Master of Science Thesis

MIOM05 Degree Project in Production Management

Value assessment of cloud manufacturing for large-scale manufacturing organizations

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PREFACE

With this M.Sc. thesis, our five-year journey in Lund studying Industrial Engineering and Management at LTH is drawn to its conclusion. The knowledge and experiences we have gained during our time at the university have been utilized to conduct the thesis project. The thesis was conducted at the Division of Production Management at LTH and was facilitated by Elastic Move.

There have been multiple people who have supported and guided us through this journey, whom we would like to recognize for their efforts. We would first like to express our gratitude to our supervisor of this project, Danja Sonntag, Associate Professor at the Division of Production Management, for her support and guidance throughout this entire project. This thesis would not have been possible without your dedication and support. We would also like to extend our gratitude to Johan Marklund, Professor of Production Management, who mentored us at the beginning of the thesis project.

Secondly, we would like to thank Maria Ivarsson and Simon Palmhager, our mentors from Elastic Move, who have given us numerous insights into the world of cloud computing and the Industrial Internet of Things and dedicated much effort to this project. Finally, we would like to express our gratitude to all the interview respondents who dedicated their time to provide us with their insights, without you, the thesis project would not have been possible to conduct.

As this project will now come to an end, we want to express our deepest gratitude to you all, thank you!

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Victor Willners and Simon Dalbom

ABSTRACT

This master thesis assesses the potential of Cloud Manufacturing applications in large-scale manufacturing. Firstly, this thesis determines the benefits and drawbacks of and the barriers to the implementation of Cloud Manufacturing. Secondly, five interviews were conducted with two companies that had begun implementing Cloud Manufacturing within their organizations. Lastly, Cloud Manufacturing was analyzed, using both the findings of relevant literature and insights from the two case studies, to identify where current research and the real-world converged, or diverged. The Hierarchical Production Planning framework was utilized to connect the identified advantages of Cloud Manufacturing to its impact on production systems. Further, the Diffusion of Innovation model was used to evaluate the barriers to implementing the application. This analysis provided a basis for both the potential impact and the complications of the implementation and utilization of each Cloud Manufacturing application. Consequently, it provides an assessment of the overall potential that Cloud Manufacturing can bring large-scale manufacturing organizations.

Cloud manufacturing is overall found to provide benefits in terms of cost savings, improved data accessibility, increased efficiency, and higher resource utilization. Some key barriers that are necessary to overcome for wider adoption across the manufacturing industry are capable infrastructure, adequate organizational skills, proper management of data, and high investment requirements.

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Key Words

Cloud Manufacturing, Cloud Computing, Industrial Internet of Things, Internet of Things, Case Study, Manufacturing Industry

ABBREVIATIONS

AaaS	Acceleration-as-a-Service
AWS	Amazon Web Services
B2B	Business-to-Business
CaaS	Container-as-a-Service
CapEx	Capital Expenditure
CC	Cloud Computing
CMfg	Cloud Manufacturing
CSP	Cloud Service Provider
ERP	Enterprise Resource Planning
EU	European Union
FaaS	Function-as-a-Service
FTE	Full-time equivalent
IaaS	Infrastructure-as-a-Service
IIoT	Industrial Internet of Things
IT	Information Technology
KPI	Key Performance Indicator
LAN	Local Area Network
NIST	National Institue of Standards and Technology
OpEx	Operational Expenditure
PaaS	Platform-as-a-Service
PLC	Programmable Logic Controller
PPC	Production Planning and Control

SaaS	Software-as-a-Service
SMEs	Small- and medium-scale enterprises
VPN	Virtual Private Network
WAN	Wide Area Network
WIP	Work-in-progress

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1 INTRODUCTION

1.1 Background

During the 21st century, the information technology (IT) industry has expanded rapidly and brought new digital solutions to companies, changing how they operate and conduct business (Faynberg et al., 2016). Digitalization has been an ever-increasing trend in companies, and investments in digital transformation are increasing (Lohr, 2023; Wang et al., 2022). One hot topic in recent years is Industry 4.0 (Lohr, 2023). Industry 4.0 technologies are highly relevant for companies today due to their potential impact on an organization, such as improving production processes and enabling companies to improve their products (Dalenogare et al., 2018). Whether to implement these solutions and, if so, how to use them are important strategic decisions for many companies. Understanding the effects a company might experience by utilizing Industry 4.0 technologies is, therefore, an interesting subject to delve deeper into and is the basis for this thesis project.

One technology that falls under the Industry 4.0 umbrella is cloud manufacturing, a concept that connects two technologies, cloud computing and the Industrial Internet of Things. Cloud computing refers to the technologies used to handle data within the cloud. This regards a wide variety of aspects, such as data storage and security. The Industrial Internet of Things concerns the digitalization of machines used in the manufacturing industry by installing sensors and other devices to gather data, operate machines, and improve processes (Haghnegahdar et al., 2022). The Industrial Internet of Things connects the physical systems within the manufacturing process through smart devices, such as sensors, to a network from which it can communicate with digital systems (Jeschke et al., 2017). When the physical system is digitalized through the Industrial Internet of Things and connected to the cloud, cloud manufacturing is born, and new avenues to improve various processes are opened.

The usage of cloud computing and the Industrial Internet of Things are mostly used for basic applications. In 2021, cloud computing was mainly used for company emails, file storage, and office software, and not necessarily more advanced applications connected to cloud manufacturing (Eurostat, 2023a). Only 48 percent of large-scale companies in 2021 used the Industrial Internet of Things in some way, where the most popular usage area were security applications for the premises, such as smart-alarms and security cameras (Eurostat, 2023b). While cloud computing has been available for some time now, only 40 percent of manufacturing companies in the European Union were using it by 2021, and only 17 percent uses it together with the Industrial Internet of Things, indicating a low level of Cloud Manufacturing usage (Eurostat, 2023a). Although cloud manufacturing has been adopted by some companies, there remains a significant portion of companies that have yet to embrace it.

This thesis investigates the potential value and the barriers of cloud manufacturing in a real-world setting. The thesis is based on case studies of two customers of Elastic Mobile Scandinavia AB (Elastic Move), an IT-consulting firm certified by Amazon Web Services Inc. (AWS) and specialized in implementing cloud solutions in medium- and large-sized enterprises. The company is based in Lund with satellite offices in Kalmar and Karlstad, with a total of 25 employees. The international customer base is dominated by manufacturing companies, especially in the food and beverage industry, but it also includes companies from various other industries, such as logistics and government organizations. Elastic Move's primary business area is developing solutions for companies and assisting them in their digital transformation by migrating the companies' IT and data storage systems from on-prem solutions to the AWS cloud. On-prem, or on-premises, are solutions where an organization's IT and data handling systems are hosted on computers in-house or through a third-party supplier. Moving the data systems to the cloud allows companies access to on-demand virtual computing resources with a payment model where only the services used are paid for (Rountree & Castillo, 2013).

To enhance customer service and gain insight into how to encourage more companies to adopt cloud manufacturing, Elastic Move wanted to collaborate on a master's thesis to investigate the value of their cloud services and identify the motivations for manufacturing companies to implement such services. Elastic Move provided the authors with two case companies that expressed interest in participating in the case studies. By combining insights from relevant literature with the experiences of these case companies, valuable insights into cloud manufacturing were obtained. While these findings may not fully represent the entire industry, they offer valuable indications for future research to build upon.

1.2 Purpose

The thesis assesses and investigates the value that cloud manufacturing solutions, such as cloud computing and the Industrial Internet of Things, offer large-scale manufacturing firms in their manufacturing processes. The aim is to understand the motivations for implementing cloud manufacturing solutions, the barriers to such implementations, and what manufacturers aim to achieve with digital solutions in the future. The thesis project is conducted by interviewing two manufacturing companies and contextualizing their cloud manufacturing experience through insights gathered from the interviews and literature.

1.3 Structure of the report

Chapter 1 - Introduction: The background to the purpose of this thesis project is presented.

Chapter 2 - Methodology: The thesis project's methodology is presented. Furthermore, the project’s selection criteria of case companies are presented, and the research quality is discussed.

Chapter 3 - Theory: The models, theories, and frameworks of the project used in the analysis are presented.

Chapter 4 - Case Companies: The case companies and interview subjects are presented.

Chapter 5 - Analysis: The collected data from literature and interviews are analyzed through the lens of the frameworks and models presented in the theory chapter. The chapter aims to provide relevant conclusions to the thesis project’s purpose.

Chapter 6 - Conclusion: The findings of the analysis are summarized, and the results are critically discussed. Furthermore, research topics for future work are presented.

2 METHODOLOGY

This chapter describes the thesis project’s research approach and method. The data types are detailed, and the collection method is described. Furthermore, the selection method is discussed, and selection criteria are presented. Lastly, the considerations to research quality are discussed.

2.1 Research approach

This thesis project aims to assess and identify the value cloud manufacturing may offer large-scale manufacturing firms, and the barriers to its implementation. However, there are different approaches that can be taken to investigate this. Some of them are more suitable than others. The general purpose of a master thesis can be categorized according to four different types: *descriptive*, *exploratory*, *explanatory*, and *problem-solving* (Höst et al., 2006). Höst et al. (2006) describe descriptive studies as studies that aim to investigate and describe the characteristics of a population or a phenomenon, providing a comprehensive understanding of how they operate or function. Exploratory studies, on the other hand, focus on in-depth investigations of specific aspects to better understand their operation or function. Explanatory studies seek to identify causal relationships and explain how a population or phenomenon operates or functions. Problem-solving studies aim to identify and propose solutions to a specific problem or set of problems.

One of these categories typically describes the overarching purpose of the project. However, the purpose might also be described as a combination of several categories. Additionally, if multiple research questions are posed, each of these can have different purposes. Depending on the type of purpose, some research methods are more or less suitable to achieve the purpose of the study. Höst et al. (2006) list four research methods: *surveys, case studies, experiments,* and *action research*. Therefore, it is important to choose a research method that fits well with the thesis project’s purpose.

- A *survey* is a method used to compile and describe a phenomenon or population. It typically aims to provide a comprehensive understanding of the population by either surveying each individual or selecting a representative sample.

- *Case studies* are in-depth studies of one or several cases and typically involve studying a smaller sample than surveys. Unlike surveys, the sample of a case study is not randomly chosen and is, thus, not statistically significant.
- *Experiments* involve a comparative analysis of two or more solutions, where several factors are isolated and manipulated to find causations and explain what effect the factors have on the studied object.
- *Action research* is a carefully observed and documented study of an activity to solve an identified problem. This method typically involves four stages: plan, do, study, and act. In the planning phase, the problem and its causes are identified. In the "do" phase, changes are proposed and implemented. In the study phase, the success of the changes is evaluated. In the "act" phase, depending on the success of the changes, they are either permanently implemented or abandoned.

As the goal of the thesis project is to identify and assess the value of cloud manufacturing technologies at manufacturing companies, it is most suitable to approach the thesis project as an exploratory study. Case studies are the main research method to achieve the thesis’ purpose by studying cloud manufacturing technologies at two case companies. Case studies were chosen instead of surveys to provide deeper insights into the value and issues of cloud manufacturing technologies.

2.2 Data types

To achieve the purpose of the thesis, collecting data related to the subject was necessary. Generally, there are two primary data types: quantitative and qualitative (Höst et al., 2006). Quantitative data includes measurable and countable attributes, such as machine utilization and scrap rate, and is typically analyzed with statistical methods. On the other hand, qualitative data includes sentiments, opinions, and experiences gathered through interviews, focus groups, and other forms of data collection.

When evaluating the perceived value of cloud manufacturing technologies, it is important to understand an organization's perspective of the current and future value it brings. This requires analyzing qualitative information gathered through interviews and relevant literature.

Data can also be categorized as either primary or secondary. Primary data is collected for a particular study by the researcher conducting the analysis through methods such as interviews or surveys. On the other hand, secondary data is empirical material collected for different purposes, such as conclusions and insights from previous studies (Alvehus, 2013; Bryman & Bell, 2015). The main difference between primary and secondary data is who collected it and for what purpose.

This thesis project was mainly based on primary qualitative data gathered from interviews. Moreover, secondary qualitative data was collected from existing literature on relevant topics, serving as a means to substantiate the analysis and corroborate statements made by the interviewees. The literature served as a foundation for designing the interview guide.

2.3 Data collection methods

The thesis project used two main methods to collect data: literature, and interviews. The following section describes how the data was collected.

2.3.1 Literature

Secondary data was collected from literature, utilizing both publicly available databases and those accessible through Lund University. Literature reviews serve three main purposes: firstly, to understand the present state of research on the subject; secondly, to pinpoint relevant theories, articles, and findings relating to the subject; and thirdly, to identify areas where knowledge gaps exist (Bhattacherjee, 2012).

Moreover, a literature review typically has three steps (Bryman & Bell, 2015; Höst et al., 2006). The first step is a wide search to identify relevant literature and gain an understanding of the current state of research. This is typically done by specifying keywords related to the area of interest and searching through databases and libraries to find relevant literature for the thesis project. The keywords in this thesis project included: *cloud computing, public cloud, cloud manufacturing, on-premises, digitalization in manufacturing, Industrial Internet of Things,* and *Industry 4.0*. The literature identified from the keywords was skimmed to gather a general understanding of the main takeaways and their relevance to the thesis project. The second step of the literature review was to select which of the literature to delve deeper into, depending on the relevance to the purpose. The last step of the literature review was to perform a deeper search of related literature. This provided further insights and knowledge regarding areas of interest that had been identified from previous steps in the literature review and interviews.

The literature primarily supplemented the authors’ existing knowledge of the subject, provided insights and relevant theories to the analysis, and gave an overview of the current research on the subject. The knowledge gathered through the literature was used as a basis for the interviews with the case companies. Furthermore, the literature provided valuable insights that substantiated the analysis and corroborated statements made by the interviewees.

2.3.2 Interviews

Primary data was collected through interviews with various stakeholders at the case companies. The qualitative data received from the interviews pertains to the companies’ processes, IT solutions, and motivations for investing in new IT solutions. Interviews can be classified as *fully structured*, *semi-structured*, and *unstructured* (Alvehus, 2013; Bryman & Bell, 2015).

Fully structured interviews follow a predetermined set of questions and, sometimes, predetermined answer alternatives to ensure that each interviewee receives the same stimulus. Although structured interviews allow for aggregating answers from several interviews, the fixed nature of the questions may limit the depth of answers.

Unstructured interviews typically follow an interview guide with a list of topics with varying sequences of questions and phrasing. An unstructured interview often allows for a natural development of the conversation with minimal interaction from the interviewer(s). An issue with unstructured interviews is the lack of structure which may cause the interviewee to spend large amounts of time on the interviewee’s preferred topics. To mitigate this, it is proposed to limit topics to a specified time (Höst et al., 2006).

Lastly, a *semi-structured interview* combines fully structured and unstructured interviews. The interview follows, to a large extent, an interview schedule, but the sequence and phrasing of questions might vary between interviews. Depending on the answers, the interviewer(s) can ask follow-up questions during the interview.

In the thesis project, semi-structured interviews were conducted with relevant interviewees at the case companies. In section *2.4 Selection of case companies and interviewees*, the selection of the companies and the interviewees are described. An interview guide was created before the interviews with questions related to predetermined areas of interest identified in the literature review (see Appendix A). All interviews were recorded and transcribed. The video files of the interviews were deleted once they had been transcribed. In addition to the recording, notes were taken in each interview. One of the thesis project's authors was responsible for asking the questions, while the other was responsible for taking notes. The interviews are used in *Chapter 5 - Analysis* to analyze the value of cloud manufacturing solutions.

2.4 Selection of case companies and interviewees

In any type of research, a selection must be performed. For this thesis project case companies and interviewees had to be selected. The selection is of great importance to the quality of the study. As for case studies, the researcher must choose whom to interview and what cases to study. Lekvall and Wahlbin (2001) list two primary categories of selection methods: *probability* and *non-probability selection.* Probability selection is suitable when conducting statistical analysis with a large number of companies. The thesis project used a non-probability selection to select the case companies. Two non-probability methods are *purposive* and *convenience* selection.

Purposive selection is often used in exploratory studies where the main goal is not to provide conclusions based on statistical data. Instead, the focus is on delving deeply into specific topics, usually by studying one or more cases that meet specific criteria (Lekvall & Wahlbin, 2001).

Convenience selection utilizes data sources, such as companies or individuals, which are easily accessible to the researcher (Alvehus, 2013; Lekvall & Wahlbin, 2001). This method is often used due to financial, practical, or time restrictions.

This thesis project relies on a non-probability selection method using a combination of purposive and convenience selection. The two case companies were selected based on specific criteria and the ease of access through Elastic Move. The advantage of the approach is the practicality and time-saving benefits of studying and interviewing companies and employees, which are readily available and fall within the specific criteria set in accordance with the purpose of the thesis. However, there are disadvantages to the approach, which are discussed in *6.2 - Critical Discussion*.

The two case companies were chosen according to the following three criteria:

- **Size:** Large-scale companies
- **Type:** Manufacturing
- **Digitalization:** Cloud manufacturing journey has been initialized

In addition to the above criteria, the case companies were also selected from Elastic Move's customer list. This selection was done out of convenience due to practical and time-saving reasons.

Size

The size of a manufacturing company is likely to impact its needs, and in turn which benefits it observes from the usage of CMfg technologies. Thus, for the purpose of this thesis only the size of a manufacturing company is likely to impact its needs, and in turn which benefits it observes from the usage of CMfg technologies. Thus, for the purpose of this thesis only large-scale enterprises are considered. The European Commission (n.d.) defines large-scale enterprises as having more than 250 employees and a turnover exceeding €50 million.

Type

The study is limited to manufacturing companies as the target type of organization. However, no specific limitations are imposed on the particular sector within the broader manufacturing industry. Exploring the implementation of cloud solutions within an industrial manufacturing context is interesting, because of the potential synergies between cloud computing and other technologies, such as the Industrial Internet of Things.

Digitalization

In addition to size and type, the inclusion of digitalization as a criterion is considered important. This thesis project focuses on companies that have either fully or partially migrated their IT systems to the cloud and have either planned to or already implemented smart devices for the Industrial Internet of Things in their production processes. This deliberate choice allows the interviewees to offer valuable insights into completed implementations as well as their motivations for pursuing further advancements.

2.5 Research quality

When determining the quality of research, it is important to consider its reliability, validity, and representativeness (Höst et al., 2006; Rosengren & Arvidsson, 2002). Reliability refers to the trustworthiness and consistency of data collection and analysis. Validity denotes the extent to which the research effectively captures and measures the intended construct. Representativeness concerns the degree to which the research findings may be generalized beyond the sample population and to the larger target population.

To ensure reliability, it is important to be meticulous when gathering data and conducting the analysis (Höst et al., 2006). The interviews with different individuals were standardized so that each participant's interview environment was similar by using the same question formulation and asking questions in the same order. However, because the interviews were semi-structured, follow-up questions differed between interviews; therefore, the interviews were not identical. During the interviews, there was no attempt to steer interviewees towards certain answers, as this could compromise the integrity of the data. Standardizing the interviews in this way improved the reliability of the thesis. Moreover, the interviews were conducted with individuals with different roles to provide different perspectives on cloud manufacturing.

To further validate the thesis project, the insights gathered from the interviews were corroborated by the insights from current research gathered from the literature. If the insight from the interview was not corroborated by literature, it indicated a gap between academia and real-life practice, which provided valuable insights in itself.

Regarding representativeness, the project focuses on two large-scale manufacturing companies whose experiences provided in-depth insights into the subject of the thesis project. The interviews were paired with a literature review to ensure representativeness and to generalize the findings. In cases where literature and interviews did not corroborate each other, the findings provide insights into gaps regarding current literature.

3 THEORY

This chapter introduces relevant theories and models, which combined make up the thesis project’s theoretical framework.

Firstly, the concept of Industry 4.0 is introduced. Industry 4.0 refers to a multitude of different technologies that can provide value to all parts of an organization's value chain. Two of the technologies are Cloud Computing and the Industrial Internet of Things. Cloud Computing refers to utilizing the cloud to access, store, and analyze data on a central platform. The Industrial Internet of Things refers to connecting devices and machines within a manufacturing environment to understand, optimize, and automate processes and activities. When the connected devices of the Industrial Internet of Things can access and communicate through a cloud platform, this is called cloud manufacturing. The potential applications of cloud manufacturing are described, and the potential value they can provide an organization's production process is discussed. The discussion includes the benefits and drawbacks of utilizing the applications and the barriers to adopting them.

Secondly, the Hierarchical Production Planning Framework is introduced. This framework categorizes all activities and processes within an organization's production according to a hierarchy, from long-term strategy to short-term operations. The framework is used to connect the benefits observed from both the theory and interviews to evaluate the impact they have on a production system. This will provide a deeper understanding of the value cloud manufacturing can provide to an organization's production process.

Lastly, the Diffusion of Innovation Model is introduced. This model has two purposes. Firstly, it divides and characterizes companies into five groups of adopters based on their inclination toward adopting innovations. The companies interviewed in this thesis are characterized according to this model to analyze their motivations for implementing cloud manufacturing technologies. Secondly, this model provides five attributes that influence the adoption rate of an innovation. Cloud manufacturing will be evaluated based on these five attributes. This will determine how complex the integration process of cloud manufacturing is and, thus, evaluate its potential barriers to adoption.

3.1 Industry 4.0

The concept Industry 4.0 was first coined at the Hannover Fair in 2011 as the term to represent the fourth industrial revolution and Germany's digital strategy, which refers to the emergence of disruptive intelligence and information technologies (Bai et al., 2020; Borangiu et al., 2019; Hannovermesse, n.d.; Tysk-Svenska Handelskammaren, n.d.). Today, other initiatives have been created globally to address the same phenomenon, such as Advanced Manufacturing (USA), e-Factory (Japan), and Intelligent Manufacturing (China). However, in this thesis project, the term Industry 4.0 will be used (Borangiu et al., 2019). Frank et al. (2019) divide Industry 4.0 technologies into two layers: front-end and base technologies (see Figure 1). Front end-technologies directly impact an organization's processes and activities, whereas base technologies enable and support the front-end technologies.

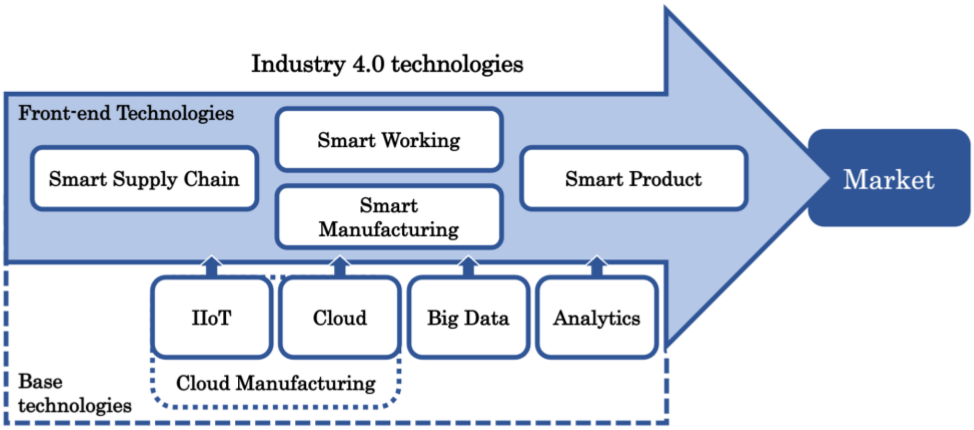

Figure 1. Theoretical framework of Industry 4.0 technologies (Frank et al., 2019)

3.1.1 Front-end technologies

As seen in Figure 1, the front-end technologies consist of smart supply chain, smart working, smart manufacturing, and smart products. These four technologies are directly linked with the production process of an organization and, therefore, have an end-application purpose in the company's value chain. They are ordered according to their role in the chain, starting from the procurement process (smart supply chain) to delivering the finished product (smart product) (Frank et al., 2019).

Smart supply chain considers the exchange of information between parties in the supply chain, integrating parties to synchronize the manufacturing process. This integration has the potential to decrease delivery times and information distortions. It can also allow for resource collaboration and information sharing between the parties in the supply chain, increasing innovation capabilities in manufacturing.

Smart working describes a socio-technical evolution of the human role in production. Through information and communication technologies, smart working aims to provide better conditions for workers to improve their productivity and provide remote access to shop floor information. For example, a digital platform can display information about the utilization rate of the machines on a production floor, allowing workers to better monitor the production process.

Smart manufacturing considers technologies that impact the production system of an organization. These technologies can connect the machines and devices on the production floor, allowing them to communicate with each other and process data. This can enable a company to both monitor and improve its production system.

Smart products refer to technologies that can be embedded into the final product. This technology can provide data feedback for the production process and new features for customers. For example, a product can be embedded with sensors that allow a customer to monitor a product's condition. This allows the customer to understand and utilize their purchased product better. Additionally, the supplier can utilize the data to produce a better product.

Front-end technologies can impact the entire value chain of an organization. This thesis aims to determine the impact that cloud manufacturing technologies can provide on the production process of a manufacturing organization. Thus, the applications of Industry 4.0 that are considered further in this thesis are the two front-end technologies that directly impact the manufacturing process, smart manufacturing, and smart products.

3.1.2 Base technologies

Figure 1 shows that the base technologies include the Industrial Internet of Things, cloud computing, big data, and analytics. The base technologies are named as such due to their presence throughout front-end technologies, enabling interconnectivity throughout an organization and providing intelligence for manufacturing systems (Frank et al., 2019).

The Industrial Internet of Things represents the integration of smart devices, such as sensors, in machines and equipment in an industrial environment. These technologies connect the different machines and equipment in the manufacturing environment and enable them to communicate and process data.

Cloud computing and services enable the integration of different devices without limitations to physical proximity and computing limitations through on-demand remotely accessed computing resources. The cloud can, thus, be leveraged to "share information and coordinate activities" between different devices and business entities (Frank et al., 2019).

Big Data and *Analytics* can be utilized through a combination of the Industrial Internet of Things and the cloud, where the data collected by the sensors can be stored in the cloud and analyzed through machine learning and data mining technologies. Big Data and Analytics are key enablers for more advanced applications of Industry 4.0. This thesis focuses on the base technologies of cloud computing and the Industrial Internet of Things (IIoT), whereas Big Data and Analytics are seen as complements to cloud computing and IIoT.

3.2 Cloud Manufacturing

IIoT and cloud computing are unified under the concept of cloud manufacturing (CMfg), as seen in Figure 2. Cloud services and physical manufacturing systems are interlinked in the cloud-based manufacturing environment (Qi & Tao, 2019). IIoT enables data collection through sensors and actuators connected to different devices in the manufacturing chain, which are then stored in the cloud. Cloud services and tools may then process this information to give commands to the devices.

CMfg utilizes well-established manufacturing resources, such as Enterprise Resource Planning (ERP) systems, and connects them to the cloud, making information easily accessible and connecting multiple systems together. This typically incorporates more aspects of the company's processes, such as manufacturing, logistics, planning, and maintenance, as illustrated in Figure 2.

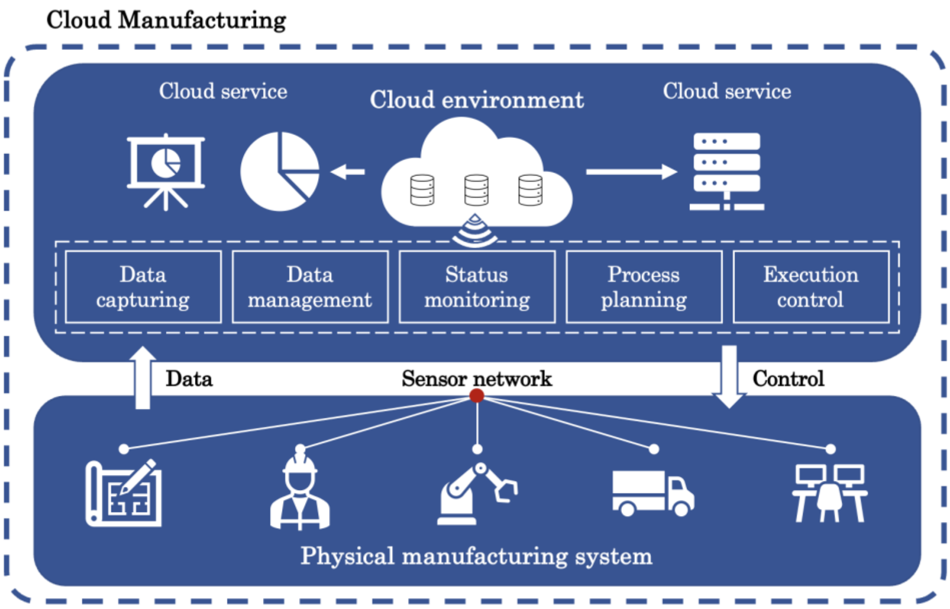

Figure 2. The cloud-based manufacturing system architecture (Qi & Tao, 2019).

3.2.1 Cloud Computing

Traditionally, new software-based products and services were slow to launch on the market and had high upfront investments and operational costs. One cause of these difficulties is that organizations' IT and data handling systems were hosted on-prem. Cloud computing has enabled companies to launch the same software-based products and services differently, reducing time-to-market, with lower investments, and minimizing risk (Kavis, 2014; Faynberg et al., 2016). Instead of operating computing resources on-prem, with cloud computing companies can access the same resources through the internet. These resources, which are hosted through the internet, are referred to as “the Cloud” (Cha, 2015; Cloudflare, n.d.).

Although cloud computing (CC) is already used to a certain degree in various enterprise and analytics applications, it has been historically difficult to define CC due to varying opinions of what it is (Rountree & Castillo, 2013; Rüßmann et al., 2015). This has resulted in many different definitions to describe the concept (Vaquero et al., 2008). One of the most used and accepted definitions is the one proposed by Mell & Grance (2011) of the American National Institute of Standards and Technology (NIST) (Rountree & Castillo, 2013; Serrano et al., 2015) Mell and Grance (2011) define cloud computing as:

"Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction." (Mell & Grance, 2011)

Although NIST's definition has seen changes as cloud computing has evolved over the years, the core concept remains the same - delivering computing services via the Internet ("the cloud") (Serrano et al., 2015; Rountree & Castillo, 2013; Eurostat, 2022). To confirm the definition proposed by NIST and its relevance today, a comparison between definitions proposed by several cloud service providers (CSP) has been conducted, see Appendix B.

The main difference between the definitions of the CSPs and NIST's definition is the payment model, where NIST fails to mention it at all. Meanwhile, most CSPs mention the "pay-as-you-go" model, where customers only pay for the actual use of the services, which is also agreed upon by Eurostat (2022). An updated definition can, thus, be proposed where the original definition from NIST is complemented with the pay-as-you-go model:

<u>Proposed definition:</u> *"Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction,* ***where clients pay for the actual usage of the services on a pay-as-you-go basis.****"*

The proposed definition may not be entirely accurate for all cloud services since cloud applications such as Gmail and Zoom exist where the service is free for private users. However, it is not the norm for companies to access the services free of charge. Instead, it is more common to utilize the pay-as-you-go structure offered by many CSPs or another variety of a subscription payment, see Appendix B. Therefore, the proposed definition is used for this thesis project.

In addition to the cloud computing definition, Mell & Grance (2011) list five essential characteristics, three service models, and four deployment models, which further explain the cloud model. The five essential characteristics describe cloud computing (Rountree & Castillo, 2013). The three service models describe the relationship between the cloud provider and the user in terms of responsibility. The four deployment models describe how a cloud solution is implemented, which has effects on data accessibility and security. These different characteristics and models describe cloud computing, its implementation, and who is responsible for its different components. The service and deployment models impact the potential benefits of implementing cloud computing. Thus, it is vital to preface the benefits observed in the interviewed companies with their choices of service and deployment models.

Essential Characteristics

A cloud solution has five essential characteristics that must be fulfilled to be considered a true cloud offering: *on-demand self-service, broad network access, resource pooling, rapid elasticity,* and *measured service* (Rountree & Castillo, 2013; Mell & Grance, 2011).

On-demand self-service enables customers to request and receive services, such as additional storage space or processing power, through an automated user portal without manual assistance from the CSP.

Broad network access refers to the possibility to easily access cloud services remotely via a wide range of devices, such as laptops and cellphones with different operating systems.

Resource pooling allows CSPs to offer access to computing resources to several customers. Unlike a traditional system where the computing resources would sit idle, resource pooling allows CSPs to service more customers with the same amount of resources.

Rapid elasticity enables customers to dynamically alter the cloud computing power, such as processing power, according to their needs.

Measured services refer to the payment model of a cloud platform. Cloud services measure the usage of the provided service by a metric appropriate to the service type, such as storage size, active user accounts, or processing power. This enables the pay-as-you-go feature, where users only pay for the actual services they use.

Service Models

Gibson et al. (2012) list Software-as-a-Service (SaaS), Infrastructure-as-a-Service (IaaS), and Platforms-as-a-Service (PaaS), as the three dominant cloud service models. In recent years, service models such as Acceleration-as-a-Service (AaaS), Function-as-a-Service (FaaS), and Container-as-a-Service (CaaS) have gained traction (Varghese & Buyya, 2018). In this report, the three dominant service models are briefly explained. Figure 3 illustrates a general picture of the three service models, their components, responsible actors, example products, target users, and cloud stack. As seen in the figure, the relationship between the CSP and the customer can be ordered based on their individual level of responsibility. The decision of the service model is, thus, based on the level of responsibility a customer wishes to have over their cloud platform.

For example, if a company is less knowledgeable about leveraging the cloud, it can choose to use a SaaS model. This places more responsibility on the CSP, meaning the customer can utilize the provider's expertise to implement ready-made or outsourced tailor-made solutions. The customer does not have to spend time and resources to develop and implement cloud solutions. Instead, companies can focus on other aspects of their business. If, however, a company only requires a platform to run its software on and prefers to hold more control internally, it could utilize the IaaS service. The three service models are described in more detail in the following paragraphs.

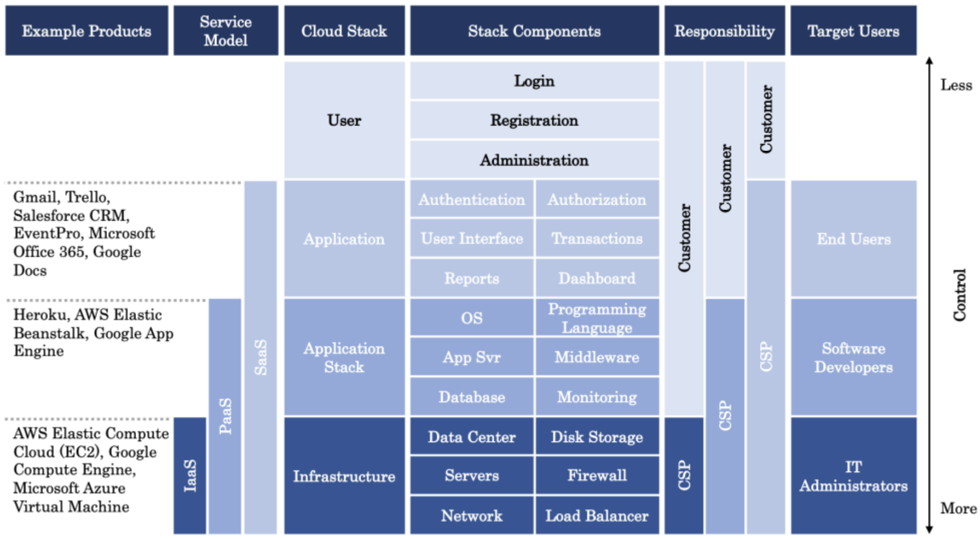

Figure 3. The Cloud Stack, complemented with example products, target users, and user control (Kavis, 2014; Plesk, 2019).

Software-as-a-Service (SaaS) provides customers with complete applications where the customer typically only must administer users and manage some application-specific parameters. The CSP manages all underlying infrastructure and the platform. Common applications are business software, for example, enterprise resource planning (ERP) and customer relationship management systems. SaaS is the typical cloud service model with applications such as Microsoft Office 365 and Google Workspace as well-known examples.

Platforms-as-a-Service (PaaS) allows customers to deploy applications on cloud infrastructure using the operating system, development platform, and database platform provided by the CSP. PaaS allows customers to focus on the business logic of the developed applications and not the supporting soft- and hardware.

Infrastructure-as-a-Service (IaaS) provides customers with basic infrastructure services. Cloud providers host the hardware (e.g., storage and processing units) where customers can install and run software (e.g., operating systems and applications). Thus, IaaS allows customers to replace in-house data centers but remain in control of which applications, operating systems, and other aspects to use.

A survey study conducted by Aziz et al. (2020) from 2018 to 2019 on CMfg in the manufacturing industry in the US revealed that 49 percent of respondents used CMfg. Among the service models, SaaS emerged as the most popular, followed by IaaS and PaaS. Additionally, approximately 5 percent of the respondents reported using a service model other than SaaS, IaaS, and PaaS. Similarly, in 2021, large enterprises who used cloud computing in the European Union reported that 94 percent utilized SaaS, 81 percent used IaaS, and 38 percent utilized PaaS, where some companies used multiple models (Eurostat, 2022).

Deployment Models

In addition to the service models, there is also a variety of cloud deployment models an organization may choose from. A deployment model defines how a cloud solution is implemented. Generally, there are four models: *public*, *private*, *hybrid*, and *community*, see Figure 4. The four deployment models Mell & Grance (2011) and Rountree & Castillo (2013) outlined are briefly presented here.

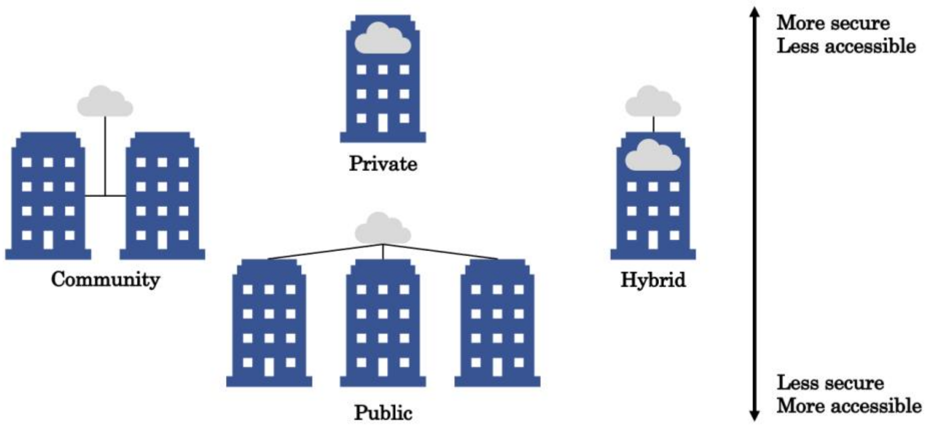

Figure 4. Illustration of the different cloud deployment models (Spiceworks, 2016)

The *public cloud* deployment model is the one most people typically associate with a cloud platform. Users of the public cloud share the cloud resources, also known as multi-tenant cloud. The providers are responsible for the management and operation of the cloud system. The systems and resources required to provide the cloud service are hosted on the provider's premises and are typically accessed through the internet. Such a solution can be accessed from any device that can connect to the internet; thus, there are multiple access points. This results in a higher level of accessibility for the user. However, since the model requires fewer authentication layers, it may also be less secure.

The *private model* is a cloud environment where all systems and resources are hosted internally at the user, or externally through a third party via a single-tenant system, i.e., off-premises. This type of cloud is often accessed through a local area network (LAN) or wide area network (WAN). Users who wish to access the cloud remotely usually access it through the internet using a virtual private network (VPN). Such a network is more difficult to access than a public cloud since it involves more layers of authentication, but this also entails increased data security.

The *community model* is a semi-public cloud in which several members share the resources of a cloud. A community cloud can be owned and operated by either a third party or one or more community members and may be either off- or on-premises. This model enables organizations to share the usage of a network while splitting the costs, which may decrease the individual costs within the community. However, this also entails a lower level of security since more organizations can access the network. Additionally, it is important to differentiate from a purely public model where any company might utilize the same computing resources. In a community cloud, access is limited to selected companies, typically with shared concerns, such as compliance considerations, policies, and security requirements.

The *hybrid model* is a combination of two or more of the other deployment models, such as a private-public cloud. The different cloud entities are connected through technology, making it possible for data to be transferred between them. In the case of a hybrid private-public model, business-critical resources might be deployed on the private cloud while the public cloud is used to meet demand peaks when the private cloud is at capacity. This model, therefore, balances the security by having some parts of the network more difficult to access while still providing higher accessibility to other parts of the network.

Which of the models is best varies between organizations as their requirements and preferences differ, such as services provided and level of control (Rountree & Castillo, 2013). In essence, the choice is based on the trade-off between data security and access. A more accessible network is typically less secure, while a more secure network can be harder to access (Rountree & Castillo, 2013).

3.2.1 The Industrial Internet of Things

The emergence of devices that can communicate through the internet is known as the Internet of Things (IoT). The concept of the IIoT refers to the digitalization of machines within the manufacturing industry (Haghnegahdar et al., 2022; Sisinni et al., 2018). The IIoT has enabled machine-to-machine communication due to recent cost reductions of sensors and advancements in communication through the internet (Frank et al., 2019).

The IIoT is an ecosystem of networking equipment, such as devices and sensors, that collect and monitor data which can then be analyzed and utilized to support real-time decision-making (Borangiu et al., 2019; Cisco, n.d.). The IIoT aims to enable companies to better understand and improve their physical systems through supervision, optimization, and prediction activities. Additionally, the IIoT not only enables data to be collected from the manufacturing process but also enables remote operation and control over machines in production (Sisinni et al., 2018).

The IIoT has many different application areas which can be divided into four categories: *environment mapping*, *process optimization*, *planning optimization*, and *process automation*. The application areas are further explained in the following sections.

Environment Mapping

Environment mapping refers to increasing the understanding of activities that occur in a production environment. Typically, this is done by installing sensors and actuators which provide data that enable companies to monitor the production process and observe any disturbances (Jeschke et al., 2017). The collected data can provide valuable insights into the processes and can be utilized to enhance decision-making based on more available information.

Environment mapping can improve resource usage within the production environment (Jeschke et al., 2017). It can decrease production costs by lowering the usage of various resources, such as water, electricity, and raw materials. The first step towards decreasing the usage of materials, manpower, and energy is understanding how much is used and where it is used within the production process. Sensors can be used to map manufacturing resources such as raw materials, equipment, energy usage, and personnel. Mapping and understanding the resource usage within the production process enables companies to manage them better and improve production efficiency (Li et al., 2017).

Energy optimization is a particularly interesting part of resource management as it relates to both financial and environmental sustainability. From the financial perspective, it has become increasingly important to lower energy usage as energy prices have increased for non-household consumers in the EU in recent years, in Sweden the electricity price increased by 44 percent between 2021 and 2022 (Eurostat, 2023d). From the environmental perspective, consumers are generally concerned about the impact their purchasing decisions can have on the climate (Insight Intelligence, n.d.). This awareness has increased the demand for companies to provide products and services with a lower climate footprint.

Process Optimization

Process optimization is the practice of leveraging the connected network provided by the IIoT to improve activities within the production process. For example, this can be done by utilizing real-time data on the utilization rate of machines on a production floor to identify any inefficiencies. Potential usage areas connected to process optimization are *intuitive interfaces, real-time analytics,* and *simulation*.

Intuitive Interfaces

The human-machine interaction is important to consider when implementing digital solutions. The IIoT can improve the relationship and interaction between machine and person, resulting in higher labor productivity (Jeschke et al., 2017). Data feeds can show field operators relevant information, improving their understanding of upcoming production activities and facilitating their cooperation with other human and robotic resources (Cimino et al., 2023).

Real-Time Analytics

The IIoT can provide analytics about the production's Key Performance Indicators (KPIs) and potential bottlenecks in real time by obtaining data regarding productivity, waste, and machine failures from sensors across the production floor. These analytics provide valuable data which can optimize efficiency (Cimino et al., 2023). For example, if a bottleneck occurs in the production line, this can be communicated throughout the production environment. Without such communication, operators at each stage of the production process may make decisions that they see as best for the efficiency of their component of the production process. However, this may not be the most effective decision for the production process as a whole. By communicating these disruptions to all components of the production process, each operator can make decisions that take these disturbances into account, allowing them to make the optimal choice for the production as a whole.

Simulation

Manufacturing lines produce a massive amount of parts, and each stage of the process can provide valuable data that can contribute to improving both the quality and volume of production. Companies typically explore thousands of ways to improve production through experimentation which can be both time-consuming and expensive (Lade et al., 2017).

The IIoT can provide an easier avenue to find these improvements. Once machines have been outfitted with sensors collecting data about their performance, a digital twin can be created. A digital twin is a virtual model that uses data from sensors to reflect the machine in a digital format. This model can run simulations to generate valuable insights by studying performance issues and generating possible improvements for the original machine (IBM, n.d). Traditional methods for building digital twins use a lot of system resources by using web services and sensor techniques. Thus, there is a limitation on the scalability of this method since it can only support a smaller section of the production process before the required bandwidth of the simulation exceeds the capabilities of a factory's servers.

The utilization of cloud solutions allows companies to improve their digital twins (Nguyen et al., 2022).

Planning Optimization

Planning optimization means utilizing the IIoT to improve the scheduling of different activities, workers, and resources within the manufacturing environment. An example of this can be utilizing sensors to detect faults within machines earlier and leveraging this knowledge to schedule maintenance in an optimal time window.

Scheduling

The IIoT creates a degree of automation towards the decisions made in Production Planning and Control (PPC). Smart PPC systems can optimize scheduling in production while simultaneously letting workers on the production floor make changes. Additionally, it can improve the visibility of production plans for all workers within the manufacturing process (Cimino et al., 2023). Konstantinos et al. (2022) showcase a digital planning platform that optimizes scheduling through algorithmic optimization and visualizes the process through a user interface. This system was tested by a fabric manufacturer and achieved a 25 percent increase in machine usage, a 15 percent decrease in machine setup time, and an overall productivity increase of 30 percent. Although these results were based on a pilot test, they highlight the potential for an IIoT-based digital planning system. Another example of such a system is provided by Grassi et al. (2020). They propose a hybrid system that integrates machines in the production system. The proposed system works by taking inputs from a high-level plant controller, which in essence, are the overarching production quotas that need to be met and using them as a frame of reference for the shop-floor scheduling. The production system consists of a virtual queue of orders, which contains the upcoming orders that need to be released to the production system, and a dispatcher, which dynamically releases jobs into production based on which it finds most suitable. The dispatcher is using an algorithm that considers the current state of the production system by utilizing data from machines that are connected through the IIoT. Based on this data it then evaluates which orders are optimal to release next. Grassi et al. (2020) found benefits in total throughput and the cycle time spent in the physical production process when evaluating a production system utilizing this logic controller. Overall, the logical controller was able to achieve higher production efficiency and a better balance regarding the total throughput.

Predictive maintenance

Predictive maintenance refers to using scheduling service actions based on knowledge regarding fatigue, wear, and tear. By utilizing sensors and data, the IIoT enables a higher level of predictability in many different areas of production (Haghnegahdar et al., 2022). By utilizing more operational data, companies can better forecast machine failures, providing several benefits (Jeschke et al., 2017). These consist of, among others, improved scheduling of repairs leading to reduced maintenance costs, and fewer stoppages in the production process (World Economic Forum, 2015). Karner et al. (2019) show an example of determining the condition of industrial plate shears; by measuring the vibrations of the machine using sensors, they were able to determine the condition of the equipment with much better precision. This example showcases the possibility for the IIoT to provide valuable data regarding the real-time condition of machines.

Additionally, knowledge of required repairs and replacements of machines can provide valuable information, allowing companies to conduct prescriptive maintenance. This refers to taking steps to prolong the lifespan of machines, which can decrease waste and optimize productivity (Cimino et al., 2023; Ahmad et al., 2018). By understanding the real-time condition of all machines on a production floor, companies can balance the workload between machines. Thus, failures of individual machines can be decreased while the efficiency of the factory as a whole can be maximized (Lee et al., 2014).

Process Automation

Process automation means utilizing the IIoT to automate processes and machines in the manufacturing environment. Incorporating the IIoT can enable machines to run different processes on the production floor without the need for an active operator (Singh et al., 2022). The technology that enables this automation is programmable logic controllers (PLC). PLCs are electronic devices with built-in processors that can control the operation of machines and interact with other technical devices. These controllers can allow each machine to run independently and autonomously, controlling its own behavior and exchanging information with its environment. The integration of PLCs in the control of production can automate a range of activities within the manufacturing process, such as the replenishment of material and the execution of production machines. Chen et al. (2022) proposes such a system, exemplifying it using a water-oil mixer. The machine requires a consistent supply of water when operating. Thus, a PLC can be used to monitor the water level and provide water when the machine requires it. This example is a simple application that shows the ability of the IIoT devices to operate and make decisions without direct control from an operator while simultaneously gathering data from the production process.

By automating activities within the production process, the need for workers to make decisions and operate machines is decreased, enabling them to focus on other activities. Additionally, these machines can perform tasks with a higher efficiency than workers. Thus, the implementation of PLCs within the production process can increase both worker productivity and overall efficiency (Fatima et al., 2022).

Barriers and challenges for the IIoT

While there are many benefits associated with the implementation of the IIoT technologies, there are also several drawbacks and barriers to the implementation. Kumar et al. (2021) presents an analysis of these challenges and how they can be attributed to different levels of a production hierarchy, from a strategic to an operational perspective. In Figure 5 the related difficulties are visualized with the inter-relationships between them.

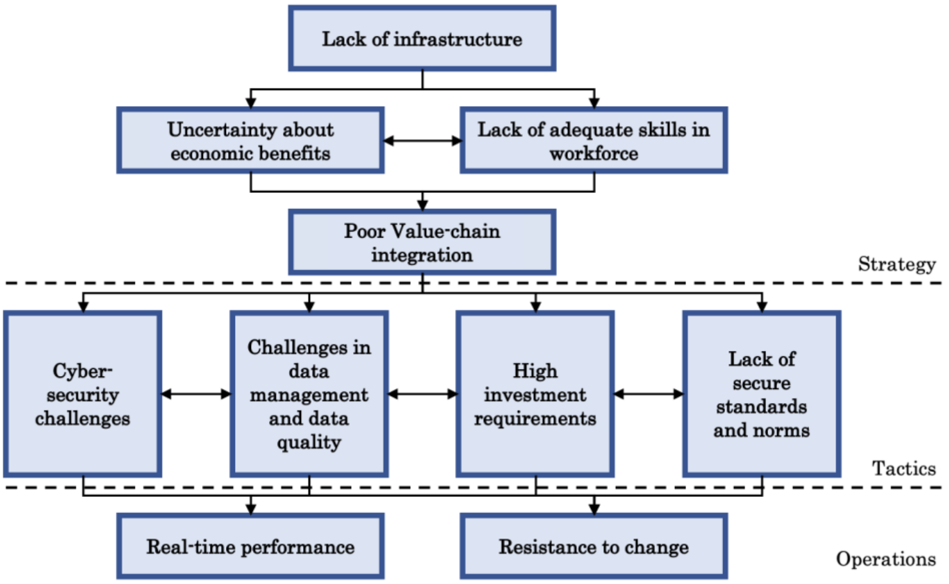

Figure 5. Barriers to Industry 4.0 implementation (Kumar et al., 2021).

Strategic barriers

Lack of infrastructure is a challenge that relates to problems in both IT infrastructure within a production site and the internet coverage it can utilize. This is the most significant barrier to adopting the IIoT, which is reasonable as it lays the foundation for using connected devices. If the required infrastructure is not established before the implementation of the IIoT, it will result in considerable difficulties (Kumar et al., 2021).

The next two barriers, uncertainty about economic benefits and lack of adequate skills in the workforce, can be an indirect result of a lack of infrastructure. Uncertainty about economic benefits refers to the challenge of an organization not being able to grasp the benefits that the IIoT solutions can provide their organization. The uncertainty can be attributed to not having the infrastructure to determine the potential applications a new implementation can provide. Additionally, the lack of skills in the workforce is likely a result of not having a previous infrastructure to which employees have been accustomed to (Kumar et al., 2021).

The combination of lacking adequate skills in the workforce and having an uncertain understanding of economic benefits will likely result in difficulties integrating new implementations across an organization's value chain. This creates difficulties in establishing interoperability and integration between different technologies and systems (Kumar et al., 2021). A lack of interoperability among devices and departments can increase both the cost and complexity of the deployment of the IIoT, which could drive further challenges on a tactical level (Sissinni et al., 2018).

Tactical barriers

There are four tactical barriers: cyber-security challenges, high investment requirements, data management and data quality, and lack of security standards and norms. Cyber-security challenges are a result of the basic principle of having an interconnected network which, if the value chain is poorly integrated, will be ever more challenging (Sissinni et al., 2018). Additionally, substantial investments are associated with the implementation of the IIoT technologies, which will likely be exacerbated without proper integration and planning processes for establishing interoperability. Data management and quality challenges refer to the handling, storage, and extraction of the data provided by the interconnected devices and processes within the IIoT. Such barriers likely exist when an organization does not have a proper integration between departments. Finally, an organization's lack of standards and norms refers to a lack of standardization across departments and production sites (Kumar et al., 2021). This may cause difficulties because of different ways of measuring data, thus, creating difficulties in comparing and analyzing data between different production sites and departments.

Operational barriers

The tactical barriers and challenges may increase the operational barriers. Resistance to change refers to employees showing unwillingness to adopt new technologies (Kumar et al., 2021). This will likely incur problems with workers being unwilling to learn and properly utilize the implemented technology. The next barrier, real-time performance challenges are difficulties with the timing and reliability of the data communicated by the connected devices within the IIoT network (Sissinni et al., 2018). Different processes and activities within a production may require short communication times of data within a system, and, thus, if an IIoT technology cannot meet such requirements, it will cause disturbances.

3.2.3 Adoption of CMfg technologies

The implementation and adoption of Cloud Manufacturing-technologies today varies depending on how far a company has traveled on its Industry 4.0 journey (Frank et al., 2019). Cloud is the most adopted base technology, especially in companies that Frank et al. (2019) considers low- and medium-adopters. Following the cloud, the Industrial Internet of Things is the second most implemented technology, followed by big data and analytics. Of large enterprises in the European Union, 71.6 percent bought CC services, and 48,4 percent used IoT in 2021, while only 34,3 percent analyzed big data (Eurostat 2023a, 2023b, 2023c).

In 2021, only a minority of large-scale enterprises in the EU had adopted the IIoT for the purposes seen in Figure 6. Monitoring energy, which is a part of environment mapping, is the most adopted IIoT application, at 27 percent. The second most adopted application, at 21 percent, is condition-based maintenance. Lastly, both the IIoT for automating production processes and logistics management are the least adopted applications, with 17 and 18 percent, respectively. The adoption rate of all these applications is relatively low and gives an indication that the overall adoption of the IIoT in production is still in an early stage.

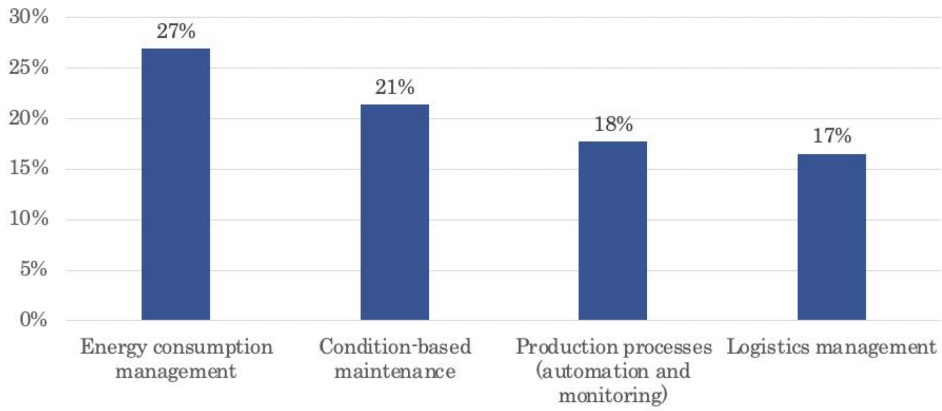

Figure 6. Share of companies with 250 employees or more in the EU who uses IIoT per category in 2021 (Eurostat, 2023b)

To increase the implementation of the IIoT, companies must take certain steps to realize the IIoT potential (Lorenz et al., 2019). To realize the potential, Lorenz et al. (2019) illustrate a four-step approach, depicted in

Figure 7. Firstly, it is important to set the scope of ambition by determining the current status of the IIoT within all business units and based on current internal and external factors, such as customer feedback and technology trends. Secondly, the company should assess and prioritize opportunities based on customer needs, competitors, and feasibility. In the third step, the will and ambition are realized by building the right capabilities. To do that, the necessary skills must be identified and acquired if missing. Lastly, the company must anchor its ambition by establishing a governance structure and steering team to improve coordination between different business units, integrate legacy and new business, and foster new initiatives. If a company takes these steps, implementing and using CMfg technologies will likely prove to be a more seamless process. Therefore, the organizational readiness of a company may be a substantial factor for the adoption of a CMfg technology.

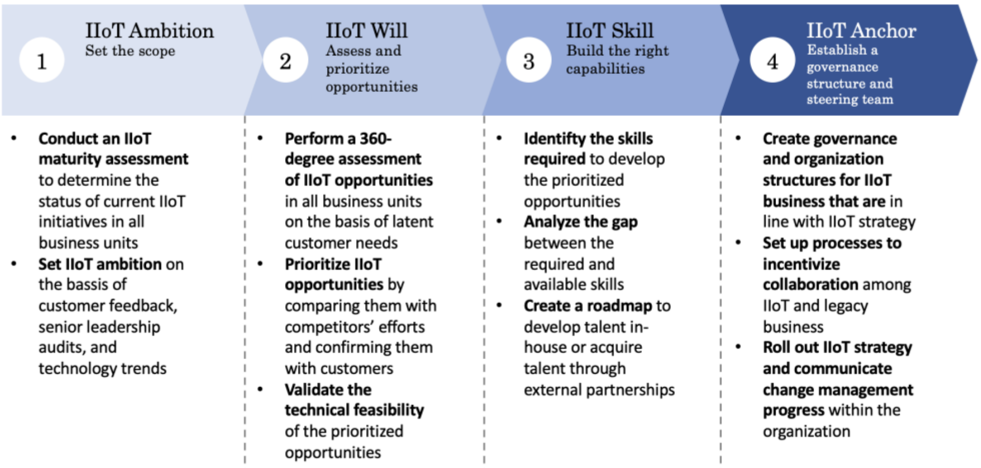

Figure 7. Four steps for vendors to realize their IIoT potential (Lorenz et al., 2019).

3.3 The Hierarchical Production Planning Framework

To deeper analyze how cloud manufacturing can impact the production management of large-scale manufacturing companies, the Hierarchical Production Planning Framework is utilized. This model provides an overview of the activities and processes within a manufacturing system, see Figure 8 (Hopp & Spearman, 2008). It describes the different levels of production planning and the control hierarchy for production systems. It is firstly divided into three basic levels: long-term strategy, intermediate-term tactics, and short-term operations planning. Within each level there are modules, which describe a combination of analytical models, computer tools, and human judgment that address individual planning problems. The basic levels and their modules are further explained in the following paragraphs.

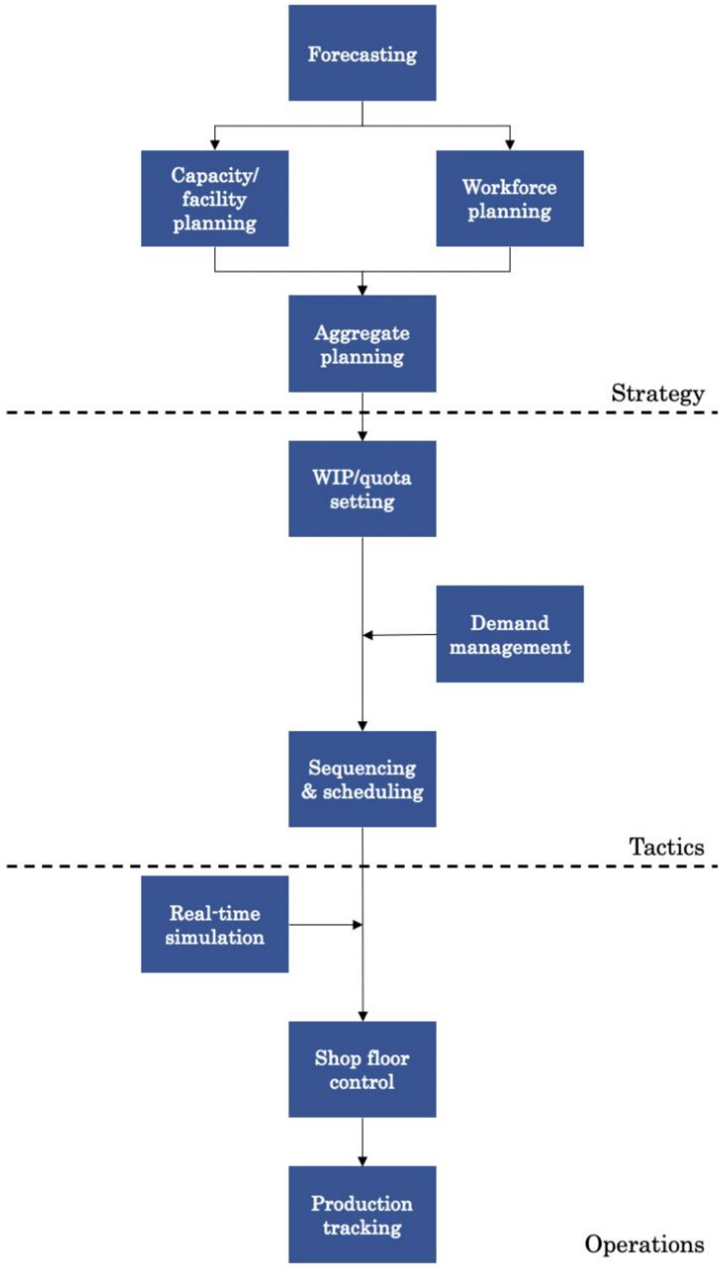

Figure 8. Production planning and control framework (Hopp & Spearman, 2008)

Strategic level

The primary function of long-term strategic planning is to account for a plant's overall goals, such as number of production orders, and ensure that the production environment can meet them. Within this level, the first planning module is forecasting. This module takes in parameters from the market to estimate the demand that needs to be met by the factory. To meet the demand set by the forecast, the factory's production capabilities are determined through the following two modules: *capacity and facility planning*, and *workforce planning*.

Capacity and facility planning account for the factory's capabilities to manufacture a specific amount of products. On a basic level, it concerns how much and what kind of equipment is required long-term. On this level, a company is concerned with a multitude of factors that affect the long-term capacity of their factory, such as product lifetimes, variability of production, and the reliability and maintenance of machines.

Workforce planning similarly uses the forecast to staff the factory with the number of workers needed to manufacture products according to the forecasted demand. Workforces are naturally inelastic; to increase the workforce, hiring and training need to be done, and to decrease the workforce, companies must fire individuals. Thus, workforce planning is a long-term strategic issue that cannot majorly be altered on a daily basis.

The last module on the strategy level, aggregate planning, makes a long-term production plan regarding how much and what to produce. This plan is based on the forecasted demand and the capacity of the factory and workforce.

Tactical level

The aggregate plan formed in the previous step acts as input to the tactical level. This level combines the long-term strategy with customer orders to prepare the plant for upcoming production.

The work-in-progress (WIP) and quota-setting module set periodic production quotas at a relatively infrequent rate, such as weekly or monthly, which are difficult to alter in the short-term. Thus, the company needs to determine the production capacity to meet customer needs when placing production orders. Furthermore, the demand management module provides customer orders based on, for example, customer importance. The module needs to be able to balance customer needs with the capability of production to communicate delivery times for customers.

The sequencing & scheduling module translates this Master Production Schedule into a workforce schedule with a horizon of, for example, the next week. The creation of such a schedule typically requires several iterations between the Master Production Schedule and the aggregate plan, which can be time-consuming and complex.

Operational level

The last level, short-term operational planning, is in direct control of the factory. The module "shop floor control" refers to the real-time flow of material according to the schedule determined on the tactical level. On this level companies use the schedule as guidance but needs to account for the disturbances that occur in real-time during production.

The production tracking module measures the progress of the schedule. This information can be relevant for a person overseeing the production in real-time to ensure there are no disturbances. It can also be used by modules at a higher level of the hierarchy. For example, capacity or facility planning can utilize the tracking of production over a longer period to determine the factory's capability.

Lastly, this level contains the real-time simulation module, which models scenarios of problems in a simulation environment that may occur in production, such as machine breakdowns. This gives valuable insights into the effects it may have on the production environment. Additionally, it can help to determine process improvements by simulating the effects of altering certain aspects of the process. For example, if it is possible to decrease the energy usage of a machine without affecting the quality of the product it produces.

3.4 Diffusion of innovations model

The adoption of different cloud manufacturing technologies can be understood further using the diffusions of innovation model introduced by Rogers (2003). This model describes the process as an innovation is established itself within an industry by analyzing the different groups that adopt an innovation. These groups can be observed in Figure 9. The companies interviewed in this thesis will be categorized according to this curve in *Section 5.1 - Characterizing the companies as adopters*. This classification will provide a deeper insight into the motivations the case companies have for adopting cloud manufacturing technologies.

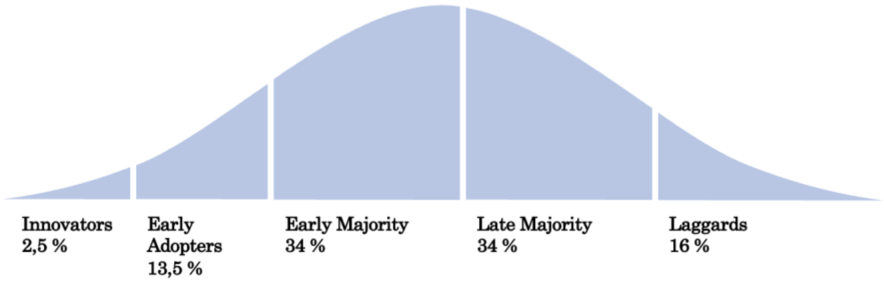

Figure 9. Diffusion of innovation curve (Rogers, 2003).

The diffusion of innovation curve, as seen in Figure 9, describes five segments of adopters: *innovators*, *early adopters*, *early majority*, *late majority*, and *laggards*. Innovators are characterized as venturesome and eager to try new things. This comes with accepting a certain degree of risk for occasional setbacks if an adopted innovation is unsuccessful. Being the first group to adopt an innovation, they act as a gatekeeper to new technologies and their experience may act as a benchmark for other adopters. Early adopters have the greatest influence among all groups regarding opinion leadership and serve as role models in change leadership. One of their main roles in interpersonal networks is to decrease uncertainty regarding an innovation's risks. The early majority is characterized as deliberate and may take some time before adopting an innovation. They seldom hold a leadership position, but their position between the early adopters and late majority makes their decision to adopt an innovation an important step for innovation to establish itself within an industry. The late majority is characterized as skeptical and adopts an innovation after a majority of companies have adopted it. They typically have relatively scarce resources. Therefore, almost all uncertainty must be removed before adopting an innovation. Laggards are characterized as traditional and hold little to no opinion leadership.

In addition to the categorization of adopters, the diffusion of innovation model defines five attributes that drive the rate of adoption. These attributes will be used to analyze the different applications of cloud manufacturing in *Chapter 5 - Analysis* to evaluate their potential for adoption. These are:

i. *Relative advantage* refers to the degree of perceived improvement which the innovation holds over the existing alternatives.
ii. *Compatibility* refers to how compatible the innovation is with existing values, past experiences, and needs of potential adopters.
iii. *Complexity* pertains to how difficult an innovation is to understand and use.
iv. *Trialability* refers to the degree to which an innovation can be tried before being implemented.
v. *Observability* regards how easy it is to understand the benefits of adopting an innovation.

4 CASE COMPANIES & INTERVIEWS

In this chapter, the interviews that were conducted with the two case companies are discussed and described. Firstly, the two case companies, and the employees that were interviewed, are presented. Secondly, the conduction of the interviews is described.

4.1 Selection of Case Companies

The case companies were selected according to the criteria presented in *Section 2.4.1 - Selection Criteria of Case Companies*. The two case companies in the study are customers of Elastic Move, henceforth called Company A and B due to anonymity requests. Their headquarter location, number of employees, turnover, industry sector and number of production sites are shown in Table 1.

Company A is a large-scale Swedish producer in the food and beverage industry, with a turnover of roughly €80 million and an employee count ranging from 180 full-time employees (FTE) during low season, to 240 FTEs during high season, in 2022. Because of the number of employees during high seasons and the turnover, Company A is treated as a large-scale enterprise in this thesis. The company produces beverages targeted to consumers, but sales are mainly centered on distributors. The production chain is to a large extent standardized, with a relatively small product mix comprising roughly 125 products, such as apple juices and ciders. Most of the activities in the production chain are conducted through the usage of machines with human operators, however, a number of activities, are done manually. The production is conducted on one site, but the company also operates an office space and a warehouse in two other locations.

Company B is a global producer of customized metal parts and products used in manufacturing environments headquartered in the United States. In 2022 they had a turnover of approximately € 470 million. The company has over 2000 FTEs across five continents, operating 12 production sites in ten countries. Their portfolio consists of over 50 000 different products available for purchase. These range from small-scale products such as machine cogs to large carbide rods. The material they use for their production is advanced, and the products they produce are complex and specialized. The sales of Company B are focused on B2B, and they work in close connection with their customers to deliver products according to their particular needs and specifications.

Table 1. Anonymized overview of companies

Company:	A	B
Sector	*Food & Beverages*	*Industrial Parts*
Headquarter	*Sweden*	*USA*
Number of employees (In FTEs)	*180-240*	*+2000*
Turnover, 2022	*€80 million*	*€470 million*
Production sites	*1*	*12*

In Table 2, the list of interviewees at each company is presented in an anonymized form. The interviewees were chosen due to their role within the companies where they have knowledge of the IT solutions within the company or of the production processes. Furthermore, as seen in Table 1, the size of the two case companies varies a lot; therefore, it was deemed necessary to conduct three interviews with Company B due to the size difference to Company A.

Table 2. Anonymized overview of interviewees

Interviewee	Role	Company	Company Sector
A1	*IT Manager*	*A*	*Food & Beverages*
A2	*Production Manager*	*A*	*Food & Beverages*
B1	*Global IT Operations Manager*	*B*	*Industrial Parts*
B2	*IT Manager*	*B*	*Industrial Parts*
B3	*Technical Manager*	*B*	*Industrial Parts*

At Company A, interviewee A1 is the IT manager, responsible for the IT department, which consists of four additional employees. As the IT manager, the interviewee is responsible for the entire IT infrastructure development, software, and hardware. The IT department works closely together with the technology department, which operates and maintains the machines in the production facility. The second interviewee, A2, is the production manager responsible for the largest production process at the company. The interviewee leads approximately 35 operators in the factory whose primary activities consist of mixing, bottling, and packing the products.

At Company B, interviewee B1 is the Global IT Operations Manager and responsible for the operations of all IT departments across all facilities. Interviewee B2 is the IT Manager of two of the company's production sites in Europe. The interviewee is also the first point of contact for all the company's IT solutions at the two production sites and is involved in the company's IIoT project. Interviewee B3 is the Technical Manager at one of the production facilities in Europe. Interviewee B3 leads a team of seven employees who develop new solutions for two of the company's product categories. The team also conducts process improvements and troubleshooting in the facility's production processes.

4.2 Conduction of Interviews

The theory chapter provides a significant knowledge base for the interviews. When forming the interview questions, the main areas to cover were related to the CMfg technologies. The benefits and challenges for the CMfg technologies from the theory chapter are summarized in Table 3.

The questions and structure of the interviews can be found in Appendix A. In general, the interviews had the following structure: Firstly, the companies are asked to describe their production process and business model, and what their motivations are for implementing new technologies. This provides context to the decisions they make regarding what CMfg applications they implement. Additionally, the diffusion of innovation model is used to categorize the companies by the type of adopter they are based on their motivations for implementing new innovations.

Furthermore, the implemented CMfg solutions at the companies were discussed. When the implemented solutions had been detailed questions were asked to understand the motive to implement them and what effects they experienced or expected to get. These questions were based on the benefits observed in theory, seen in Table 3. Lastly, the interviewees were asked about the outlook for the coming years, which technologies they plan or want to implement, and why they have not implemented them yet. These questions were based on the barriers observed in theory, seen in Table 3. In the following chapter, the insights gained from these interviews are used to connect the potential benefits observed in theory with the experiences and opinions of the interviewed companies. Additionally, the reasons for not implementing CMfg applications provides a basis to discuss the barriers to adoption. This discussion is based on the five drivers of adoption from the diffusion of innovation model.

Table 3. Opportunities and challenges of CMfg (Sisinni et al., 2018; Kavis, 2014; Faynberg et al., 2016).

Technology		**Benefits**	**Barriers**
Cloud Computing		- Elasticity - Cost savings - Accessibility	- Security concerns - Complex to integrate
IIoT	Environment Mapping	- Visibility of operations - Simulation of processes	- Lack of infrastructure - Difficult to assess economic benefits - Workers' digital capabilities - Value chain integration - Cyber-security challenges - Investment requirements - Difficult to manage data quality - Standards and norms - Resistance to change - Real-time performance
	Process Optimization	- Intuitive interfaces - Real-time KPIs - Resource utilization	
	Planning Optimization	- Improved schedule communication - Dynamic scheduling - Predictive maintenance	
	Process Automation	- Reduce decision-making of workers	

5 ANALYSIS

This chapter covers the analysis of cloud manufacturing, which is based on the theories and models described in *Chapter 3 - Theory* and the qualitative primary data gathered through the interviews. First, the motivation to adopt new technologies at the case companies is analyzed and characterized through the Diffusion of Innovations model. Secondly, each application type of cloud manufacturing is analyzed using the input from the interviews.

5.1 Characterizing the companies as adopters

5.1.1 Company A

Company A made clear in the interviews that they have several motives behind new IT implementations. The most important motivation for an investment is the potential time- and cost-saving benefits that can be leveraged from a solution. For example, automating the process of mixing the ingredients for their beverages could lead to shorter production times and increased production output.

In the last six years, the company has almost quadrupled in terms of revenue and staff. This growth resulted in many investments to fix problems, which resulted in solutions not being satisfactory. Furthermore, many of the solutions were new, making the company among the first to implement these solutions. Their negative experiences have made them less willing to adopt innovations until other, more risk-prone companies have implemented them. Now that growth has stagnated, the focus has shifted to long-term solutions compatible with current IT systems and long-term goals. The shift in focus has made customized, rather than turnkey solutions, an important consideration for future implementations.

Company A could, therefore, be seen as having moved backward on the diffusion of innovations curve from being an early adopter to being part of the early majority, see Figure 10.

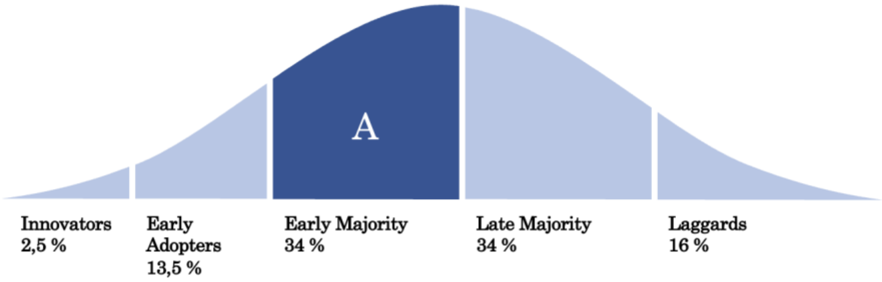

Figure 10. Company A's placement in the diffusion of innovation curve.

5.1.2 Company B

In the interviews, Company B explained that the most important aspects to invest in new technologies are the cost and revenue benefits to be leveraged. The financial focus behind investments has increased since the company was acquired by a large investment company in 2018. Since then, to implement an innovation, it must provide clear advantages that, directly or indirectly, result in financial benefits. One example of an indirect financial benefit is sustainability. If an innovation leads to lower emissions, the production results in a smaller environmental footprint which is important to certain customers and may help them secure additional contracts, and, consequently, increase revenue.

Company B is a large organization with production sites in many different countries. Therefore, it is often difficult for them to adopt new innovations across their organization as a whole. However, one of their production facilities in Europe is used as a testing site for new technologies and innovations. At this location, Company B runs proof-of-concept tests on many new solutions for their production. This makes them early adopters in comparison with the rest of their industry. Based on their willingness to explore new technologies in this factory, Company B is identified as an early adopter, bordering on the early majority in the diffusion of innovation curve, see Figure 11.

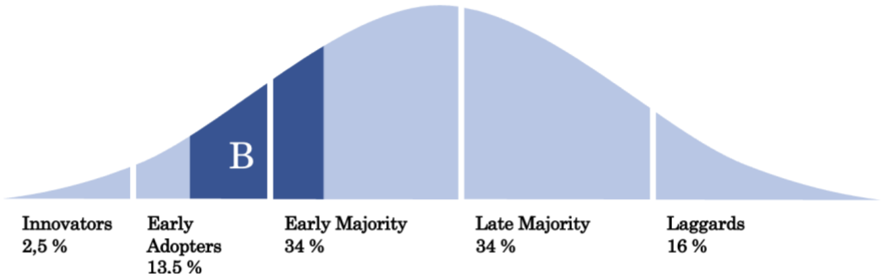

Figure 11. Company B's placement in the diffusion of innovation curve.

5.2 Analyzing the five applications of CMfg

In this section, the five application areas of CMfg namely cloud computing, environment mapping, process optimization, planning optimization, and process automation are analyzed through the theoretical models with qualitative data from interviews and literature. This analysis is meant to provide insights into the impact, benefits, and adoptability of CMfg that have been observed from the companies interviewed in this thesis.

5.2.1 Cloud Computing

There are several ways to use cloud computing. In *Chapter 3 - Theory*, the most common ways were briefly presented. Firstly, the service model is chosen, where the most common are IaaS, SaaS, and PaaS. The different service models provide varying levels of control of the applications between the CSP and the customer. Secondly, a deployment model is chosen. There are four typical cloud deployment models: public, private, hybrid, and community. The benefits and drawbacks of cloud computing vary depending on the choice of deployment and service models. One major trade-off companies make when implementing cloud computing is security versus accessibility and costs. The trade-off is mainly connected to the choice of deployment model. In the following sections, the different aspects of the trade-off are discussed in more detail.

Implementation

When a cloud migration is conducted, this may pose difficulties in the implementation process itself. The workforce within an organization must have the necessary skills and technological competence to deal with the migration to ensure an implementation process with minimal interruptions to the organization. Without the necessary technological and organizational readiness, the benefits of cloud computing are likely to be lower than possible (Oliveira et al., 2014). From the interviews with Company A, it became clear that compatibility has been an issue throughout the implementation process due to several reasons. Network infrastructure, such as internet connectivity, has resulted in higher latency with the cloud compared to the previous on-prem solution. Legacy systems have not been able to be moved to the cloud due to a lack of compatibility between legacy software and the cloud platform. Additionally, the lack of in-house competence has resulted in high consultant costs to implement the solutions. Company B, on the other hand, had a smooth transition as they had previously upgraded their network infrastructure which could handle the transition to the cloud. This allowed them to easily migrate their systems to the private cloud and rapidly scale when the Covid-19-pandemic hit. This indicates that companies with established infrastructure are likely to find the transition phase easier to manage.

The CSP is responsible for most activities after implementing the cloud, especially with the SaaS service model. Since both case companies primarily utilize SaaS, it is easier for them to implement additional services to the existing cloud platform. Company B has been able to add new services to a small number of employees to trial the services before implementing them company-wide. With the pay-as-you-go model and the rapid elasticity of the cloud, the services can be trialed inexpensively and deployed rapidly because companies do not have to procure and install resources to handle the additional services. Additionally, because of the solutions and services provided by CSPs, companies can focus on their primary business areas instead of developing and maintaining in-house systems (Villareal & Lee, 2020; Faynberg et al., 2016). This has allowed Company B to implement new solutions, which were previously not possible due to a lack of in-house IT development capabilities. However, the shift of responsibility to the CSP does not always improve processes. Company A has experienced slower service times when problems occur with its cloud systems compared to the previous on-prem system. With the on-prem system, IT technicians could respond within fifteen minutes and were able to quickly service the systems because of their knowledge of the system. With the cloud-based system, the response time is increased to sometimes several hours to fix issues because the support is outsourced to the CSP.

While the SaaS service model provides solutions that are easy to implement in companies' cloud platforms, Company A expresses concern regarding the customizability of the solutions. Company A wishes to move toward IaaS solutions to develop tailor-made systems, which are compatible with its legacy systems to move the legacy systems to the cloud. However, moving to IaaS increases the need for in-house IT capabilities as more responsibility and control is placed on the company rather than the CSP.

Accessibility and Security

Accessibility is an important aspect to operations within an organization. Especially strategic production planning relies on access to the correct and relevant data to effectively plan production according to needs and demands. Large amounts of data and software applications typically generate difficulties with respect to consolidation and access. It requires IT administrators within the organization to implement applications that can consolidate data, ensure that the software applications follow internal policies, and that proper approval is given before employees can access the dataset. Furthermore, certain data and applications might only be accessible at the company's local network. With cloud computing, large datasets and software applications can be consolidated in a cloud platform to increase accessibility. Employees can easily access the necessary information and tools stored in one digital location, which also enables remote work through the internet (Iyer & Henderson, 2010). However, the accessibility of data is subject to a company's chosen deployment model. Data and applications stored on a private cloud require additional authorization layers, such as VPNs and approvals from IT administrators to access certain systems, to increase the protection of the company's intellectual property.

Accessibility is also highly relevant to the case companies. Company A's IT systems operate on a hybrid cloud where parts of the system are hosted on the public cloud while others are still on-prem. Due to the difficulty of moving certain legacy software to the cloud, Company A has kept this software on-prem. The systems hosted on the public cloud have enabled them to access data and communicate better between departments. Previously, when making production orders, four paper copies needed to be printed and delivered to different departments. With the cloud solutions today, production orders are available online and can be changed instantly. However, the hybrid solution poses accessibility and communication issues because systems on the cloud and the legacy systems on prem have been difficult to consolidate. Company A's goal is to move almost all its IT systems to the cloud to increase access and communication between systems and within the organization even further.

Company B opted for a private cloud model, which increased the accessibility to their IT systems compared to the previous on-prem solution. When the Covid-19 pandemic began, Company B had already moved its systems to the cloud. The cloud allowed IT administrators to easily provide access to applications and data to employees through VPNs, which eased the transition from working at the office to working from home. However, as Company B hosts their systems on the private cloud, there are certain accessibility issues. According to the interviewees, the main problem with the private model is the difficulty of granting access to hired consultants who use their own equipment such as laptops. Additionally, some systems are not accessible outside the company's premises which limits the possibility of working from home. The reduced accessibility is due to the choice of a private cloud model, as security concerns posed by using a public model outweighed the accessibility benefits.

Security is one of the most prevalent concerns cloud customers have. However, although cloud solutions contain security flaws, they typically stem from a poor implementation due to a lack of knowledge and expertise on the customer's end (Faynberg et al., 2016; Paxton, 2016; Kavis, 2014). With cloud computing, the CSPs provide security mechanisms and are responsible for upgrades and updates. If these are properly implemented by the cloud customer, cloud computing can be more secure than on-prem systems (Kavis, 2014). Both case companies highlight security as a major concern, and for Company B, it is their primary concern. Although the case companies could not provide any specific examples, both had knowledge of competitors who have experienced security breaches. Even though the cloud can be, in theory, as secure or more secure than on-prem if properly implemented, the experiences of the case companies show that this aspect remains an important strategic issue to both companies. Trade-offs need to be made whether to prioritize accessibility or security by choosing the private or public model. This choice ultimately affects the relative advantage of the cloud compared to on-prem.

Costs

One major relative advantage of cloud computing compared to on-prem is cost reduction. By moving from typically under-utilized computing resources on-prem to the virtualized environment offered by the cloud, companies only pay for the resource they need with a pay-as-you-go model. The pay-as-you-go model reduces Capital Expenditure (CapEx), as investments into hardware are no longer needed, and Operational Expenditure (OpEx), as the operation and maintenance of the resources are handled by the CSP (Faynberg et al., 2016). Due to decreased needs for hardware, CapEx in cloud computing is 80 percent lower compared to the total cost of ownership of similar on-prem resources (Faynberg et al., 2016). Furthermore, OpEx is reduced significantly as certain responsibilities are shifted to the CSP, including maintenance which typically accounts for two-thirds of an IT budget (Faynberg et al., 2016). However, the OpEx-savings of the cloud depend on a variety of factors, such as the choice of deployment model.

The cost benefits of private clouds are lower than public clouds as the pooling of resources is less efficient due to the single-tenant nature of private clouds (Kavis, 2014). Additionally, if a company already has an on-prem solution, CapEx has already been invested. Therefore, the company might be less incentivized to implement a cloud solution. If, however, the company’s computing resources require upgrades, need to be expanded, or can be resold, moving to the cloud from on-prem would be more attractive. Therefore, cloud computing is more attractive to companies such as start-ups lacking the necessary resources in-house or companies needing to replace current resources.

Although decreased CapEx in computing hardware, such as servers, is observed by both companies, Company A could not observe total expected cost savings in CapEx and OpEx. The reason is that due to a lack of in-house knowledge, the implementation and maintenance of the cloud platform at Company A has been outsourced to IT consultancies which are costlier than in-house personnel. Additionally, when the ERP system transitioned from single- to multi-tenant, several issues arose, such as increased response times to software applications and legacy software suddenly becoming non-functioning, which required additional consulting hours. The lack of in-house expertise regarding the cloud has resulted in OpEx remaining almost the same. Although, part of the cost may be attributed to the IT department, which service and maintain IT systems that are still hosted on-prem.

Summary

To Summarize, cloud computing’s effectiveness depends on the chosen deployment and service models, and a company's IT capabilities. Cloud computing enhances accessibility, communication, and data-sharing, impacting strategic, operational, and tactical levels within an organization. However, security risks arise from insufficient knowledge. Actual cost benefits vary according to different infrastructures and cloud models chosen by companies. Private clouds offer higher security, but limited access and fewer cost benefits compared to public clouds. Furthermore, the benefits are more prominent in companies with strong digital infrastructure and internal cloud implementation capabilities. Trialability depends on service models and existing cloud implementation. Moving from on-prem to the cloud can be costly, but once integrated, new services can be trialed incrementally. Compatibility issues may arise with legacy software, necessitating on-prem systems alongside the cloud.

5.2.2 Environment Mapping

Environment mapping refers to the use of IIoT technologies, such as sensors, to connect machines and processes within a production environment.

Data Accessibility

The implementation of sensors can enable companies to standardize the data points where they collect data in their production, automate the collection process and thereby increase the amount of data gathered.

The utilization of connected sensors can provide greater access to data for daily operations. By implementing sensors on the shop floor, companies can access machine data in real-time. This data can be uploaded automatically to the factory's IT systems, giving easier and faster access to relevant information about the production. Both Companies A and B have identified difficulties with collecting and compiling their daily production data, and hope to improve this through the implementation of sensors. Their production machines lack the ability to communicate with other devices, therefore, they must manually download and compile their data to access it. For Company B, this has caused difficulties in their production. They currently measure cycle times and stoppages of their machines manually. They have target rates for these KPIs, and if they observe that a machine is performing below target, they attempt to take corrective action. Their current process to collect this data is only done weekly since it is time-consuming to download the data manually. Consequently, when they identify any issues and take corrective actions, this action is often delayed. If the company connects their machines to the network this process can be automated, and the relevant data points can be viewed and analyzed in real-time. This would allow them to identify issues affecting their KPIs faster, and as a result, take corrective action earlier. However, Company B has identified compatibility difficulties with this implementation. Because their production sites have a significant amount of legacy machines that are difficult to equip with sensors. Therefore, the company needs to invest in upgrading their machines or find sensor solutions that are compatible with the legacy machines before they can fully implement sensors in their production.

Company A has experienced similar problems but has also identified further compatibility issues. IIoT suppliers offer turnkey solutions in which the company does not only buy the sensors but also must use the software systems provided by the supplier. These software systems are generally time-consuming to integrate into a joint platform. Therefore, if a company uses multiple suppliers for IIoT solutions, the company will have to integrate each supplier's system if they wish to consolidate the data in one location. This has stopped Company A from investing in sensors to map their environment and is one of the reasons why they wish to implement IaaS, as discussed previously in *Section 5.2.1 - Cloud Computing*. With IaaS, they can develop their own systems to gather the data from sensors of different suppliers and are not reliant on one IIoT supplier.

A problem Company B has experienced is that their factories are unable to effectively communicate with each other. The company is a large organization with production facilities in several countries across continents. These factories have IT solutions tailormade for each site, instead of having a uniform system that is standard for all of them. The data that is measured and collected varies from each factory and is, therefore, only applicable to the site from which it was obtained. For example, one site is using a system to measure the amount of scrap by weight while a different factory measures it by volume. This makes it difficult for the company to compare performance between their factories. The company wants to implement sensors that measure standardized data points across all factories to allow fair comparison of different processes between sites. This will provide benefits when introducing a new machine in a European factory because they are able to compare the benefits to a machine in a factory in North America. Based on this comparison, they can decide whether to introduce the new machine in the North American factory as well. If the company is also using a cloud platform, this data can easily be communicated and accessed throughout the organization as it is no longer tied to the on-prem IT systems of the different factories. However, Company B has also observed some barriers to the implementation of this application. The company needs to integrate all factories under the same measurement system and must synchronize what they measure across the entire organization. This means purchasing new sensors for all locations. They have observed that this is a difficult process which requires a substantial investment in terms of both time and money.

Increased Data

Sensors can also be used to collect data that companies previously have not been able to measure. Company B has identified that this could benefit their resource usage in their manufacturing process. Their processes use different fuels such as gas, electricity, and compressed air to operate. As a result of rising energy prices, they have noticed that this usage needs to be monitored closely for them to be able to find opportunities to lower them. Their current systems do not have any solutions to measure the usage. The only time they can determine the usage is when they receive a bill for their usage across an entire factory. If they notice that the usage is fluctuating, it is, therefore, difficult to identify if a certain machine or process is the culprit of the increase. They want to implement sensors to better understand the individual usage of fuel from a machine or process. By mapping the usage, they could identify which areas of the production process typically consume more energy and, thus, be able to take preventive measures. Additionally, they will be able to observe this data in real-time. Thus, if there are fluctuations created from a small leak in a specific machine, they could take immediate action to correct such a problem. The implementation barriers to these sensors are the same as previously discussed, namely that companies do not want to rely on one supplier but want to be able to integrate multiple systems.

Summary

As seen in *Section 3.1.2 - Base Technologies*, the adoption rate of IIoT is 48 percent, which indicates that this application is relatively established in the industry. According to the diffusion of innovation curve, the adopters of this application should, thus, be classified as early adopters or early majority. Both companies have begun implementing this application to some extent and have found use cases to develop it further. However, they still have not fully adopted the application. This reflects that the identified barriers such as, compatibility with infrastructure and the difficulties of using multiple suppliers are significant barriers for the implementation of environment mapping.

To summarize, the application of using the IIoT for environment mapping can help companies to track issues in their production processes faster and more accurately. It further helps to compare processes between machines or factories. The advantages impact all levels of an organization's production hierarchy. The benefits are easily observable as actions can be taken directly when they arise instead of waiting on weekly or monthly reports. However, while the usage of IIoT technologies for environment mapping is not dependent on the usage of the cloud, synergies have been identified because a cloud platform can consolidate the information gathered by the sensors. The information can then easily be accessed across the organization, which further enables companies to analyze it. Thus, cloud computing is an enabler that can improve the adoption of environment mapping.

5.2.3 Process Optimization

Process optimization is an application of the IIoT that focuses on improving the processes and activities within an organization. The main benefits observed in the interviews with the companies are process efficiency and resource utilization.

Process Efficiency

One application of the IIoT that can improve efficiency is the utilization of increased data streams to build simulation models or digital twins. Such models can be built with more detail when more machines are connected to the network since more data streams result in a better depiction of the real environment. By utilizing simulations, possible disturbances can be modeled to determine the impact they can have on daily operations. However, both companies showed no interest in using simulations for this purpose. Instead, they want to utilize simulations to improve their organizations on a strategic level. Company B uses simulations to model the production process when developing new products. This has allowed them to reduce possible disturbances that new products may cause in the production environment, such as increased waiting times in the production line. These simulations are conducted on a weekly basis and require a substantial amount of bandwidth. Previously simulations were run on prem at their factories, but now they run them on their cloud platform. This has resulted in cost benefits since they only pay for the bandwidth when they use it, instead of having servers often having a low utilization.

Resource Utilization

Simulations can be utilized to improve energy and material usage in production processes. While Company A does not currently use simulations of their manufacturing environment, they are interested in utilizing them to identify issues in their production processes. The company has observed an issue regarding the material and energy utilization of its processes. When they produce beverages, their machines take in water and heat it to a certain temperature. The company believes they use more water than is necessary to manufacture the product, and that the temperature they use is higher than required. They want to run simulations on this process, changing the temperature and amount of water used, to determine the effects this has on the final product. The results from these simulations could then be used to improve the overall energy and resource usage in their production process.

While simulations can be an effective tool to improve efficiency and resource utilization, they can also be difficult to implement, both in terms of compatibility and complexity. The compatibility of process optimization is correlated to the capability of a company's data management. A simulation model will only provide valuable insights if it is built on data that is representative of the actual environment it is simulating. Therefore, to effectively utilize this application, a company needs to access and properly manage its data. If a company has poor protocols for data collection and storage, the utilization of process optimization will be less advantageous. Furthermore, the gathering and organizing of necessary data may be difficult and time-consuming. Thus, it will likely require a substantial commitment to test this application. Additionally, the complexity of using simulations is dependent on the complexity of a company’s production process. If a company’s production process is dependent on many factors, then a simulation will require a larger amount of data points to represent it accurately.

A cloud platform can provide benefits to process optimization, especially for complex production systems with large data quantities. Cloud computing can improve data collection from sensors by increasing the accessibility to data. Additionally, it can provide computing resources to run the simulation on.

Summary

To summarize, the advantages of using process optimization have an impact on all levels of a company’s production hierarchy. Both companies have adopted this application to some degree and have shown interest in adopting it further. However, while simulations could be made to improve both day-to-day activities and to improve processes with a strategic perspective, the companies interviewed only saw a strategic value. This could indicate that the complexity and compatibility of building simulations are too difficult to utilize on a daily basis. Thus, if companies want to utilize the full value of simulations, they will need to improve their infrastructure and management of production data.

5.2.4 Planning Optimization

Planning optimization is an application of the IIoT that focuses on improving the scheduling of activities, workers, and maintenance. The main observed benefits are improved planning of workers and activities, and predictive maintenance.

Improved Planning of Workers and Activities

Scheduling optimization refers to the optimization of worker and activity schedules and can provide a strategic and tactical impact on an organization's production. The data provided by the connected sensors of IIoT can be utilized through scheduling software to improve monthly and yearly production plans. Neither Company A nor B has seen a substantial need for optimized scheduling of activities and workers. Company A describes a potential use case to optimize the production line by being able to determine what product should be mixed before and after another. However, the interviewees claim that such optimizations are further in the future. Company B mentions challenges, such as a lack of adequate skills in the workforce and data management issues as the main barriers to implementing process optimization, but they could not specify that any further.

The reluctance and disinterest shown by the case companies indicate that such planning systems may be too complicated, costly, or not beneficial enough for companies to utilize them. This could be attributed to a lack of relative advantage over current systems, difficulty to trial, low compatibility, and high complexity of the system. An organization would have to adopt an entirely new planning system based on inputs from the IIoT, which is time-consuming and results in high investment costs, instead of continuing with the current system that fulfills their requirements. Furthermore, the economic advantages would be difficult to discern since any efficiencies gained by an optimized schedule would only be visible in the efficiency of a factory over a longer time.

Predictive Maintenance

The second usage of planning optimization is predictive maintenance. This refers to using sensors in machines to detect when it will require maintenance. The utilization of predictive maintenance impacts the strategic level of a production system. By utilizing operational data, companies can forecast machine failures. This allows them to schedule maintenance of machines in optimal time windows to minimize the impact on production-Company B is interested in utilizing predictive maintenance because their current system does not take machine conditions into account when conducting maintenance. Instead, repairs are done based on the time since the last repair. This has resulted in machines breaking down and requiring maintenance unexpectedly, resulting in bottlenecks in production and high costs. Additionally, the current maintenance system results in machines going through maintenance earlier than necessary. The company wants to implement sensors that measure multiple aspects, such as vibrations and run time of the machines, and build data models to predict when a machine actually requires maintenance. This would enable them to avoid unnecessary machine inspections and unexpected breakdowns. However, Company B has identified some barriers for them to implement this application. The complexity of predictive maintenance is considered the largest barrier for them. The lack of expertise in their workforce to develop prediction models and data management challenges within their organization makes predictive maintenance one of the most difficult applications to implement. When a prediction model is built, and data management issues are solved, the prediction might still not be accurate due to incorrect assumptions in the model or overlooked factors that affect the machines' condition. Therefore, the prediction model might have to be tweaked several times to account for those shortcomings and might still not be completely accurate due to unexpected events.

Predictive maintenance can also be used to improve the procurement of spare parts for machines. Determining when machines will require maintenance allows companies to better determine the number of necessary parts they need to procure. Consequently, this can allow companies to keep fewer spare parts. Company A's current procurement system does not have any method to account for how many spare parts are needed at their factory. They order spare parts and keep them on hand, but they experience problems with both shortages, and overstocking. By implementing predictive maintenance Company A will be able to synchronize their procurement process with their maintenance needs. This will benefit them by reducing unnecessary inventory costs and improving their maintenance process by always having the necessary spare parts in storage.

Summary

To summarize, the usage of IIoT to improve the scheduling of workers and activities can impact a company's strategic and tactical planning. However, it does not provide clear enough advantages for the industry to contemplate an implementation. For predictive maintenance, both companies have identified a potential value, but neither has implemented it yet. Figure 6 shows that the adoption rate of the IIoT for the maintenance of machines is 21 percent. According to the diffusion of innovation curve, the first 21 percent of adopters are categorized as being part of the early adopters. Since Company A is categorized as part of the early majority, it is, therefore, reasonable that they have only shown an interest but have not adopted it yet. However, company B has not adopted predictive maintenance, while being categorized as an early adopter. This could be attributed to the complexity of their production process. The products they manufacture are often modified according to their customers' requirements, and, thus, their production process needs to be flexible to handle these modifications. The conclusion is that predictive maintenance is more attractive to companies that have a more standardized manufacturing environment.

5.2.5 Process Automation

Process automation refers to implementing the IIoT technologies to automate manual tasks performed by operators in the production machines.

Automated machines

The practice of utilizing automated machines to conduct tasks that human workers previously performed can provide several advantages to an organization. Human operators can be expected to make mistakes during the production process, which need to be accounted for when determining their production capacity. By utilizing PLCs to automate operator tasks it is easier to determine the factory's capacity on a yearly and monthly basis, providing both strategic and tactical value. However, none of the companies interviewed identified the value of automated machines as strategic or tactical, instead, they saw it as operational. The value they see in automated machines is the potential to increase efficiency, and not to improve planning. Company A’s production is largely standardized with a relatively small production mix which enables automation of many processes within the production. One of these processes is the mixing of beverages in their production. These products have a set recipe, and the machines that mix the ingredients are operated manually by workers in the factory. By utilizing a cloud platform and a connected machine they could make this process fully automated. The machine could access the recipes from a cloud platform and perform the process without human involvement. Company A expects the automation of this process to improve efficiency. However, the company has also identified barriers for implementing. The operators who currently work in their production see automated machines as a replacement for human operators and are, therefore, resistant to them, which can impede the implementation. Furthermore, they have previously experienced problems with latency from using their cloud platform. If an automated machine experiences such delays, it will counteract the efficiency gains they expect from this implementation.

Company B is in the proof-of-concept stage for implementing automated cutting machines within its production process. The machine is an intelligent rotary cutting solution that can measure and monitor parameters that influence cutting performance. For example, their products are made of different materials that require different pressure when cutting, this machine adjusts this pressure automatically based on the material it is cutting. The machine utilizes PLCs to operate independently and allows an operator to monitor its performance. Additionally, it can alert the operator when issues occur while operating. Consequently, this enables a single operator to oversee multiple machines on the production floor instead of a single one while only taking action when disturbances occur. In contrast to Company A, this machine does not replace standardized tasks but is able to modify the cutting process according to specifications, such as cutting pressure. This machine makes these adjustments more efficiently than a human operator can. Thus, the usage of automated machines provides higher efficiency for individual workers, who are now able to oversee more machines, and the production process itself. However, the automated machine is not integrated into existing systems. Instead, it replaces the entire cutting machine previously used. This shows that automated machines can be difficult to trial before implementation, which can be a barrier to implementation. While the

Company has observed advantages with this proof-of-concept, it has required a substantial investment in costs and time.

Summary

To summarize, while automated machines can provide strategic value to organizations, the interviews revealed that the companies only see operational value. These benefits may be more observable for the companies as they have a direct comparison to their previous system of using human operators. However, as seen in Figure 6, the adoption rate of IIoT for automating processes is only 18 percent for the industry as a whole. Based on the diffusion of innovation curve, it would mean adopters of this application should be categorized as early adopters. Company B has begun a proof-of-concept test for this technology, while Company A has only identified an interest in it. This accurately fits the groups they have been characterized as. The results indicate that no specific type of manufacturing industry is more inclined to adopt process automation through IIoT. It is a relevant application for all manufacturing industries, no matter if a company has a wide and highly customizable product mix or a small standardized product mix. However, the adoption rate for the industry is relatively low. This reflects that the identified barriers of the application—resistance to change, real-time performance, and high investment requirements are generally difficult to overcome for companies.

6 CONCLUSION

To conclude the thesis project, a brief summary of the project is presented, a critical discussion of the findings is conducted, the knowledge contribution of the thesis project is presented, and future research subjects are proposed.

6.1 Summary

The purpose of this thesis project is to determine the value of cloud manufacturing and assess the implementation motives and barriers to large-scale manufacturing organizations. By contextualizing current research through the experiences and perspectives of the case companies, the thesis project contributes knowledge by providing insights into the value, motives, and barriers of cloud manufacturing in large-scale manufacturing organizations. It underscores the tradeoffs between accessibility and security in cloud computing, and the potential benefits of the IIoT applications in areas such as environment mapping, process optimization, planning optimization, and process automation. Additionally, it sheds light on the complexities and challenges hindering the adoption of these applications, emphasizing the need for addressing barriers to enable their wider implementation across the manufacturing industry. To summarize the findings of *Chapter 5 - Analysis*, Figure 12 shows the benefits identified with each CMfg application and are shaded in a darker blue with an "X".

	Cloud Computing	IIoT			
		Environment Mapping	Process Optimization	Planning Optimization	Process Automation
Costs	X	-	X	X	-
Accessibility	X	X	-	-	-
Efficiency	-	X	X	X	X
Utilization	-	X	X	-	-

Figure 12. Overview of benefits of each application area of CMfg

Firstly, the implementation of cloud computing decreases both CapEx and OpEx. However, the savings are dependent on deployment models, service models, and the company's IT capabilities. Cloud computing enables greater access to data for companies on a strategic, tactical, and operational level, through a single platform from which data can be accessed. Environment mapping increases the accessibility to data further by standardizing which data is measured, automating the process of collecting it, and increasing the number of processes that are measured.

CMfg further increases both efficiency and resource utilization. Environment mapping enables companies to discover inefficiencies, and simulations provide solutions that can improve processes. Furthermore, these two applications also improve resource usage in production processes. Sensors can detect if certain machines are consuming excessive amounts, and simulations can optimize the number of resources that is necessary. Predictive maintenance, a sub-technology to planning optimization, improves the scheduling of maintenance and decreases disturbances that occur from unexpected machine failures and can further decrease OpEx through decreased warehousing costs. Automation further reduces disturbances and improves the efficiency of both machines and operators.

Although cloud computing and the IIoT are separate technologies and not dependent on each other, synergies have been identified from integrating the two technologies. One example of this is that a cloud platform enables companies to have better access to their data, and the usage of the IIoT, through sensors, enables companies to standardize what data is measured, thus, increasing their ability to compare data between different factories.

Even though CMfg has plenty of benefits, this thesis identified barriers that hinder companies from implementing and utilizing CMfg in *Chapter 5 - Analysis*, which are summarized in Figure 13. The darker blue squares with an "X" inside represent what type of barrier have been identified for each respective application.

	Cloud Computing	IIoT			
		Environment Mapping	Process Optimization	Planning Optimization	Process Automation
Network Infrastructure	X	X	X	X	X
Uncertainty of Economic Benefits	-	-	-	X	-
Adequate Skills	X	X	-	X	-
Value-Chain Integration	-	-	-	X	-
Security	X	-	-	-	-
Data Management	-	X	X	X	-
Investment Requirements	-	X	X	X	X
Performance	X	-	X	-	X
Resistance to Change	-	-	-	X	X

Figure 13. Barriers to adoption of CMfg technologies.

The key barriers that are identified from the analysis are network infrastructure, adequate skills, data management, investment requirements, and performance. The barrier that affects most applications of CMfg is network infrastructure. Without the proper facilities and resources, it is difficult to implement and utilize any of the applications. Additionally, investment requirements are identified as barriers for three of the IIoT applications. The cost in terms of both time and money will need to be reduced in order for these applications to be adopted. The real-time performance of implemented solutions is also a barrier to multiple applications. It is observed that latency issues have been a factor that has decreased the willingness to adopt CMfg. Such technical problems will need to be solved to increase the adoption of CMfg.

Furthermore, it is difficult to adopt CMfg if companies do not have the necessary skills. Without adequate skills, companies are unable to fully utilize CMfg, resulting in either decreased advantages or increased costs from hiring outside experts. Additionally, the management of data within an organization is a barrier for all IIoT applications. For example, sensors provide valuable data that can be used to improve an organization, but without the proper systems to manage this data, it is difficult to take advantage of it. However, cloud computing can reduce both of these barriers. If a company is utilizing a cloud platform, they can utilize the knowledge and capability of the provider of this platform to implement systems, without having the necessary skills themselves. The platform is also a resource that improves the handling of data by gathering it on a joint platform, where the data from the IIoT solutions is easier to manage.

To decrease the barriers for CMfg, and take advantage of the benefits, organizational readiness is one of the most important aspects. Many barriers to CMfg are a result of organizations not taking proper steps to ensure that their production is capable of implementing or utilizing CMfg. Companies should make sure that their network infrastructure is capable of supporting the applications, that their employees have the necessary skills to utilize CMfg, and that their systems for managing data are able to take full advantage of the data produced from the IIoT.

To conclude, the findings of the thesis project provide valuable knowledge to primarily three actors: academics, manufacturing companies, and suppliers of cloud computing and the IIoT solutions. To academics, the project combines previous research on CMfg with the experiences of two case companies which provides a real-life perspective on theory. Furthermore, the project highlights important aspects to consider for manufacturing companies, such as the trade-off between security and accessibility, and what impacts the cost benefits of cloud migration. Lastly, the barriers to implementation identified can provide suppliers with important insights into how to package and improve their services to meet demands and secure further success within the field.

6.2 Critical Discussion

The conclusions drawn from this thesis are contextualized with the number of companies interviewed. The industry of large-scale manufacturing firms is very wide and contains a variety of sectors, with companies of different sizes and niches. Therefore, it is likely that not all conclusions drawn from the experience of the case companies reflect the industry as a whole. The experiences of the two interviewed companies may have been affected by many different factors, such as which CSP they use and in-house capabilities.

As the two companies interviewed were customers of Elastic Move, it could have affected their willingness to disclose problems and complications from using CMfg. Although this project aimed to discourage companies from withholding such information, it is important to recognize and acknowledge this fact as a preface to the findings. It would, therefore, have been suitable with more time, to include more case companies, using companies that were not partnered with Elastic Move. Other companies might have had a different experience if they chose another consultancy, or if they performed the implementation in-house, which could affect the benefits those companies have observed and what barriers they have had. Furthermore, as Elastic Move is certified by AWS and implements their solutions, the experiences of the case companies might not be applicable to all cloud services provided by other CSPs. By including more case companies with cloud services provided by different CSPs, the validity of the results could be increased. The companies are also at the beginning of their CMfg journey, especially regarding application areas within the IIoT. By interviewing companies that have implemented many IIoT solutions, the depth of the analysis could be improved by combining their experiences with the case companies' experiences. Additionally, including companies that would traditionally be categorized as laggards, could provide the thesis project with a deeper perspective on the barriers of CMfg to companies more reserved for further technological advancement.

In addition, the claims made in the analysis section of this thesis are supported solely through qualitative data. The decision to only use qualitative data was based on the time constraints of this project and the inability to access any relevant data from the companies interviewed. The inclusion of such data could possibly provide more accurate results of CMfg’s impact, and a better foundation to build conclusions on. Future research could build upon the qualitative data provided in this thesis and contextualize it through quantitative data.

6.3 Future Research

This thesis has only covered a portion of the possible applications of Industry 4.0 in the context of a large-scale manufacturing organization. As discussed in the theory section, the applications of Industry 4.0 technologies can be divided into four areas: smart supply chain, smart manufacturing, smart working, and smart products. The two areas, smart supply chain, and smart products, were not considered in this thesis. The findings of the potential value of cloud manufacturing have only considered applications that directly impact the production process. This value can be expanded on by looking at activities that improve the supply chain, and activities that improve the final product. Future research could build upon the findings of this thesis to create a more complete picture of the potential value that cloud manufacturing can provide in all aspects of an organization's operations.

While cloud manufacturing only covers two of the base technologies of Industry 4.0, there are also more advanced technologies, such as big data and analytics. These are relevant for the potential value that Industry 4.0 can provide a manufacturing organization but were not considered in this thesis. Future research could build upon the thesis’ findings regarding cloud computing and the IIoT to explore the potential of these more advanced technologies.

Due to time constraints and accessibility issues to quantitative data, the thesis project relied solely on qualitative data gathered from the case companies through interviews. Future research could build upon the qualitative findings in this thesis project and combine them with quantitative and qualitative data to gain deeper insights into the value of CMfg and measure its actual effects.

This thesis has only observed CMfg’s impact on large-scale manufacturing organizations. Future research could explore the impact on both small- and medium-scale enterprises (SMEs). Such enterprises will likely have different opportunities and challenges with the usage of CMfg, and thus, future work will likely yield different results. SMEs are likely to have much smaller IT Departments, or possibly no dedicated IT personnel at all, which would increase their dependence on consultancies. Meanwhile, CMfg, especially cloud computing, can open avenues and computing resources previously not available to companies of such scales.

Finally, the thesis project has to a large extent, discussed the technologies of cloud computing and the IIoT separately. However, the thesis project has identified certain areas where synergies between the two technologies are prominent. Future research could further investigate the synergetic effects and explore the ramifications of using one technology without the other.

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APPENDIX

A. Interview guide

Introduction

- Thank the interviewee(s) for taking the time to participate
- Short introduction of us
- Brief introduction of the thesis project's purpose
    - Purpose: *The purpose of this thesis is to assess and define the value that cloud-based IT solutions may offer a large scale manufacturing firm in their digital transformation and understand the motivations for the implementation of these solutions.*
- Mention the approximate length of the interview (X hours)
- Ask for permission to record the interview. Explain that the recording will only be used to transcribe the interview and that the audio file will be deleted once that has been completed.
- Student X will ask the questions and student Y will take notes

The Company

- Can you briefly explain your position and responsibilities at the company?
- Can you give a brief overview of the company?
    - No. of employees?
    - Sector/industry?
    - Approx. turnover?
    - No. of sites/factories?
    - Countries in which the sites/factories are located
- Can you tell us about your manufacturing process?
    - Are there some key aspects that could be improved through digitalization solutions?
    - Have you experienced some clear bottlenecks that could be improved?
- Regarding technical innovation in your industry
    - How would you categorize your company in terms of implementing innovation?

    - Do you wait until an innovation is established in your industry before committing to adopting it?

Your implemented solutions

- What cloud-based solutions have you implemented in your company?
    - Industrial Internet of Things?
    - Cloud computing?
- How would you categorize these solutions in terms of adoption in your industry?
    - Are they established technologies that are widespread or are they new innovations?
- What motivated you to implement these?
    - Direct economic benefit
    - Improving business/administrative processes
    - Improving operational processes
    - Building digital capabilities
    - Other motivations
- How have these impacted your manufacturing process?
    - IIoT:
        - Has digitalization enabled you to understand your processes better?
            - Better overview of what is happening in real-time?
            - Better communication along the production line?
        - Automation of tasks/decisions
            - Are there any parts of the process which have recently been automated?
            - Has this improved your manufacturing process?
        - Production Planning
            - Has there been any implementation that has improved the scheduling and planning of some part of your production process, i.e. work schedule, activity scheduling?

        - Have you been able to decrease the usage of resources within the production process, i.e. fewer work hours, fewer machine hours, less energy or material?
    - Production processes
        - Have you observed any increase in the quality of your product?
        - Has it become easier to use the machines in your process?
        - Have you been able to visualize and understand your production process better?
    - Purchasing
    - Predictability
        - Have you observed any benefits in relation to the maintenance of your machines?
    - Which of the discussed benefits of using the IIoT do you view as the most important?
- Cloud
    - Server cost
        - Have you observed a decrease in server cost?
    - Data access
        - Has the access to data been improved from your cloud migration?
    - Data analytics
        - Are you currently utilizing the cloud to perform analytics of your production process?
        - If so, what benefits has these analytics provided for your processes?
    - Data security
        - Are you using a private, public, or hybrid cloud?
        - What motivated this decision?
    - Flexibility
        - Have you been able to decrease or increase your data usage based on your demands?

            - What benefits have you observed from this flexibility, i.e. faster upscaling, decreased costs, better capabilities for data usage?
        - Which of the discussed benefits of using the cloud do you view as most important?
    - Which areas have seen the biggest impact?
    - Are there, or have there been any significant bottlenecks to the implementation?
- Are there any benefits that you expected from the implementation that you haven't observed yet?

Future implementations

- What is your outlook for the next five years in regard to cloud-based technologies?
    - Are there solutions you are seeking to implement within the next five years?
    - What is motivating these future implementations?
- Are there any restrictions to solutions you want to implement, i.e. are there any technological constraints in cloud computing today which doesn't allow you to implement certain solutions?

Closing remarks

- Is there anything you would like to add?
- Is it ok if we get in touch in case we want to ask an additional question?
- Thank you very much for your participation!

B. Table of Cloud Service Providers' definitions of cloud computing and market share in Q3 2022

Cloud Service Provider	Cloud computing definition	Market share, % (Statista, 2023)
Amazon Web Services	"Cloud computing is the **on-demand delivery** of **IT resources over the Internet** with **pay-as-you-go** pricing. Instead of buying, owning, and maintaining physical data centers and servers, you can access technology services, such as computing power, storage, and databases, on an **as-needed basis** from a cloud provider like Amazon Web Services (AWS)."	34
Microsoft Azure	"Simply put, cloud computing is the **delivery** of **computing services**—including servers, storage, databases, networking, software, analytics, and intelligence—**over the Internet** ("the cloud") to offer faster innovation, flexible resources, and economies of scale. **You typically pay only for cloud services you use**, helping you lower your operating costs, run your infrastructure more efficiently, and scale as your business needs change."	21
IBM Cloud	"Cloud computing is **on-demand access**, **via the internet**, to **computing resources**—applications, servers	3

	(physical servers and virtual servers), data storage, development tools, networking capabilities, and more—hosted at a remote data center managed by a cloud services provider (or CSP). The CSP makes these resources available for a **monthly subscription fee or bills them according to usage**.”	
Google Cloud	“Cloud computing is the **on-demand availability** of **computing resources** as services **over the internet**. It eliminates the need for enterprises to procure, configure, or manage resources themselves, and they **only pay for what they use**.”	11
Alibaba Cloud	“Cloud computing is the **delivery of on-demand computing resources** (including servers, databases, storage, platforms, infrastructure, applications, etc.) **over the Internet**. Cloud computing can be used on a **pay-as-you-go** basis, which means you pay just for what you need.”	5
Oracle Cloud	“In simple terms, cloud computing allows you to rent instead of buy your IT. Rather than investing heavily in databases, software, and hardware, companies opt to access their compute power **via the internet**, or the cloud, and **pay for it as they use it.** These cloud services now include, but are not limited to, servers, storage, databases,	2

	networking, software, analytics, and business intelligence. Cloud computing provides the speed, scalability, and flexibility that enables businesses to develop, innovate, and support business IT solutions.”	
OVHcloud	“In the simplest terms, cloud computing is the practice of **delivering IT services remotely**, hosting them in one or more external datacentres rather than through on-premises dedicated servers. Rather than purchasing and deploying the digital resources they require in-house, organisations can access them remotely via a cloud provider, on a **pay-as-you-go** basis.”	
DigitalOcean	“Cloud computing is the delivery of **computing resources as services**, meaning that the resources are owned and managed by the cloud provider rather than the end user. Cloud computing is enabled through the abstraction of computing resources from the underlying hardware, allowing users access to resources that they do not physically maintain or own. Cloud services can be used to develop and distribute web applications, host computing infrastructure for businesses and organizations, store digital media,	

	provide browser-based software, and process data workloads. These services often give businesses and developers greater capacity to **rapidly scale** computing resources and optimize computing costs in comparison to on-premise hardware and software. However, given the abstracted nature of cloud services, many of their technical details are hidden away from user oversight and control.”	
Linode	“Cloud computing is the delivery of **computing services** – servers, storage, databases, networking, software, analytics, intelligence, and more – **over the Internet** (“the cloud”) to offer faster innovation, flexible resources, and economies of scale. You typically **only pay for the cloud services you use**, helping lower operating costs, run infrastructure more efficiently, and scale as your business needs change.”	