B explains that it is not feasible for the company to invest large amounts of resources when there are uncertainties concerning the payback for some of these investments. This is considered an issue, since being forced to always count decimals has resulted in rather safe, streamlined projects being carried out almost exclusively. As put by Interviewee B, the focus has been on “picking the low-hanging fruit,” meaning that investments are made only in the technologies which they are certain will create value for the company. Therefore, he hopes to see more trust being showcased from higher up in the organization and more funds being opened up, giving the company financial support to try out more daring ideas. However, as of today, they still need to find their own ways of experimenting with new technologies, which is one of the main reasons as to why the company currently is working together with local universities with some of these technologies – to identify cost-effective ways to incorporate the technologies in the different stages of the production process. As doing these projects internally would require both much time and resources, collaborations with external partners are considered highly valuable.

4.3.2 STRATEGY AND LEADERSHIP

An issue which all interviewees agree on is the lack of clear strategic guidelines from the central corporate level, not only in terms of their work with I4.0, but their overall efforts on increasing digitalization and automization. Interviewee B claims that even when it comes to areas that are prioritized at the organization as a whole, such as incorporating IoT into the products that are sold, information has been limited regarding how this will impact the operating environment at a company level. Consequently, the interviewees emphasize the importance of a clearer focus moving forward. For example, Interviewee A argues that the organization needs to develop a more distinct plan describing where they want to be in 5-10 years, and Interviewee C calls for clear technology standards and structures to make sure the different organizational units throughout the world work more uniformly. This view is shared by Interviewee B, although he emphasizes that individual characteristics of specific factories need to be taken into consideration so that not everyone is forced to work in the exact same way.

Connected to the lack of strategic guidelines is the absence of clear leadership. Directions from the central corporate level concerning the way in which the company should move are limited, and as a result, individual responsibility has become critical. Interviewee B explains that they are dependent on initiatives from either external partners, such their suppliers, or from their own workers. In other words, leadership has to come from below. While the lack of central leadership presents some issues, such as uncertainties about where the organization is heading, Interviewee A explains that making decisions in small, agile teams further down in the organization is the best recipe for staying innovative and successful. Because it is not unusual for important issues to be discussed and decisions to be made over their coffee breaks, he describes this way of working as "making coffee-machine decisions." These types of decisions are considered highly valuable since, as put by Interviewee A, "the higher up in the organization decisions are made, the longer it takes and the worse the result."

4.3.3 ORGANIZATION AND CULTURE

Linked to the decentralized organizational structure which characterizes the entire organization, as well as the requirements on the investigated company to reach a certain annual result, are some inherent conflicts. For example, when people from the factory are needed for a central corporate project which requires them to leave the factory for some time, Interviewee B explains that he as the manager of the factory might have to oppose to this because the people are needed at the factory in order to reach the performance required from them. Even though temporarily letting go of a few of his employees to work on a central project might be for the greater good of the organization, he has other priorities which are more important and urgent to both him and the factory. Therefore, Interviewee B sees the need of having people on a central corporate level specifically focused on working together on different kinds of projects, such as those concerning new technologies, so that people do not have to be "borrowed" from elsewhere in the organization.

The decentralized organizational structure has also resulted in difficulties in finding good internal examples of how new technologies can be employed. However, while the lack of cases to draw inspiration from is seen as a problem in itself, it has also forced the company to go their own way and thereby encouraged an experimental culture. Indeed, Interviewee B describes their way of working with new technologies as slowly moving in the right direction through a lot of trial-and-error, and Interviewee C emphasizes the importance of not being afraid to keep trying and continuously learn from their experiences. He further explains that while formal educational seminars was the most common form of learning in the past, the most effective way of learning is by actually doing. Therefore, making sure to experiment with new technologies as much as possible is considered highly important in the process of becoming more digitalized, while keeping in mind the financial limitations.

4.3.4 HUMAN RESOURCES

While describing the factory workers as highly valuable and the production engineers in particular as a great asset, Interviewee B admits that some of them do not have a mindset adjusted to I4.0. Since the company has a history of working with lean, he explains that the engineers' knowledge about this kind of work is great, but that they are not as comfortable working in an I4.0 environment. Since I4.0 and the enabling technologies represent some completely new areas to many of them, he does not consider this too surprising. Nevertheless, in the specific context of I4.0, some of the engineers are described as somewhat "old-school." As an example, when confronted with a problem in the production, these engineers will try to solve it in a traditional, non-optimal manner, rather than removing the problem altogether through an automated solution. In other words, as expressed by Interviewee B, they "see a hammer rather than a scanner."

While emphasizing the importance of having people with different mindsets, Interviewee B admits that the competencies of some of the engineers need to be updated. Specifically, he claims that a generation gap exists, where the younger generation is able to adopt to the new production environment faster, while the older generation might require more time. However, as all engineers are considered both talented and eager to learn about new technologies, Interviewee B is convinced that this will not be an issue moving forward. As long as the company keeps seeking ways of exposing the engineers to new technologies and new ways of working, for example by involving them in their collaborations with local universities, it will only be a matter of time before they have accommodated to the I4.0-way of working.

Expanding the perspective and looking at the workforce as a whole, Interviewee C describes the employees as having a relatively positive attitude toward change. Although there will always be people who demonstrate some kind of resistance, he argues that the vast majority is fully committed to their increasingly digitalized way of working. Comparing this situation to the organization's other units throughout the world, Interviewee C claims that Sweden is in the forefront in terms of general attitude toward adopting new technologies. He believes this has a deep cultural and political explanation. As Sweden has always been dependent on its export industries, the country has been forced to develop a curiosity to stay innovative, and learn from other countries. Additionally, high salary costs have required productivity improvements in order for Sweden to stay competitive as a country. Often, these improvements have come in the form of various kinds of automated solutions, which explains why the Swedish attitude toward new technologies traditionally has been very positive. According to Interviewee C, this kind of attitude is highly evident among most employees at the company, and is considered critical in regard to their work with I4.0 and the enabling technologies moving forward.

5. ANALYSIS AND DISCUSSION

This chapter is divided into two main sections. The first section analyzes the case company's work with I4.0, mainly focusing on their experiences with the eight enabling technologies. This analysis includes assessing each technology's degree of readiness, eventually leading to an overall degree of I4.0 readiness being calculated for the company. An alternative degree of readiness is also presented, taking into consideration the relative importance of the enabling technologies for the company. The second and final section analyzes the company's readiness for I4.0 from an organizational perspective. More specifically, it discusses the organizational barriers and ways in which the company can overcome these to increase their readiness.

5.1 I4.0 READINESS AT THE INVESTIGATED COMPANY

The framework developed by Pacchini et al. (2019) aims at measuring the degree of I4.0 readiness for a company by evaluating its readiness for eight I4.0-enabling technologies. While it might seem confusing to evaluate the readiness of a technology which the company is already working with, it should be clarified that working with a specific technology in one way or another does not necessarily mean the company is ready for a widescale implementation of all aspects of that technology. In contrast, a technology which the company has not yet adopted could potentially be associated with a relatively high degree of readiness. Therefore, the company might actually reach a higher degree of readiness for a technology which they are currently not working with than for one already being used.

In the following sections, the enabling technologies of I4.0 will be analyzed in the context of the investigated company, eventually leading to an assessment of their respective degree of readiness. The degree of readiness for each technology will be presented at the end of the analysis of each technology, and will be expressed as a percentage rate. As the technologies all have six different prerequisites, making the total number of prerequisites to evaluate 48, not all of them will be discussed here. However, it should be noted that the interviews generated enough information to make a fair evaluation of the extent to which the company meets each prerequisite of each enabling technology. Therefore, all prerequisites will still be taken into consideration in the assessment. Later in this chapter, the degree of readiness for each enabling technology will be added up and then averaged in order to arrive at an overall degree of I4.0 readiness for the company.

5.1.1 BIG DATA

Despite being a widely dispersed organization characterized by a decentralized structure, much of the data generated from its different units, including the investigated company, is managed at the central corporate level. The fact that a large share of the generated data is being stored, structured and processed centrally clearly shows big data is a prioritized area with a strategic importance. Therefore, prerequisite BD5 ("The company should treat big data at the strategic level") is considered fully met.

However, not all data is managed at a central corporate level. For example, data generated from the products that are manufactured at the factory is sent back directly to the investigated company for analysis. While customers' unwillingness to share their data or to pay extra for additional services may limit the amount of data flowing back to the company, the interviewees expect this to change moving forward. Nevertheless, it can generally be said that decisions regarding what and where data is managed seem to be made only after careful consideration. This suggests a high level of maturity and an understanding of where the data can generate most value and how it can be best used. Therefore, prerequisite BD6 ("The company should know the problems to solve with the obtained data") is considered fully met.

According to Wessel (2016), by understanding how data can be most effectively utilized, companies can increase the value of their data. In turn, this could eventually lead to new streams of revenue (Bean, 2017). Looking at the investigated company, where data is being increasingly incorporated into their customer offerings, a new revenue stream seems to have been identified. By convincing more customers about the high value of the analyses made in regard to their products, this might even result in a new business model for the company in the future. However, regardless of whether or not a new business model will emerge, I4.0 relies heavily on the insights gained from efficiently managing data (Preeti & Prasad, 2018). Therefore, it is necessary for the company to make good use of all the data they collect, which they indeed seem to do. Since collecting, processing and analyzing data in an efficient and effective way is central to the company, they clearly seem to have qualified employees, and therefore reach a relatively high level for prerequisite BD4 ("The company should have personnel empowered to collect and analyze data").

As the discussion above indicates, analyzing the company's work with big data clearly shows that most prerequisites are fully met. Taking all six prerequisites into consideration, the total degree of readiness for big data is 88.9 %, as seen in Table 5.1.

BIG DATA					
Prerequisite	Adoption Level				Degree of Readiness
	0	1	2	3	
BD1				✓	*88.9 %*
BD2				✓	
BD3			✓		
BD4			✓		
BD5				✓	
BD6				✓	

TABLE 5.1: *DEGREE OF READINESS FOR BIG DATA*

5.1.2 INTERNET OF THINGS (IoT)

Another prioritized technology is IoT. The interviews indicate that IoT is considered highly valuable, especially in regard to the products that are manufactured at the factory and sold to their customers. Here, several of the technology's most fundamental components are being incorporated in one way or another, such as various types of sensors, electronic codes and IoT software. This enables the products to send back data regarding their current status, both automatically through the Internet and manually through physical scanning. As a result, the company can monitor and track their products throughout their lifetime, and constantly stay updated on their general condition long after they have left the factory, which according to Zhong and Ge (2018) are some of the main benefits of the IoT technology. This means that the company reaches a relatively high level for prerequisite IoT1 ("The company should fully utilize RFID technology"), and is considered to fully meet prerequisite IoT 2 ("The company should fully utilize Electronic Product Codes").

However, it is important to remember that IoT should serve an important purpose not only outside the factory, but also within it. Here, the interviewees convey an impression that the technology is much less developed. For example, while materials arriving on a daily basis are equipped with both sensors and product codes, the lack of automatic scanning requires a considerable amount of time to be spent on scanning the materials manually, consequently resulting in human errors being made from time to time. Additionally, although machines within the factory have been installed with various software to allow the company to detect whenever any maintenance work is required, the machines do not seem to be self-regulating in the same way Chou (2019) argues they should.

Nevertheless, looking at the specific prerequisites for IoT, the investigated company can on a general level be seen as meeting them well. While there are some uncertainties as to how IoT can best be incorporated into certain functions within the factory, most of the technology's key components are indeed present. In sum, the total degree of readiness for IoT is 77.8 %, as can be seen in Table 5.2.

INTERNET OF THINGS					
Prerequisite	Adoption Level				Degree of Readiness
	0	1	2	3	
IoT1			✓		*77.8 %*
IoT2				✓	
IoT3			✓		
IoT4			✓		
IoT5				✓	
IoT6			✓		

TABLE 5.2: *DEGREE OF READINESS FOR INTERNET OF THINGS*

5.1.3 CLOUD COMPUTING

Considering that cloud computing is a technology which the company only relatively recently started working with, it is noteworthy how much of a significant role it already seems to play. The interviewees explain that clouds are used to support the collection, storing and sharing of data, both internally and externally. At the same time, the interviewees heavily emphasize the importance of carefully considering what kind of data is stored in their different clouds. Using internal clouds for their more sensitive data and requiring employees to go through various forms of training every year shows that cyber security is a prioritized area. As such, the company is considered to fully meet prerequisite CC1 ("The company should have information security systems to mitigate any cyber-attacks").

Alcácer & Cruz-Machado (2019) emphasize the value of cloud computing in terms of connecting the manufacturing company with its customers and suppliers. As such, another important application of the technology seems to be the provision of solutions which enable the interaction between the actors throughout the value chain. In this regard, the investigated company is using external clouds to which their customers and suppliers can connect. These clouds are planned to be developed further to increase external cooperation even more, thus indicating that the company is increasingly moving toward CMfg, where network, software and manufacturing resources are shared among the cloud users (Jiafu et al., 2016). Therefore, the company reaches a relatively high level for prerequisite CC3 ("The company should have a culture aiming at the external transference of private data").

Despite experiencing various difficulties in relation to the cloud computing technology, such as integrating the clouds with their ERP-system, the company is considered to meet most of the technology's prerequisites. Consequently, the total readiness for cloud computing of 83.3 %, as can be seen in Table 5.3

CLOUD COMPUTING					
Prerequisite	Adoption Level				Degree of Readiness
	0	1	2	3	
CC1				✓	*83.3 %*
CC2				✓	
CC3			✓		
CC4			✓		
CC5				✓	
CC6			✓		

TABLE 5.3: *DEGREE OF READINESS FOR CLOUD COMPUTING*

5.1.4 CYBER-PHYSICAL SYSTEMS (CPS)

Alcácer and Cruz-Machado (2019) describe CPS as the merger between the physical and the digital through the creation of virtual representations of physical spaces. As such, it seems as if one of the main ways in which a company can work with CPS is by creating digital copies of the physical manufacturing environment, which then can be used for a variety of purposes. In this regard, the investigated company has started taking small steps, mainly by collaborating with a local university on a project concerning digital twins. However, while the interviewees explain that this will allow them to experiment with different ways to organize their factory, they also question the value of this project considering that layout changes do not occur particularly often. As such, it is uncertain whether or not the CPS technology actually is relevant to the company, at least in this regard.

Despite questioning the relevancy of the technology, the fact that the company is still putting efforts into CPS is a positive sign. As argued by Machado et al. (2019), transitioning to I4.0 and adopting the concept's enabling technologies is a process characterized by considerable uncertainty. This uncertainty might discourage companies from going through with the change, and must therefore be met with curiosity and positivity. Because the investigated company not only in regard to CPS, but many of the other enabling technologies as well, continuously try to find ways of incorporating them into their production process, it seems as if they have a positive general attitude toward their work with I4.0.

Considering that the company does not work much with CPS, their degree of readiness for this technology is surprisingly high. This can be explained by the prerequisites for CPS, as they are strongly linked to many of the other enabling technologies. As it happens, the technologies referred back to in these prerequisites are the ones which are most prominent at the investigated company, namely IoT, big data and cloud computing (see prerequisite CPS2, CPS3 and CPS4, respectively). In sum, the company's total degree of readiness for CPS is 72.2 %, as can be seen in Table 5.4.

CYBER-PHYSICAL SYSTEMS					
Prerequisite	Adoption Level				Degree of Readiness
	0	1	2	3	
CPS1			✓		*72.2 %*
CPS2			✓		
CPS3			✓		
CPS4			✓		
CPS5				✓	
CPS6			✓		

TABLE 5.4: *DEGREE OF READINESS FOR CYBER-PHYSICAL SYSTEMS*

5.1.5 ADDITIVE MANUFACTURING

As of today, the company uses traditional manufacturing methods for the components which later are assembled into final products, but has started working with printers to produce different types of fixtures and prototypes. However, the interviewees already see a limitation in the technology's potential due to the high complexity characterizing their products. Additionally, they seem to consider their current processing machines superior to 3D printers, thus contradicting Chun et al. (2019) who argue that additive manufacturing offers numerous advantages compared to traditional manufacturing, such as the production of a wide variety of objects with advanced attributes. Recent developments within the additive technology even enables the integration of electronic components in the fabrication of the objects (Dilberoglu et al., 2017). Hence, it seems as if the company has made no proper evaluation regarding their ability to adopt the technology, consequently resulting in a rather low level for prerequisite AM2 ("The company should evaluate its technical capacity to deal with additive manufacturing").

As explained by Rayna and Striukova (2016), in order to be able to print various objects, a digital model in 3D needs to be created for each object. The fact that the company has no plans to start using additive manufacturing on a wider scale anytime soon clearly implies that 3D models are missing for the great majority of their products. At the most, digital models in 3D are limited to the few objects that today are manufactured using the additive technology, and potentially some rare spare parts, as the interviewees explain that they are considering 3D printing these due to their long lead times. Therefore, in regard to prerequisite AM6 ("The company should have all its product drawings in 3D digital files"), the company reaches a relatively low level.

Creating a digital file for all components would naturally require a lot of work. Additionally, the interviewees argue that the cost of purchasing the number of 3D printers required to print all their components is too high. This could explain why additive manufacturing is only used to a limited extent today, and why the company is waiting for future product generations before willing to consider adopting the technology on a wider scale. Because the company uses additive manufacturing only for objects that are deemed appropriate, it seems as if thought has been put into what objects can be manufactured using the technology and what objects cannot. As such, the company is considered to fully meet prerequisite AM1 ("The company should consider the feasibility of parts to be produced through additive manufacturing").

As is clear from the discussion above, some prerequisites for additive manufacturing are not considered met by the company, while some are, thereby indicating a relatively average total score. This is reflected by the overall degree of readiness for additive manufacturing, which is 55.6 %, as shown in Table 5.5.

ADDITIVE MANUFACTURING					
Prerequisite	Adoption Level				Degree of Readiness
	0	1	2	3	
AM1				✓	*55.6 %*
AM2		✓			
AM3				✓	
AM4		✓			
AM5		✓			
AM6		✓			

TABLE 5.5: *DEGREE OF READINESS FOR ADDITIVE MANUFACTURING*

5.1.6 AUTONOMOUS ROBOTS

As there are numerous application areas for autonomous robots (Fragapane et al., 2020; Alcácer & Cruz-Machado, 2019), it would be fair to assume that the technology could be adopted at various functions at the investigated company. However, contradicting the literature, the interviewees claim that they do not see any obvious use for the technology. They argue that this is mainly due to the nature of their production, which is characterized by high complexity and low volume. It could be questioned whether the company actually is aware of the technology's limitations, as there most likely are application areas for the robots which have not yet been looked into. However, by showing an understanding as to why the technology might not be appropriate to implement in the production process, the company reaches a relatively high level for prerequisite ARO2 ("The company should understand the limitations of collaborative robots").

During the interviews, it was explained that the company has worked with external consultants in the past to improve the automation of their assembly line through the use of autonomous robots. The project failed, however, and it seems as if this negative experience has caused the company to neglect the potential value that the technology could add if implemented appropriately. Being "stuck" in this mindset, it is perhaps not surprising that the company is finding it hard to see where these robots can be incorporated. Additionally, by experimenting with only one robot, which is what the company is currently doing, the full potential of the technology might be difficult to assess. Indeed, Pedersen et al. (2016) implies that in order to reap the full benefits of the technology, *multiple* robots working in unison are required, thus meaning that the company might need to test the technology on a wider scale in order to be able to make a fair assessment of its value. Finally, considering that the company does not plan to implement robots in the production anytime soon, it is clear that the people who might eventually work alongside the robots have not yet been prepared for this transition. As such, the company is not considered to meet prerequisite ARO5 ("The company should prepare the labor force to work side by side with robots").

While autonomous robots have the potential of significantly improving the manufacturing process in a variety of ways, the company is still in the early experimentation phase with this technology. This is reflected by the overall degree of readiness for autonomous robots, which is only 33.3 %, as seen in Table 5.6.

AUTONOMOUS ROBOTS					
Prerequisite	Adoption Level				Degree of Readiness
	0	1	2	3	
ARO1		✓			*33.3 %*
ARO2			✓		
ARO3		✓			
ARO4			✓		
ARO5	✓				
ARO6	✓				

TABLE 5.6: *DEGREE OF READINESS FOR AUTONOMOUS ROBOTS*

5.1.7 AUGMENTED REALITY (AR)

Because the interviewees emphasize the importance of supporting the factory workers in their daily operations, AR seems like a technology which potentially could add a lot of value to their specific factory. However, since the digital instructions system currently used is reported to be highly appreciated among the factory workers, it does not come as a big surprise that the company is not yet seriously considering adopting AR. Nevertheless, making sure their workers are operating in a satisfactory environment is clearly a prioritized area, which is why the company reaches a relatively high level for prerequisite AR1 ("The company should consider the work environment of operators").

An interesting observation from the interviews is that the company typically has a careful approach when it comes to adopting new technologies, owing a lot to uncertainties in terms of how the technologies can best be incorporated into the production process. The fact that recent research shows that the application of AR is challenging (Egger & Masood, 2020) might therefore help explain why the company is not planning to adopt the technology anytime soon. The interviewees do have some potential areas of application in mind, such as in the assembly function, which is typically where the technology is most widely applied (Blanco-Novoa et al., 2018). However, because the company has made no investments specifically in AR as of today, they only reach a relatively low level for prerequisite AR5 ("The company should have adequate software and hardware to support AR").

In sum, although the company reaches relatively high levels for some of the prerequisites of AR, the total degree of readiness for this technology is rather low. Specifically, the company's degree of readiness for AR is 38.9 %, as can be seen in Table 5.7.

AUGMENTED REALITY					
Prerequisite	Adoption Level				Degree of Readiness
	0	1	2	3	
AR1			✓		*38.9 %*
AR2	✓				
AR3			✓		
AR4	✓				
AR5		✓			
AR6			✓		

TABLE 5.7: *DEGREE OF READINESS FOR AUGMENTED REALITY*

5.1.8 ARTIFICIAL INTELLIGENCE (AI)

AI is another technology which the company has not started working with. Since AI typically is infused with other enabling technologies (Lee et al., 2019), it seems as if it is able to provide significant synergy effects. However, this implies that the other enabling technologies need to be in place *before* implementing AI. For example, ML, which is a specific niche within AI, could be incorporated into autonomous robots in order to help them become smarter and thereby more independent. The issue here is that the company is working with autonomous robots only to a very limited extent, thus making it difficult to incorporate AI here. Because the situation is similar for most other technologies which AI can be incorporated into, the company reaches a relatively low level for prerequisite AI5 ("The company should have other enabling technologies implemented").

According to the interviewees, another reason as to why AI has not yet been implemented is because they are waiting for someone else to make a first move to confirm the technology's potential. However, as Lee et al. (2019) explain that there is a lack of success in regard to AI in the manufacturing industry, it seems as if the implementation of this technology in the investigated company lies in a distant future. Furthermore, although the engineers showsgreat determination in terms of wanting to learn how the technology works, they still have trouble seeing exactly how it can be employed. As such, while the technology might offer great benefits for the company, the road to reaping its full benefits is still uncertain, hence resulting in a relatively low level for prerequisite AI2 ("The company should have knowledge of AI and a clear strategy for its implementation").

Looking at the prerequisites for AI and the extent to which they are fulfilled by the company, most of them reach a medium level of adoption. As seen in Table 5.8, this is reflected by the total degree of readiness for AI, which is 55.6 %.

ARTIFICIAL INTELLIGENCE					
Prerequisite	Adoption Level				Degree of Readiness
	0	1	2	3	
AI1		✓			*55.6 %*
AI2		✓			
AI3			✓		
AI4			✓		
AI5		✓			
AI6				✓	

TABLE 5.8: *DEGREE OF READINESS OF ARTIFICIAL INTELLIGENCE*

5.1.9 SUMMARY I4.0 READINESS

So far, the degrees of readiness for the eight I4.0-enabling technologies have been evaluated by assigning a level of adoption to each technology's six different prerequisites. However, as the main research question of this study requires an overall degree of I4.0 readiness to be calculated, the average degree of readiness across all enabling technologies needs to be considered. Calculating the overall degree of I4.0 readiness shows that the investigated company is 63.2 % ready for a full-scale adoption of I4.0, as can be seen in Table 5.9.

Technology	Degree of Readiness	Total Degree of Readiness
Big Data	*88.9 %*	*63.2 %*
Internet of Things	*77.8 %*	
Cloud Computing	*83.3 %*	
Cyber-Physical Systems	*72.2 %*	
Additive Manufacturing	*55.6 %*	
Autonomous Robots	*33.3 %*	
Augmented Reality	*38.9 %*	
Artificial Intelligence	*55.6 %*	

TABLE 5.9: *TOTAL DEGREE OF I4.0 READINESS*

The 63.2 % degree of readiness for the case company indicates a similar result to the one found by Machado et al. (2019) in their assessment of the I4.0 readiness of a number of Swedish manufacturing companies. While most of the companies included in their study only reached modest levels of readiness, those of the larger size were generally deemed more ready for the implementation of I4.0, with most of them reaching an intermediate level of readiness. As the company investigated in this study is considered to be a large-sized company, their I4.0 readiness of 63.2 % thus seems to match the readiness of the companies of similar size in the study conducted by Machado et al. (2019).

Similarities can also be identified in relation to the study conducted by Castelo-Branco et al. (2019). Based on data published on the ICT usage and digitization across a number of EU countries, the researchers found a rather average degree of I4.0 readiness for Sweden. Since their study is based on a country-level analysis, the extent to which their results can be directly compared to the 63.2 % readiness calculated in this study is limited. Nevertheless, the fact that this study shows a level of readiness for the case company which is similar to the results of Castelo-Branco et al.'s (2019) study is still interesting, as it reinforces the perception of the Swedish manufacturing sector still having some way to go before it can be considered fully ready to adopt I4.0. Considering that I4.0 plays a central part in the Swedish Government's strategy "Smart industri" to strengthen the global competitiveness of its industrial sector, the rather moderate levels of readiness identified in this and previous studies therefore call for increased governmental support.

Before moving further on in the analysis and discussing what the calculated degree of I4.0 readiness means for the case company, it needs to be recognized that during the interviews, the interviewees explicitly suggested that some enabling technologies are not as relevant to the company as some of the others. While it is important not to assume that the interviewees know exactly which technologies are relevant and which are not, mainly because some of the technologies have not yet been looked into properly, the authors of this study agree on the idea that all enabling technologies do not share the exact same importance. Therefore, before discussing potential ways for the company to increase their I4.0 readiness, an alternative degree of readiness is calculated, taking into consideration the relative importance of the different technologies.

As seen in Table 5.10, each technology has been assigned a specific weight. These weights are based on both the discussions held during the interviews and the descriptions in Chapter 2 of the enabling technologies and the purpose they serve in an I4.0 context. Since no enabling technology is completely irrelevant, assigning different weights to some of them rather than excluding them altogether from the assessment was considered the most appropriate way of dealing with their varying importance for the investigated company.

Enabling Technology	Old Weight	New Weight
Big Data	1	1.5
Internet of Things	1	1
Cloud Computing	1	1.5
Cyber-Physical Systems	1	0.75
Additive Manufacturing	1	1
Autonomous Robots	1	0.75
Augmented Reality	1	0.5
Artificial Intelligence	1	1
Total Weight	8	8

TABLE 5.10: *OLD AND NEW WEIGHTS*

Looking at Table 5.10, it can be seen that big data and cloud computing have been assigned weights higher than 1. This is because they are considered overarching technologies important for the entire I4.0 concept. For example, Wessel (2016) claims that I4.0 would be unimaginable without big data, and the NIST definition of cloud computing highlights the value of the technology in terms of enabling quick access to, and storage and management of, large amounts of data. This, in combination with the fact that the interviewees clearly implied that big data and cloud computing are highly important for the company, resulted in these technologies being assigned higher weights.

In contrast, CPS, autonomous robots and AR have been assigned weights less than 1. AR has a new weight of only 0.5, mainly due to the fact that the company already has a relatively advanced system employed in the assembly process, which is where AR is most commonly adopted (Blanco-Novoa et al., 2018). CPS and autonomous robots have a new weight of 0.75. This is because even though the interviewees claim that these two technologies are not able to add much value to the company, they should still serve an important purpose according to the literature. For example, Frontoni et al. (2018) claim that CPS has the potential of revolutionizing traditional warehouses, and Pedersen et al. (2016) argue that incorporating autonomous robots into the production process is essential in order to reach the flexibility necessary. As such, 0.75 is a compromise between the empirical and the theoretical findings.

By assigning the technologies different weights, the risk for the case company to solely focus on the low-importance technologies for the single purpose of increasing their total degree of I4.0 readiness is mitigated. Since the least important technologies are associated with the lowest degrees of readiness, increased efforts on these would presumably be the quickest way to increase the overall I4.0 readiness. However, by assigning the technologies different weights based on their relative importance, the company is more likely to work with the technologies that are the most important to them.

With the new weights, the overall degree of I4.0 readiness is increased from 63.2 % to 68.2 %, thus meaning that the company is starting to approach a more advanced stage of readiness. However, as they are still relatively far from being fully ready to implement I4.0 on a wider scale, it is clear that there are room for improvements. In order to gain a better understanding of the company's readiness for I4.0, the factors which currently seem to limit their possibilities of becoming more ready for I4.0 will now be discussed. Specifically, because not only technology, which has been the main focus area thus far in the analysis, but also organizational aspects play a critical role in becoming more ready for I4.0, the next section focuses on the more general, organizational side of the company's readiness for I4.0.

5.2 ORGANIZATIONAL READINESS

While the investigated company has either already started adopting the enabling technologies of I4.0 or at the minimum discussed potential application areas for them, the interviews clearly demonstrate that there has not been much talk at all regarding "Industry 4.0." This might not be too surprising considering that the I4.0 concept is still in its emerging phase and therefore lacks a commonly agreed upon definition (Schneider, 2018). Because no one knows exactly what the concept entails, expecting a company to have in-depth discussions about it might be unrealistic. The fact that the organization has its roots in the United States could also contribute to the lack of discussions about I4.0, since it is a term originating from Germany. While the German government-led initiative for I4.0 is called "Industrie 4.0," the American version is called "Advanced Manufacturing Partnership." As such, different terms might be used to describe the same concept. However, when discussing their work with I4.0, no other concept or term equivalent to I4.0 was mentioned by the interviewees.

Although potential reasons can be identified as to why there has not been much talk about I4.0 at the company, Horváth & Szabó (2019) emphasize the importance of making sure that everyone involved in the work with I4.0 is clear on what they are dealing with. Therefore, even though the interviewees share relatively similar interpretations of the concept, the lack of explicit discussions about I4.0 should still be considered a problem. Additionally, as might be expected from the fact that they are not talking about I4.0, there has not been any strategy developed for its adoption, nor any evaluations made of their current I4.0 readiness. Because these steps constitute the foundation of a successful adoption of I4.0 (Kane et al., 2018), it clearly seems as if there is a lot of work left to do for the company in this regard.

Despite not describing I4.0 in the exact same words, all interviewees paint a picture in which I4.0 and its surrounding technologies are used as a set of tools to help the company become increasingly digitalized and automated. However, while recognizing the potential of some of the enabling technologies, it seems as if they do not fully understand the importance of the I4.0 concept as a whole. Drath and Horch (2014) argue that I4.0 is critical for manufacturing companies and their long-term survival. To maintain their competitiveness, these companies have to be fully devoted to I.40, rather than merely see it as a way to support their factories. In other words, I4.0 is more than "a set of tools" to increase digitalization and automation, but an inevitable path for many manufacturers' existence. Since this path is long and characterized by significant uncertainty (Machado et al., 2019), a long-term approach is essential (Botha, 2018).

However, considering that the company is strictly controlled financially, it is difficult to imagine how they could find the opportunity to develop a long-term strategy for their work with I4.0.

As a result of the company being expected to deliver a certain result on a year-to-year basis, the projects that are carried out in relation to I4.0 are to a large extent of the safer kind. While these are almost guaranteed to generate a positive payback, only "picking the low-hanging fruit" implies a risk of missing out on great opportunities and great technologies, as well as potential synergy effects between different technologies. Therefore, the interviewees' calls for more trust and financial resources from the central corporate level to invest in more high-risk/high-reward projects, as well those that are more long-term, seem justified. While the payback of these projects might be unsatisfactory in the short term, they might generate a superior payback over time compared to most of the projects carried out today.

Another interesting finding from the interviews is that the investigated company to a large extent seems to build their work with I4.0 on their previous efforts with lean. As Rojko (2017) explains that it is common for companies to introduce the I4.0-enabling technologies gradually and by building on their already existing technological infrastructure in order to not jeopardize their production, this might not come as a big surprise. However, Alcácer & Cruz-Machado (2019) emphasize that companies that are serious about I4.0 should make a collective effort and implement *all* technologies in parallel to reach the full potential of I4.0. As such, the fact that the investigated company looks at only one or a few technologies at a time further reinforces the impression that I4.0 is seen more as a set of helpful tools rather than something critical for their survival.

Furthermore, the interviewees explain that chances are small they will completely abandon their previous work with lean in order to strictly focus on I4.0. Therefore, it does not seem as if their pattern of gradually transitioning to I4.0 by looking at one or a few technologies at a time will break anytime soon. This way of clinging on to the past is reminiscent of what Kane et al. (2018) refer to as competency traps, where working methods which have led to success in the past are continued as they are expected to lead to future success as well. Considering that central goals of both I4.0 and lean are to increase efficiency and reduce waste, it can be argued that these concepts share several similarities and that it therefore makes sense for the company to continue to build on their previous efforts with lean. However, considering the importance of being fully devoted to I4.0, it still seems as if the company could benefit from letting go of their deeply rooted lean mindset, at least to some extent, and allow themselves to increase their focus on I4.0.

Finally, one of the major factors influencing the company's work with I4.0 is the decentralized organizational structure of the organization. While the decentralized structure on the one hand gives the company a relatively high degree of freedom in deciding what technologies are used and in what way, it has also resulted in a difficulty in knowing how to best apply them. As a result of all the acquisitions made throughout the years, the organization has become diverse and every organizational unit has its own preferred way of working. This could explain why the interviewees experience a lack of cases within the organization to draw inspiration from, which in turn might have contributed to their cautious approach to some of the I4.0-enabling technologies.

While discussions regarding structure thus far have focused on the organization as a whole, it seems as if a decentralized structure is present at the factory level as well. The interviewees explain that they are dependent on individual initiatives from their employees, and that leadership as a consequence must come from below. Fortunately, both the factory workers in general and the production engineers in particular are highly praised. Being described as talented and eager to learn indicates that neither their competencies nor attitudes toward change constitute an issue. However, while the purely technical knowledge is there, there are great uncertainties in regard to how different technologies can be best incorporated into the production process. Additionally, it seems as if some of the engineers, mainly those of the older generation, are somewhat reactive, focusing on correcting inefficiencies rather than identifying completely new ways of solving the problems that emerge (Botha, 2018). Although it is emphasized that a mix of different mindsets is important, making sure everyone develops the required competency and shares the same progressive attitude seems to be important for the company's future work with I4.0.

6. CONCLUSIONS

This chapter is divided into three main sections. The first section provides answers to the three research questions of this study. The second section presents the study's theoretical and practical contributions. The third and final section discusses the limitations of the study, and provides suggestions for future research.

6.1 TOWARD AN INCREASED I4.0 READINESS

This study investigated the degree of I4.0 readiness of a Swedish manufacturing company using an analytical framework developed by Pacchini et al. (2019). Three research questions guided the research. Answers to these questions are provided below, starting off with the main research question:

***RQ1**: What is the degree of I4.0 readiness of a Swedish manufacturing company?*

To answer the first research question, eight enabling technologies were thoroughly examined in an empirical investigation. By assigning adoption levels to the six different prerequisites of each technology, a total degree of I4.0 readiness of 63.2 % was calculated. This corresponds to an intermediate level of readiness for the investigated company, indicating that they still have some way to go before considered fully ready for a widescale adoption of I4.0. This is in line with the findings of the few previous studies conducted on I4.0 readiness in Sweden, which also have found rather average levels of readiness. As I4.0 is a main focus area in the Swedish Government's strategy "Smart industri" to strengthen its industrial sector's global competitiveness, the result of both this and previous studies thus indicate that increased support to companies within the sector is necessary in order for them to become better prepared for adopting I4.0.

The calculated degree of I4.0 readiness of 63.2 % is based on each enabling technology having equal weights, thus aligning with the literature which emphasizes that all technologies play a critical role in I4.0. However, theory does not always mirror practice. The empirical investigation revealed that some enabling technologies are not as relevant to the case company as some of the others, which is why an alternative degree of readiness was calculated. The alternative assessment resulted in a new degree of I4.0 readiness of 68.2 %, thus meaning the company is approaching a more advanced stage of readiness, but still have work to do in order to be considered fully ready to adopt I4.0 and its surrounding technologies. However, adopting the enabling technologies of I4.0 is more than a technological task, which is why a second research question was addressed in order to provide a more holistic understanding of the case company's readiness:

RQ2*: What are the major organizational barriers to an increased I4.0 readiness at the company?*

While the case company does not consider all enabling technologies equally relevant, thus contradicting the I4.0 literature, the identified organizational barriers clearly correspond to those most frequently discussed in the literature. The most significant barrier at the company is the lack of an explicit strategy for I4.0, as the strategy is supposed to guide them throughout the entire process. Causing this lack of strategy is a number of factors, including the absence of internal discussions about I4.0, the limited recognition of the importance of the I4.0 concept, and the decentralized organizational structure. This has also resulted in the company not being aware of their current readiness for I4.0. However, since the I4.0 readiness of the company has been thoroughly assessed in this study, this barrier could already be considered mitigated. Because knowing where you stand today is critical for developing a plan for the future, the evaluation of the company's current readiness could be used as a starting point for their future work with I4.0.

Another major barrier identified at the company is the limited financial support and trust being showcased from the central corporate level. The restrictions which this barrier has put on the company in terms of limiting their capacity to invest in new technologies could explain why they have not fully devoted themselves to I4.0, but adopted a more careful approach. However, the company's way of gradually transitioning to I4.0 is not only a result of them being strictly financially controlled, but also the result of a conscious decision to build their work with I4.0 on their previous efforts on lean. Although the company sees I4.0 as closely connected to lean, not being willing to let go of their old ways of working also implies that they are stuck in a competency trap. Therefore, this has been identified as another barrier to an increased readiness for I4.0. A competency trap does not only exist on the company level, but also on an individual level, where some of the workers at the factory are stuck in their old mindsets of solving problems using traditional methods.

These organizational barriers, as well as the calculated degree of I4.0 readiness, clearly indicate that there is room for improvement. In order to help identify ways of increasing the company's readiness for I4.0, a third research question was formulated:

***RQ3**: How can the company increase its I4.0 readiness?*

Looking at the term "I4.0 readiness" as it is used in this study, improving readiness entails increasing the adoption levels for the prerequisites of each enabling technology. Therefore, probably the most efficient way for the company to increase their I4.0 readiness would be to focus on the enabling technologies which currently are associated with the lowest degrees of readiness, and find ways to raise these. However, this does not take into consideration the fact that some of these technologies are not considered as relevant for the company as some of the others. Therefore, in terms of their overall work with I4.0 moving forward, the company might benefit more from focusing on the technologies already associated with relatively high degrees of readiness.

While arguments can be made for both sides in terms of what technologies the company should focus on, the authors of this study are humble to the fact that the company knows themselves the best, and thus are better suited to decide on what technologies work best for them. Therefore, the answer to this third research question does not include any specific recommendations regarding which technologies the company should prioritize and which they should not. Rather, it focuses on the organizational factors which seem to inhibit the company's work with I4.0 today. The authors of this study argue that addressing these organizational factors will ease the overall transition to I4.0, and indirectly help facilitate the process of adopting the enabling technologies.

A natural starting point for the company moving forward is to increase their understanding of I4.0 and what benefits a full-scale adoption of the concept could provide. This, combined with the knowledge gained from this study's assessment of their current degree of I4.0 readiness, would lay a solid foundation for the development of an I4.0 strategy. With a clear I4.0 strategy, the company would have a more dedicated, long-term approach to I4.0, which in turn could help the company avoid their competency trap of not wanting to let go of their previous work with lean.

Although the decentralized organizational structure in some respects constitutes a barrier to the company, it also has its advantages. Therefore, a structural reorganization does not seem to be the right solution to the problems they experience. However, by increasing the internal collaborations among the different organizational units, experiences and knowledge of how the enabling technologies can be incorporated into the production can be shared. Combined with continued external collaborations, for example with local universities, these internal projects could enhance the competency of the company's workers, and thus help remove competency traps also at the individual level. As a result, the experimental culture of the company can be maintained, and by showing good examples of how technologies are being used, the central corporate level might increase their confidence in the company and allow them to influence important strategic decisions to a larger extent in the future.

6.2 CONTRIBUTIONS

By providing answers to the research questions, this study fulfills the purpose of responding to the calls for more empirical research on I4.0 in general and on I4.0 readiness in particular. The study contributes to both theory and practice. On the theoretical side, it has tested the viability of a specific model developed for evaluating I4.0 readiness by applying it to a company in the Swedish manufacturing sector. Additionally, the study has showed how the evaluation of I4.0 readiness can be altered in order to account for the relative importance of the different technologies for the company being investigated, and thereby identified a way in which the model can be improved. The in-depth approach adopted for this evaluation also means that this study has taken a different perspective than the few already existing I4.0 readiness studies, which to a large extent are based on quantitative methods. As such, this study has highlighted the qualitative side of I4.0 readiness assessments.

On the practical side, this study has evaluated the I4.0 readiness of the case company. This assessment will help increase the company's understanding of their current situation, and can be used as a foundation for their future work with I4.0. While the generalizability of this study is limited, the study has also shed light on some of the barriers companies experience in preparing for the implementation of I4.0, as well as how these barriers can be mitigated in order to increase their I4.0 readiness. Therefore, the results of this study are not only of interest to the case company, but also to other manufacturing companies of similar size and nature that are interested in adopting I4.0.

6.3 LIMITATIONS AND FUTURE RESEARCH

While this study contributes to both theory and practice, it also has its limitations which need to be highlighted and which can be addressed through additional research.

One of the major limitations of this study is that the calculated degree of I4.0 readiness relies on the eight enabling technologies identified by Pacchini et al. (2019) as being the most central to the I4.0 concept. Although the identification of these technologies was based on a comprehensive review of the I4.0 literature and discussions with I4.0 experts, the fact remains that there are other technologies playing an important part in the context of I4.0 as well. Consequently, the authors of this study suggest that future research evaluates a larger number of technologies in order to gain a more accurate view of the I4.0 readiness of the company being investigated. Since all technologies might not be considered to share the same relevance to the company, weights can be used as a way to account for this issue. As argued by the authors of this study, using weights is better than excluding certain technologies from the assessment altogether, since the exclusion of technologies could lead to a misleading degree of I4.0 readiness being calculated.

Another limitation of this study is that the case company's calculated degree of I4.0 readiness only takes into consideration the technological side of the I4.0 concept. While this issue has been mitigated in this study by also examining a range of organizational barriers, a suggestion for future research is to develop a tool for assessing I4.0 readiness which includes a wider range of aspects than only those that are purely technological.

A final limitation of this study refers to the relatively small number of interviewees. Although measures were taken to ensure that the individuals interviewed all had relevant experiences and knowledge of the company's work with I4.0, and although the interviews generated a large amount of valuable information, it can be questioned whether the perspectives of three people can provide a complete understanding of an entire company. Therefore, the authors of this study emphasize that future research should make sure to include a wider range of perspectives in the assessment of a company's I4.0 readiness. Additionally, as this study only examines one company, a final suggestion is to adopt a wider approach in order to allow conclusions to be made about the I4.0 readiness not only of a specific company, but a larger group of companies or even an entire industry.

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IMAGES

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APPENDIX 1 – INTERVIEW GUIDE

OPENING QUESTIONS

- Tell us a little bit about yourself (the company you work at, your role, etc.).
- What does Industry 4.0 mean to you?
- How long have you been working with Industry 4.0 at X (the investigated factory)?
- What are your overall goals and ambitions with you work with Industry 4.0?
- What is your personal role in this work?

FIRST SET OF KEY QUESTIONS

Are you working with the following technologies? If no, why not? If yes, in what way?

- Big data
- Internet of Things (IoT)
- Cloud computing
- Cyber-Physical Systems (CPS)
- Additive manufacturing
- Autonomous robots
- Augmented Reality (AR)
- Artificial Intelligence (AI)

Additional questions were asked about these technologies, drawing inspiration from their respective prerequisites (see Appendix 2). However, as the specific questions asked varied considerably depending on what was said during the interviews, they are not included here.

SECOND SET OF KEY QUESTIONS

- How big of an influence has your work with Industry 4.0 had on your day-to-day operations? Has it required you to change your ways of working, acquire new knowledge, or anything similar?
- Do you have any strategy for your work with Industry 4.0?
- Are you involved in any collaborations with external partners, such as your suppliers or customers, in relation to Industry 4.0?
- What kind of challenges do you experience in relation to your work with Industry 4.0? How are these addressed?
- What factors are most important for you moving forward in order to be able to stick to your strategy and reach your goals in relation to Industry 4.0?

- Do you know your current degree of I4.0 readiness? Have any efforts been made to assess your current status?

CLOSING QUESTIONS

- Do you have any additional thoughts on what we already have discussed?
- Is there anything important you believe we have forgotten to ask you?

APPENDIX 2 – ENABLING TECHNOLOGIES AND PREREQUISITES

Technology 1 – Big Data (BD)

BD1. The company should have infrastructure for digital systems.
L0. The company has no infrastructure for digital systems.
L1. The company has a small infrastructure for digital systems.
L2. The company has a medium infrastructure for digital systems.
L3. The company has a complete infrastructure for digital systems.

BD2. The company should have all its reliable data/information organized and maintained in a secure digital system.
L0. The company does not have its reliable data/information organized and maintained in digital systems.
L1. The company has a small part of its reliable data/information organized and maintained in digital systems.
L2. The company has a large part of its reliable data/information organized and maintained in digital systems.
L3. The company has all its reliable data/information organized and maintained in digital systems.

BD3. The company should have a high speed and capacity wireless network.
L0. The company does not have a wireless network.
L1. The company has a wireless network with limited speed and capacity.
L2. The company has a wireless network with high speed and capacity, but not enough to operate in a satisfactory way with the I4.0 technologies that require networking.
L3. The company has a high speed and capacity wireless network.

BD4. The company should have personnel empowered to collect and analyze data.
L0. The company does not have qualified personnel to collect and analyze data.
L1. The company has a small proportion of qualified personnel to collect and analyze data.
L2. The company has a large number of qualified personnel to collect and analyze data.
L3. The company has qualified personnel to collect and analyze data.

BD5. The company should treat Big Data at the strategic level.
L0. The company does not treat this technology at the strategic level.
L1. The company has started to treat this technology at the strategic level.
L2. The company is already advanced in the treatment of this technology at the strategic level.
L3. The company treats this technology at the strategic level.

BD6. The company should know the problems to solve with the data obtained.

L0. The company has not defined what it wants to resolve with the data collected.
L1. The company begins to define what it wants to solve with the data collected.
L2. The company already has a good part of what it wants to solve with the data collected
L3. The company has already defined what it wants to resolve with the data collected.

Technology 2 – Internet of Things (IoT)

IoT1. The company should fully utilize RFID.
L0. The company does not have sensors installed or RFID or similar technologies.
L1. The company is starting to install sensors but does not yet have RFID or similar technologies.
L2. The company already has sensors installed and is starting to implement RFID or similar technologies.
L3. The company already has sensors installed and has RFID or similar technologies.

IoT2. The company should fully utilize Electronic Product Codes.
L0. The company does not have Electronic Product Codes.
L1. The company is starting to implement Electronic Product Codes.
L2. The company has a large part of its inventory equipped with Electronic Product Codes.
L3. The company has Electronic Product Codes.

IoT3. The company should have a high speed and high capacity wireless network.
L0. The company does not have a wireless network.
L1. The company has a wireless network with limited speed and capacity.
L2. The company has a wireless network with high speed and capacity, but not enough to operate in a satisfactory way with the I4.0 technologies that require networking.
L3. The company has a high speed and capacity wireless network.

IoT4. The company should have a communication protocol which guarantees the interoperability of its processes.
L0. The company does not have a communication protocol.
L1. The company has started thinking about a communication protocol.
L2. The company already has an open communication protocol.
L3. The company has an M2M communication protocol.

IoT5. The company should have information security systems to mitigate cyber-attacks.
L0. The company does not have information security systems.
L1. The company already has studies for the implementation of information security systems.
L2. The company is already implementing information security systems.
L3. The company has information security systems in full operation.

IoT6. The company should have on-the fly event streaming.
L0. The company does not have event streaming.
L1. The company is developing studies to implement event streaming.

L2. The company is starting to implement the streaming of static events.
L3. The company has on-the-fly event streaming.

Technology 3 – Cloud Computing (CC)

CC1. The company should have information security systems to mitigate cyber-attacks.
L0. The company does not have information security systems.
L1. The company already has studies for the implementation of information security systems.
L2. The company is already implementing information security systems.
L3. The company has information security systems in full operation.

CC2. The company should have IT personnel prepared to deal with the technologies in cloud computing.
L0. The company has no staff prepared for this technology.
L1. The company has few people prepared for this technology.
L2. The company has a good part of the staff prepared for this technology.
L3. The company has all the staff prepared for this technology.

CC3. The company should have a culture aiming at externalizing private data.
L0. The company does not have a culture aimed at externalizing private data.
L1. The company is starting to develop a culture aimed at externalizing private data.
L2. The company already has a good part of the path taken to develop a culture aimed at externalizing private data.
L3. The company has a culture aimed at externalizing private data.

CC4. The company should have a communication protocol which guarantees the interoperability of its process.
L0. The company does not have a communication protocol.
L1. The company has started thinking about a communication protocol.
L2. The company already has an open communication protocol.
L3. The company has an M2M communication protocol.

CC5. The company should have financial capacity for investments in cloud computing.
L0. The company does not have the financial capacity to invest in this technology.
L1. The company has limited financial capacity to invest in this technology.
L2. The company has almost ample financial capacity to invest in this technology.
L3. The company has ample financial capacity to invest in this technology.

CC6. The company should have a high speed and high capacity wireless network.
L0. The company does not have a wireless network.
L1. The company has a wireless network with limited speed and capacity.
L2. The company has a wireless network with high speed and capacity, but not enough to operate in a satisfactory way with the I4.0 technologies that require networking.
L3. The company has a high speed and capacity wireless network.

Technology 4 – Cyber Physical Systems (CPS)

CPS1. The company should have a high speed and high capacity wireless network.
L0. The company does not have a wireless network.
L1. The company has a wireless network with limited speed and capacity.
L2. The company has a wireless network with high speed and capacity, but not enough to operate in a satisfactory way with the I4.0 technologies that require networking.
L3. The company has a high speed and capacity wireless network.

CPS2. The company should have sensors installed in the objects to be connected.
L0. The company does not have sensors installed or RFID or similar technologies.
L1. The company is starting to install sensors but does not yet have RFID or similar technologies.
L2. The company already has sensors installed and is starting to implement RFID or similar technologies.
L3. The company already has sensors installed and has RFID or similar technologies.

CPS3. The company should have a structure to analyze large amounts of data.
L0. The company does not know about Big Data.
L1. The company has started to learn about Big Data.
L2. The company is implementing Big Data.
L3. The company already has fully implemented Big Data.

CPS4. The company should have broad access to cloud data.
L0. The company does not know about Cloud Computing.
L1. The company has started to learn about Cloud Computing.
L2. The company is implementing Cloud Computing.
L3. The company already has fully implemented Cloud Computing.

CPS5. The company should have a sound computer infrastructure in place.
L0. The company has no computer structure.
L1 The company is thinking about purchasing computers.
L2. The company has started purchasing computers.
L3. The company has a sound computer infrastructure.

CPS6. The company should have a Service-Oriented Architecture (SOA).
L0. The company does not have an SOA.
L1. The company has a small structure for an SOA.
L2. The company has a reasonable structure for an SOA.
L3. The company has an SOA.

Technology 5 – Additive Manufacturing (AM)

AM1. The company should consider the feasibility of parts to be produced through additive manufacturing.
L0. The company is not aware of the importance of this assessment.
L1. The company is aware, but has not started considering the feasibility of parts to be produced.
L2. The company has started considering the feasibility of parts to be produced.
L3. The company has considered the feasibility of parts to be produced.

AM2. The company should evaluate its technical capacity to deal with additive manufacturing.
L0. The company has not evaluated its technical capacity.
L1. The company is thinking of evaluating its technical capacity.
L2. The company has started evaluating its technical capacity.
L3. The company has evaluated its technical capacity.

AM3. The company should have means to prevent cyber-attacks coming from external data interchange.
L0. The company does not have information security systems.
L1. The company already has studies for the implementation of information security systems
L2. The company is already implementing information security systems.
L3. The company has information security systems in full operation.

AM4. The company should prepare its labor force to deal with additive manufacturing technology.
L0. The company has no staff prepared for this technology.
L1. The company has a few people prepared for this technology.
L2. The company has a good part of the staff prepared for this technology.
L3. The company has all the staff prepared for this technology.

AM5. The company should evaluate the manufacturing cycle time of this technology.
L0. The company has not evaluated 3D manufacturing times.
L1. The company is thinking of evaluating 3D manufacturing times.
L2. The company has started evaluating 3D manufacturing times.
L3. The company has evaluated 3D manufacturing times.

AM6. The company should have all its product drawings in 3D digital files.
L0. The company does not have digitized drawings.
L1. The company has a small part of digitized drawings.
L2. The company has a large part of digitized drawings.
L3. The company has all digitalized drawings.

Technology 6 – Autonomous Robots (ARO)

ARO1. The company should have skilled and trained labor to deal with robotics.
L0. The company has no staff prepared for this technology.

L1. The company has a few people prepared for this technology.
L2. The company has a good part of the staff prepared for this technology.
L3. The company has all the staff prepared for this technology.

ARO2. The company should understand the limitations of autonomous robots.
L0. The company is unaware of the limitations of autonomous robots.
L1. The company has little knowledge of the limitations of autonomous robots.
L2. The company has much knowledge of the limitations of autonomous robots.
L3. The company is fully aware of the limitations of autonomous robots.

ARO3. The company should have financial capacity to invest in robotics.
L0. The company does not have the financial capacity to invest in this technology.
L1. The company has limited financial capacity to invest in this technology.
L2. The company has almost ample financial capacity to invest in this technology.
L3. The company has ample financial capacity to invest in this technology.

ARO4. The company should have a detailed mapping of its manufacturing processes.
L0. The company has no mapping of its manufacturing processes and trajectory.
L1. The company is starting to map its manufacturing processes and trajectory.
L2. The company has a good part of its manufacturing process and trajectory mapped.
L3. The company has mapped its manufacturing processes and trajectory.

ARO5. The company should prepare the labor force to work side by side with robots.
L0. The company does not intend to monitor its employees psychologically.
L1. The company is thinking of developing psychological counseling for its employees.
L2. The company has started developing psychological counseling for its employees.
L3. The company has psychological counseling for its employees.

ARO6. The company should have implemented safety standards ISO TS 15066; NBR 12110-2.
L0. The company has no knowledge of safety standards: ISO TS 15066; NBR 12110-2.
L1. The company is considering implementing safety standards: ISO TS 15066; NBR 12110-2.
L2. The company has started implementing safety standards: ISO TS 15066; NBR 12110-2.
L3. The company has safety standards: ISO TS 15066; NBR 12110-2.

Technology 7 – Augmented Reality (AR)

AR1. The company should evaluate the work environment of operators.
L0. The company has not evaluated the work environment of operators.
L1. The company is thinking of evaluating the work environment of operators.
L2. The company has started evaluating the work environment of operators.
L3. The company has evaluated the work environment of operators.

AR2. The company should have digitized files of the documents and parts that will be used for augmented reality.
L0. The company does not have digitized files.
L1. The company has a small part of digitized files.
L2. The company has a large part of digitized files.
L3. The company has all the files needed for digitalized augmented reality.

AR3. The company should have a detailed mapping of its manufacturing processes.
L0. The company has no mapping of its manufacturing processes.
L1. The company is starting to map its manufacturing processes.
L2. The company has a large part of its manufacturing processes mapped.
L3. The company has all of its manufacturing processes mapped.

AR4. The company should have an ergonomic evaluation of the operator's functions.
L0. The company does not have any ergonomic or ergometric studies.
L1. The company has started an ergonomic and ergometric study.
L2. The company has come a long way in its ergonomic and ergometric study.
L3. The company has finished an ergonomic and ergometric study.

AR5. The company should have adequate software and hardware to support AR.
L0. The company does not have software or hardware for AR.
L1. The company is considering acquiring software and hardware for AR.
L2. The company has acquired software and hardware for AR.
L3. The company has deployed software and hardware for AR.

AR6. The company should plan which data can be shared.
L0. The company is not aware of the importance of planning which data can be shared.
L1. The company is thinking of starting to plan which data can be shared.
L2. The company has started to plan which data can be shared.
L3. The company has planned which data can be shared.

Technology 8 – Artificial Intelligence (AI)

AI1. The company should have financial capacity to support AI implementation.
L0. The company does not have the financial capacity to invest in this technology.
L1. The company has limited financial capacity to invest in this technology.
L2. The company has almost ample financial capacity to invest in this technology.
L3. The company has ample financial capacity to invest in this technology.

AI2. The company should have knowledge of AI and a clear strategy for its implementation.
L0. The company does not have knowledge nor a strategy for AI.
L1. The company has partial knowledge, but no AI strategy.
L2. The company has full knowledge, but no strategy for AI.

L3. The company has full knowledge and a strategy for AI.

AI3. The company should have a communication protocol which guarantees the interoperability of its process.
L0. The company does not have a communication protocol.
L1. The company has started thinking about a communication protocol.
L2. The company already has an open communication protocol.
L3. The company has an M2M communication protocol.

AI4. The company should have sensors installed in the manufacturing equipment.
L0. The company does not have sensors installed or RFID or similar technologies.
L1. The company is starting to install sensors but does not yet have RFID or similar technologies.
L2. The company already has sensors installed and is starting to implement RFID or similar technologies.
L3. The company already has sensors installed and has RFID or similar technologies.

AI5. The company should have other enabling technologies implemented.
L0. The company is not aware of the other enabling technologies.
L1. The company is aware of the other enabling technologies.
L2. The company has some enabling technologies in place.
L3. The company has the enabling technologies installed.

AI6. The company should be prepared to neutralize cyber-attacks.
L0. The company does not have information security systems.
L1. The company already has studies for the implementation of information security systems.
L2. The company is already implementing information security systems.
L3. The company has information security systems in full operation.