Crossing the digitalisation chasm: Overcoming barriers to industrial digitalisation

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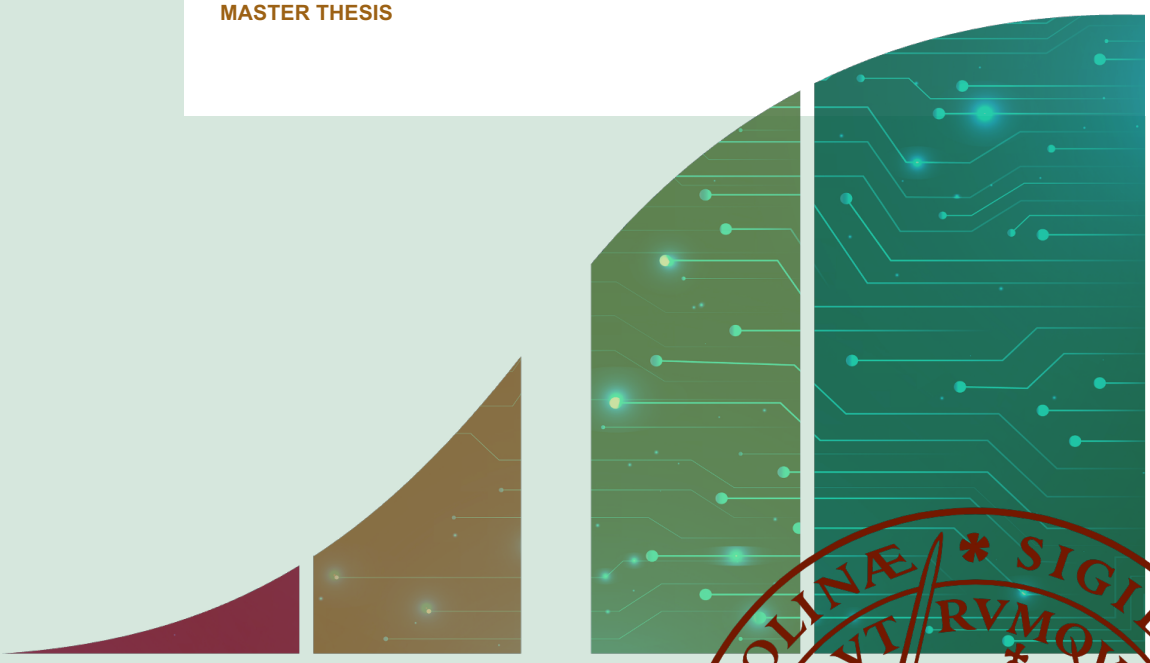

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Crossing the digitalisation chasm: Overcoming barriers to industrial digitalisation

A review and case study on the digitalisation of the manufacturing industry

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Abstract

Digitalisation is a global megatrend revolutionising every aspect of society and especially impacting businesses. Consequently, the term Industry 4.0 has emerged in the manufacturing industry. Manufacturing companies are increasingly adopting digital technologies to improve manufacturing processes, inform strategic decision-making and become more sustainable. The change towards a more digital manufacturing industry has accelerated since the Covid-19 pandemic and is increasingly being viewed as a part of the solution to some of the biggest sustainability issues facing humanity.

Companies that embark on a digitalisation journey will inevitably face barriers, both inside and outside the organisation, which need to be overcome. This master thesis investigates what those barriers are along with potential solutions which enable companies to cross the "digitalisation chasm". Additionally, some of the research has focused on what state-of-the-art research knowledge there is on digitalisation of manufacturing, as well as mapping how far digitalisation has progressed in the industry.

The research questions are answered through a systematic literature review and a multiple case study of four manufacturing companies, which are all customers of the engineering and advisory firm AFRY. The authors have collaborated with the Industrial Digitalisation Advisory Services (IDAS) team at AFRY to produce this report, aiming to provide valuable insights for both the company and their customers.

In conclusion, the findings indicate that the industry is experiencing a paradigm shift, as companies are increasingly focusing on adopting digital technologies and agile development processes. To attain the benefits of digitalisation and effectively utilise emerging technologies, manufacturing companies must overcome barriers such as skill shortages, increasing technical complexity, and employees resisting change. Effective change management, aligned leadership, a clear strategy, a positive change culture, and clear communication are all crucial for companies to cross the digitalisation chasm and fully implement digitalisation.

Keywords: digitalisation, digitalization, digital transformation, industry 4.0, manufacturing industry, challenges, barriers

Sammanfattning

Digitalisering är en global megatrend som revolutionerar samtliga aspekter av samhället och påverkar i synnerhet företag. Följaktligen har termen Industri 4.0 vuxit inom tillverkningsindustrin. Tillverkningsföretag tillägnar sig i allt större utsträckning digital teknik för att förbättra sina tillverkningsprocesser, underlätta strategiskt beslutsfattande och bli mer hållbara. Skiftet mot en mer digital tillverkningsindustri har ökat sedan Covid-19-pandemin och ses alltmer som en del av lösningen på några av de största hållbarhetsproblem som mänskligheten står inför.

Företag som ger sig på en digitaliseringsresa kommer oundvikligen att möta barriärer, både inom och utanför organisationen, som måste överkommas. Detta examensarbete undersöker vilka dessa barriärer är, samt vilka potentiella lösningar som finns för företag att ta sig över ”digitaliseringsgapet”. Delar av forskningen har därtill fokuserat på vilka de allra främsta insikterna är inom digitalisering av tillverkningsbranschen, samt kartlagt hur långt branschen har kommit inom digitalisering.

Frågeställningen besvaras genom en systematisk litteraturstudie och en flerfallstudie av fyra tillverkningsföretag, som alla är kunder till ingenjörs- och rådgivningsföretaget AFRY. Författarna har samarbetat med Industrial Digitalisation Advisory Services (IDAS)-teamet på AFRY för att producera denna rapport, med syftet att ge värdefulla insikter till både företaget och dess kunder.

Sammanfattningsvis tyder resultaten på att branschen går igenom ett paradigmskifte, där företag i allt högre grad fokuserar på att ta till sig digital teknik och agil utveckling. För att nyttja fördelarna med digitalisering och framväxande teknologier måste tillverkningsföretag övervinna hinder såsom kompetensbrist, ökande teknisk komplexitet samt att anställda motsätter sig förändring. Effektiv förändringsledning, samordnat ledarskap, en tydlig strategi, en positiv förändrings-kultur och tydlig kommunikation är avgörande för företag att ta sig över digitaliseringsgapet och implementera digitalisering fullt ut.

Nyckelord: digitalisering, digital transformation, industri 4.0, tillverkningsindustri, utmaningar, barriärer

Preface

The authors have written this report as part of their master thesis in Industrial Engineering and Management, at the Faculty of Engineering at Lund University. Through this education, both have become absorbed by the current topic of digitalisation. For the subject of this thesis, the authors wondered what barriers may hinder the proliferation of digitalisation in industrial organisations. They found common interest in the subject with the Industrial Digitalisation Advisory Services team at AFRY and worked with them for five months to conduct the research which resulted in this report.

Special thanks to Conny Jakobsson and Nico Dima for their enthusiastic support, their contributions to the report and for making the authors come into contact with their customers. Also thank you to all the interviewees who participated in the research. Finally, a big thank you to Lars Bengtsson, for keeping the authors on track these last few months and for the invaluable feedback given along the way.

Lund, May 2023

Anton Nyberg and Anton Öreberg

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List of acronyms and abbreviations

AI	Artificial Intelligence
AM	Additive Manufacturing
AR	Augmented Reality
CC	Cloud Computing
CPS	Cyber-Physical Systems
CRM	Customer Relationship Management
EU	European Union
FMS	Flexible Manufacturing System
HR	Human Resources
I4.0	Industry 4.0
IAP	Industrial Analytics Platform
IDAS	Industrial Digitalisation Advisory Services
IIoT	Industrial Internet of Things
IoT	Internet of Things
ISA	International Society of Automation
KM	Knowledge Management
MES	Manufacturing Execution System
NGO	Non-Governmental Organisation
NPD	New Product Development
RFID	Radio Frequency Identification
ROI	Return on Investment
RQ#	Research Question (number)
SDG	Sustainable Development Goals
UN	United Nations
UNIDO	United Nations Industrial Development Organization
VR	Virtual Reality

1 Introduction

The first chapter establishes the subject of the thesis, and the terms and concepts referenced throughout the report are explained. The chapter also provides background for the reader on the subject and then illustrates the problem to be answered in this thesis, along with its delimitations.

The topic of this thesis is the digitalisation of businesses, particularly those in the manufacturing industry. Manufacturers are embracing digitalisation for various reasons, such as improving production processes, enabling servitisation alongside their product offering, optimising business processes, and utilising advanced technologies to gain competitive advantages. However, digitalisation entails overcoming several challenges from both internal and external factors, which can hinder progress and prevent companies from reaching their full potential.

This thesis is a contribution towards the successful digitalisation of industry. It investigates what barriers keep companies from digitalising, and how those barriers can be overcome. The context is a world that is rapidly transitioning towards digital principles to solve some of the most pressing matters facing society, and the manufacturing industry cannot be allowed to fall behind on that progress.

1.1 Definitions

To facilitate the research and discussion herein, there is a very important note to make on the differences between the terms digitisation, digitalisation, and digital transformation. It is easy to see why one could assume that digitisation and digitalisation refer to the same concept, there are even some languages where there is no distinction between them. However, apart from the resemblance in notation, the only real similarity between the two is that digitisation is a prerequisite for digitalisation (Vrana & Singh, 2022), which in turn is a prerequisite for digital transformation. These frequently used terms are explained below, where the definitions are supported by several authors. Still, it is important to note that some sources use different definitions for these terms, or the terms may be used interchangeably. When such examples are cited in this report, the authors have interpreted their meaning by context and translated the words used to fit the definitions used in this thesis.

Digitisation

Digitisation

Merriam-Webster's dictionary (n.d.) defines digitisation as "the process of converting something to digital form". The concept can be seen as a variety of techniques for converting analogue data into digital values (Vrana & Singh, 2022; Demlehner & Laumer, 2020), or a translation of services and products into digital formats (Unruh & Kiron, 2017). The conversion of tables into spreadsheets, films into digital images or strings of digital images (DVDs), and paper mail into email are examples of digitisation, with the universality of storage as a key feature (Vrana & Singh, 2022). Specifically for manufacturing, digitising often refers to the incorporation of digital sensors to measure the production process or the external environment, as well as digital actuators to control production equipment (Enginess, 2021).

Digitalisation

Digitalisation

Digitalisation refers to the utilisation of digital tools to make procedures and operations simpler. Digitisation is therefore completely necessary if one wants to digitalise (Vrana & Singh, 2022). The purpose of digitalisation is to benefit from the recently digitised items and products (Unruh & Kiron, 2017). Building on the previous examples, spreadsheet data processors such as MS Excel, Image manipulation such as Photoshop, and workflow systems are all examples of digitalisation. Process simplification is a key feature of the digitalisation process (Vrana & Singh, 2022). In a manufacturing setting, digitalisation is by many seen as the main driver of Industry 4.0 (I4.0), which refers to digital technologies that enable more direct synchronisation and integration between the physical and industrial worlds by enabling, for example, real-time monitoring, remote control of equipment and manufacturing machines through networked infrastructure. However, digitalisation has a broader scope than I4.0 and includes all of the socioeconomic changes brought about by the convergence of information, communication, computing and connectivity technologies in a setting that is becoming more and more enriched by data (Matt, Pedrini, Bonfant & Orzes, 2022).

Digital transformation

Digital transformation

Finally, digital transformation is the most advanced of the three concepts and isn't necessarily referring to specific processes, but rather the whole business (Bumann & Peter, 2019). In general, digital transformation means the usage of technology to create new business models, software, systems, and processes leading to stronger competitive advantages, more efficiency, and higher incomes (Schwertner, 2017). To stretch the implications even further, new processes and business models could have the potential to restructure economies and cause large-scale behavioural changes brought forth by digital transformation (Unruh & Kiron, 2017). There are some examples of digital

transformation, the internet being one and the smartphone being another. These are innovations that massively revolutionised industries and society as a whole, enabling the creation of entirely new ecosystems and ways of doing business. Another at-hand example of digital transformation is in photography, where a digital camera, digital flash, GPS, tilt sensor, cloud solution, and image-enhancing AI, all from different manufacturers and providers, communicate wirelessly. Together, they can position the flash, collect data through the cloud, automatically enhance the pictures which can be accessed through a website from another provider, and finally be printed by the user on-demand (from yet another provider), while simultaneously uploading the pictures to social media platforms (Vrana & Singh, 2022). In the context of manufacturing, digital transformation can be viewed as making changes to the entire manufacturing organisation and its operating processes, utilising digital innovations to expand value propositions and facilitate new business models (Plekhanov, Franke & Netland, 2022; Ross, Beath & Sebastian, 2017). Enabling technologies for achieving digital transformation in manufacturing might be cloud communication, artificial intelligence (AI) or additive manufacturing (AM) to name a few.

1.2 Background

According to the Industrial Analytics Platform (IAP), part of the United Nations Industrial Development Organization (UNIDO), digitalisation is a technological global megatrend which is having major impacts on businesses' growth as well as industries' and nations' development. The development of digital technologies such as robotic automation of production "is indicative of the overall progression of this megatrend over the last two decades" (Altenburg & Haraguchi, 2022). This trend is largely related to the diffusion of technology in society, and both enable and are powered by new technological innovations. Overall, digitalisation means a shift not just for corporations but for how economies function and labour is employed (Altenburg & Haraguchi, 2022).

In UNIDO's Industrial Development Report, one can learn that the digitalisation megatrend was especially accelerated by the outbreak of the worldwide Covid-19 pandemic (UNIDO, 2021). As social restrictions were imposed on society, this led to skyrocketing traffic towards digital platforms, in particular for online retailers. This new behaviour, a driving force for digitalisation, was also compounded by the revelation that global supply chains were more susceptible to disruptions than previously thought. These factors thus led to intensified investments in digitalisation and automation manufacturing. Now, only a fraction of petitioned firms expects their production methods to revert to how they were pre-pandemic, as illustrated in Figure 1.1 (UNIDO, 2021).

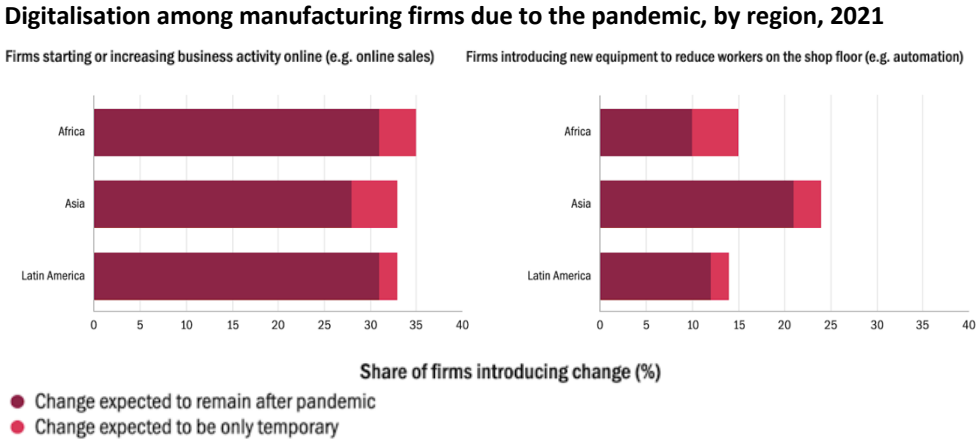

Figure 1.1 Propagation of digitalisation among manufacturers due to the Covid-19 pandemic (United Nations Industrial Development Organization, 2021).

1.2.1 Digitalisation of business

Parviainen, Tihinen, Kääriäinen and Teppola (2017) have highlighted the impact of digitalisation on businesses at various levels. At the process level, digital technologies, and tools, as well as process simplifications, are reducing or eliminating manual processes. At the business level, existing services can be offered in entirely different ways, some may become obsolete, and others may change as value chains and the roles they consist of are reworked. In short, new digital technologies are paving the way for entirely new organisational ecosystems. Organisations that adopt digitalisation concepts have the possibility to change and enhance numerous areas of the organisation, such as internal and external processes, the organisational structure, and their products/services, while also developing new long-term strategies (Parviainen et al., 2017).

The organisational goal of digitalising and digitally transforming is to facilitate business improvements. Significant business improvements can come in different forms, such as enhanced customer encounters, improved processes, or entirely new business models (Warner & Wäger, 2019). Digitalisation has encouraged radical business model innovation, and the increased focus on digital innovation during the last decade has laid the groundwork for the rapid creation of new business models during the 2010s. A significant difference now, compared to earlier eras defined by innovation, is that both innovative and traditional sectors are focusing on digitalisation and digital innovations. Previously, more traditional sectors including the manufacturing industry haven't been too concerned by tech innovations and investments (Caputo, Pizzi, Pellegrini & Dabić, 2021), but as AFRY now puts it:

> *"Digitalisation is currently fundamentally transforming the manufacturing industries and other similar industries like energy, food, and pharmaceuticals etc. A successful digital transformation of the manufacturing industry and other similar industries will be critical to strengthen the competitiveness of these industries."* (AFRY IDAS, 2020)

Despite the economic downturn brought on by COVID-19, global investments in digital transformation increased by 10.4% annually in 2020 to reach 1.3 trillion USD. This growth is expected to continue rapidly and reach an annual investment spending of 3.4 trillion USD by 2026 (Statista, 2022). Swedish companies specifically are focusing their digitalisation work and investments in numerous areas, such as automation, sustainability-oriented improvements, more efficient customer handling, and the development of new services and products (IVA, 2022).

There are however many potential barriers that organisations might face when investing in and trying to implement digital solutions. The main body of this report covers different aspects of digitalisation and Industry 4.0, in particular such present barriers. While digital transformation plays an essential part in this discussion, the concept has a less substantial role in reference to the manufacturing industry which is investigated herein, because very few manufacturers have made the journey to digital transformation in the way it has been defined here. The digital leaders of the manufacturing industry are rather situated somewhere in the late stages of digitalisation, according to consulted experts at AFRY (Jakobsson & Dima, 2023, February 3). Many more manufacturers, they say, still struggle to overcome the barriers to digitalisation and to realise its potential for their industry.

1.2.2 Industrial revolutions and Industry 4.0

The term *industrial revolution* precedes the digitalisation topic of this thesis, as it refers to the general transformation of industry. In essence, the term concerns the change in how resource processing and goods manufacturing is carried out, but also how society is fundamentally transformed as a result. A quick reminder: in modern times there have been four generally agreed-upon industrial revolutions. The first industrial revolution was ushered in using water and steam power. Following that was the second industrial revolution, made possible mainly by electricity and the division of labour, which enabled mass production. The third industrial revolution is said to have started around the 1950s and -60s with electronics, computers, and automated production, moving many processes from analogue to digital (Groumpos, 2021). The most recent and ongoing fourth industrial revolution, sometimes called the digital revolution, is driven by digitalisation and complex technologies. The term *Industrie 4.0* was introduced in Germany in 2013, originally referring to the strategic computerisation of the manufacturing industry (Philbeck & Davis, 2018). This soon became an established term worldwide, characterised by self-optimising and self-configuring flexible mass production systems, in turn, enabled by ground-breaking

digital technologies, system–machine interconnectivity and a blurring of the lines between the physical and digital world (Groumpos, 2021).

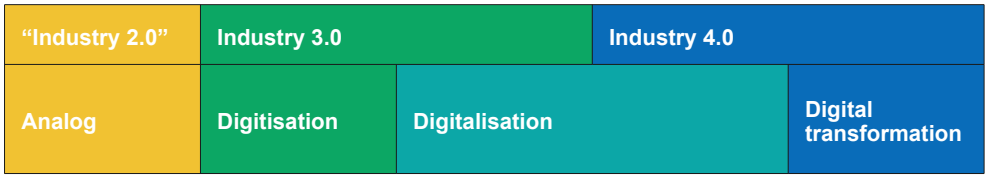

Figure 1.2 Timeline of digital paradigms supporting industrial revolutions. Adapted from Vrana & Singh. (2022).

In manufacturing, the terms Industry 4.0 and consequently Industry 3.0 have found common usage when referring to the technologies as well as strategies and business models which were enabled by their respective industrial revolutions (Vrana & Singh, 2022). On a timeline, they are concurrent but not necessarily coincidental terms to digitisation, digitalisation, and digital transformation, as shown in Figure 1.2. I.e., digitisation made possible the advent of Industry 3.0, while digitalisation is a key pillar leading up to Industry 4.0, which is further and ongoingly advanced by digital transformation.

Companies will often group technologies and systems by the terms Industry 3.0 or Industry 4.0 based on how they fit into applications for manufacturing, supply chains or other operations. With I4.0, the strategic focus is shifted from technologies mainly enabling mass production to technologies like Cyber-Physical Systems (CPS), AI and the Internet of Things (IoT), which through information exchange and supply-chain-wide collaboration enable flexible and self-adaptive production, customisation, and predictive diagnostics. These in turn may enhance manufacturing systems and inform strategic decision-making (Groumpos, 2021).

1.2.3 Digitalisation and sustainability

In 2015, all member states of the United Nations adopted the 2030 Agenda for Sustainable Development. The agenda outlined 17 Sustainable Development Goals (SDG) containing 169 targets, which aim to tackle climate change while also covering issues such as preserving the natural environment, ending poverty, and improving health, education, and equality (United Nations, n.d.).

The use of digitalisation and the digital technologies that come with it may be used in line with trying to accomplish the SDGs agreed on by the UN, and can in many ways set the stage for a smart green planet. Water quality sensing can help solve clean water problems (SDG6), I4.0 and digital technologies can be used to achieve a more sustainable industry (part of SDG9), and smart grid integration can be used to help tackle energy challenges (SDG7), among other solutions (Mondejar et al., 2021).

By combining digitalisation and sustainability, megatrends some refer to as *digitainability* when combined, the potential has arisen for society to solve a lot of environmental problems through sustainable design and innovation (Lichtenthaler, 2021). Sustainability projects such as decarbonisation, energy-efficient buildings as well as smart vehicles and smart manufacturing are all made possible through the development and use of digital technologies (AFRY, n.d.a). Digitalisation and sustainability are therefore top priorities for many businesses across different industries, proving the beneficial interdependence of the two megatrends (Lichtenthaler, 2021).

The possibilities of digitainability are also being recognised by large institutions such as the European Union. A more digital, green, and resilient Europe is the current goal of the EU, financed through the largest-ever stimulus package in Europe which calls for spending of a total of 2.018 trillion euros from 2021 to 2027 (European Commission, n.d.).

In summary, the digitalisation of our society is one of the most important forces we have at our disposal for accelerating the shift towards a more sustainable and green society.

1.3 AFRY

1.3.1 Company description

AFRY defines itself as “a European leader in engineering, design, and advisory services, with a global reach”. Their stated mission is to “accelerate the transition towards a sustainable society” (AFRY, n.d.b). With 19 000 employees, the company has offices in more than 40 countries and operates in more than 100 countries through various projects. The company strives to provide solutions for sustainable engineering and design for its customers. The company’s offering is divided into three sectors: Infrastructure, energy, and industry. Within these sectors, they provide services in six divisions: AFRY X, Management Consulting, Infrastructure, Industrial & Digital Solutions, Process Industries, and Energy (AFRY, n.d.b).

1.3.2 Company history

The Swedish companies Ångpanneföreningen and Northern Swedish Steam Generator Association were founded in 1895 and 1897, respectively, to check steam boiler safety and offer consulting services. They merged in 1964 and became ÅF.

Pöyry was founded in 1958 in Finland to build pulp mills and later expanded into energy, infrastructure, and environmental services (AFRY, n.d.c).

ÅF and Pöyry merged in 2019 to create AFRY (pronounced eɪːfɪi), focusing on engineering and advisory services in digitalisation and sustainability (AFRY, n.d.b).

1.3.3 Industrial Digitalisation Advisory Services

For this master thesis, the authors have collaborated with the team Industrial Digitalisation Advisory Services (IDAS) at AFRY, whose stated purpose is to work as a "bridge between the world of technology and that of business" (AFRY, n.d.d). They provide services on topics such as Architecture of Future Industry, Information Security and Cyber Security, Real Virtual Commissioning, Systems for Driverless Vehicles, and more. Some of their key competencies on the subject are I4.0, digital twins, machine learning and advanced analytics (AFRY, n.d.e).

1.4 Thesis description

1.4.1 Problem description

In recent years there has been a dramatic shift in how firms operate and provide value to customers, as a result of the growing importance of digitalisation in business. Despite the numerous advantages that digitalisation and digital transformation may offer, for example accelerated innovation and better customer relationship management (SAP, 2022), many organisations face significant challenges when it comes to successfully adopting digitalisation. Such challenges and barriers that organisations might face when trying to become a digital business are, for example, lack of expertise, limited budgets, pushback from employees, no understanding of why to digitalise, change-resistant cultures, lack of strategy or a well-functioning organisational structure, among others (Meléndez, 2021; Gartner, 2018; Jabil, 2017). Furthermore, the amount of conducted research on the subject of industrial digitalisation and its barriers and enablers is limited (Matt et al. 2023). Thus, the combination of a rather new area of research, a limited amount of previous research, and constantly shifting technologies, results in knowledge gaps that this thesis attempts to fill.

AFRY and their Industrial Digitalisation team help manufacturing companies create and implement digitalisation strategies throughout the whole process while leveraging new technology (AFRY, n.d.e). However, not all organisations manage to successfully implement digitalisation, and there is a need to understand why many

businesses find it difficult to fully exploit the benefits of digitalisation. It is necessary to understand why some of these barriers appear and how they can be overcome when trying to implement a digital strategy and digitalise manufacturing processes.

1.4.2 Purpose and research questions

The authors' overall objective with the master thesis is to provide AFRY and their customers with insights about barriers to digitalisation in the manufacturing industry while simultaneously contributing to academia on the subject.

The goals were discussed with the IDAS team at AFRY, as were some necessary delimitations that have been imposed to ensure that useful and accurate conclusions can be drawn within the scope and timeframe of the project. The primary objective of the thesis is to gain an understanding of what prevents some manufacturing companies from digitalising their operations with as much success as others. Furthermore, the barriers for manufacturers to successfully digitalise are to be analysed to understand how they can be avoided or overcome. In the end, the hope is that AFRY will be able to use the findings of this thesis in their day-to-day work.

The authors hope that this thesis will contribute to academia by increasing the knowledge about digitalisation barriers while simultaneously identifying knowledge gaps connected to digitalisation in manufacturing companies, thereby pinpointing areas where further research might be needed in the future. Furthermore, this report might give rise to new theories and models on the subject of barriers to digitalisation or organisational changes. Finally, this report might contribute insights into the barriers and opportunities that come with digitalisation today and spread this knowledge to organisations who are working with digitalisation or who might want to.

Based on the problem description and stated purpose of this thesis, four research questions (RQs) were set to be answered which are presented in Table 1.1.

Table 1.1 The research questions of the thesis.

RQ1	What is the state-of-the-art research knowledge on digitalisation in manufacturing?
RQ2	How far has digitalisation progressed in the manufacturing industry?
RQ3	What are the barriers for manufacturers to digitalise their businesses?
RQ4	How can the potential barriers to digitalisation be overcome?

RQ1 and RQ2 are principally intended to be answered in this report by investigation of academic sources, which then also creates a foundation for understanding the concepts which are involved in answering RQ3 and RQ4. These in turn are to be answered mainly through the research conducted by the authors.

1.4.3 Delimitations

Before starting this thesis, some delimitations had to be imposed on the scope of the research. First of all, the research focuses on digitalisation, digitalisation management, and barriers to digitalisation within manufacturing companies. Extra emphasis is put on its impact on manufacturing operations, not however overlooking the fact that company-wide action may be involved. The thesis does not specifically extend to the digitalisation of supply chains, product development, or other activities that are typically regarded as separate support functions of manufacturing. Digitalisation and its larger impact on society also will not be covered by the research of this thesis.

This report includes results from case study research. The cases that have been examined are four real-life digitalisation projects involving AFRY's customers, where AFRY have provided the clients with their services. It is important to note that the cases and organisations that are examined in this thesis have the same basis, which is that all organisations were manufacturing enterprises with their headquarters located in Sweden, along with at least part of their manufacturing organisation undergoing digitalisation. It was decided together with AFRY that the manufacturing types of the selected case companies should be similar in nature when comparing different cases, but that they did not necessarily have to be in the exact same industry, since AFRY considers the digitalisation process to be the same regardless of industry.

For the purpose of categorising manufacturing types, the International Society of Automation (ISA) have a standard called ISA 95. It includes a hierarchy describing how physical entities within a company are arranged. The standard shows how an enterprise can consist of one or more production sites, a production site can consist of one or several production areas, and each area consists of at least one of three different types of production, depending on the industry (Johnsson, 2010). AFRY adheres to this standard as well, and divides their customers' production into the types specified by ISA 95: *Batch production*, where produced units are manufactured and shipped in batches or clusters such as processed foods, pharmaceutical products or general single components; *Discrete production*, where single units consisting of many parts are delivered as individual objects like in the automotive industry; and *Continuous production*, as in continuously produced and delivered such as electricity, water and petroleum products (GE Digital, 2022). It was decided that all of the examined cases should be of companies with either batch or discrete manufacturing processes, or a combination of the two, to gain the most useful and concrete insights. The decision was made partly because of the availability of case companies, and because the third type is considered to be most dissimilar from the other two, according to AFRY (Jakobsson & Dima, 2023, February 3).

1.4.4 Target audience

The primary target audience of this master thesis is the IDAS team at AFRY as well as their current and prospective customers, for whom the authors hope to provide valuable insights and guidance on the subject. Secondly, the thesis targets other students, researchers, and organisations who are interested in digitalisation and the barriers facing the manufacturing industry.

1.4.5 Research ethics

In *The European Code of Conduct for Research Integrity*, All European Academies (ALLEA) put a lot of emphasis on the ethical, legal, and professional responsibilities of researchers to maintain research integrity and avoid fabrication, falsification, and plagiarism. It is the responsibility of the authors to follow the four fundamental principles of research integrity to make sure that research dilemmas concerning practical, moral, and intellectual problems are handled correctly. The four principles, as stated by ALLEA (2017), are Reliability, Honesty, Respect, and Accountability.

Reliability refers to the authors' designing the research and its methodology in a reliable way, while also using available resources and analysing findings with a critical mindset (ALLEA, 2017).

The principle of *honesty* concerns the researchers' responsibility in being transparent and unbiased in the way they undertake and communicate the research (ALLEA, 2017). Yin (2018) develops further on the subject of unbiased research, talking about testing findings with contrary evidence and findings. According to Yin (2018), researchers can test their tolerance for unexpected contradicting results already during the data collection phase by reporting findings to colleagues that will provide alternative theories and ideas. Thus, these findings can result in decreased risks of bias. The authors during the writing of the thesis continuously meet with their supervisors from both AFRY and LTH to report findings and try to find alternative explanations to their findings, to reduce risks of bias.

The *respect* principle underlines the importance of respecting everyone in the researchers surrounding, from research participants to the environment (ALLEA, 2017). This is of strong importance in the data collection phase of this thesis, since interviews are conducted and sensitive materials are handled. The integrity of the participants and the research is therefore of utmost importance.

Finally, the principle of *accountability* refers to the fact that the researchers must provide accountability for all stages of the research process, all the way from the idea phase to sharing the final report (ALLEA, 2017).

1.4.6 Outline

This master thesis report includes six chapters as outlined in Table 1.2, which follows the overall research strategy of the thesis.

Table 1.2 Descriptions of the contents of each chapter.

Chapter title	Description
1 Introduction	The first chapter establishes the subject of the thesis, and the terms and concepts referenced throughout the report are explained. The chapter also provides background for the reader on the subject and then illustrates the problem to be answered in this thesis, along with its delimitations.
2 Method	The research method of the thesis is described in detail in this chapter, the writing of which was crucial for guiding the authors through the work which resulted in this report. It details methodologies for both the preparatory literature review as well as the case study research and analysis of the thesis.
3 Literature review findings	In this chapter the findings from the literature review are presented through several topics, which altogether constitute a solid knowledge base on the state-of-the-art research knowledge on digitalisation in manufacturing.
4 Research results	The results of the conducted interviews and subsequent thematic analysis are exhibited in the fourth chapter. The results are the authors' observations and deductions from the open-ended interviews, yielding apparent barriers and success factors for the digitalisation of manufacturing based on the studied cases.
5 Discussion	The discussion contains thoughts and observations on the most significant results from the literature review, along with an analysis which contrasts the results from the literature with those of the case study. The chapter also discusses some limitations of the conducted research.
6 Conclusions and final recommendations	In the final chapter, the conclusions related to the research questions are presented, along with final recommendations for manufacturers to overcome the barriers they encounter and steer their digitalisation efforts in the right direction.

2 Method

In this chapter, the research method of the thesis is described in detail, the writing of which was crucial for guiding the authors through the work which resulted in this report. It details methodologies for both the preparatory literature review as well as the case study research and analysis of the thesis.

The work behind this thesis was conducted in six distinct phases, which are grounded in the research methodology of Robert K. Yin (2018). The overall research strategy and process, which is illustrated in Figure 2.1, was largely adapted and modified from Yin's book *Case Study Research and Applications (2018)*, as were the specific methods for designing and conducting the case study thereafter. However, the specific methods in each phase were also inspired by a number of other sources, in particular the work of Jan Dul and Tony Hak (2008).

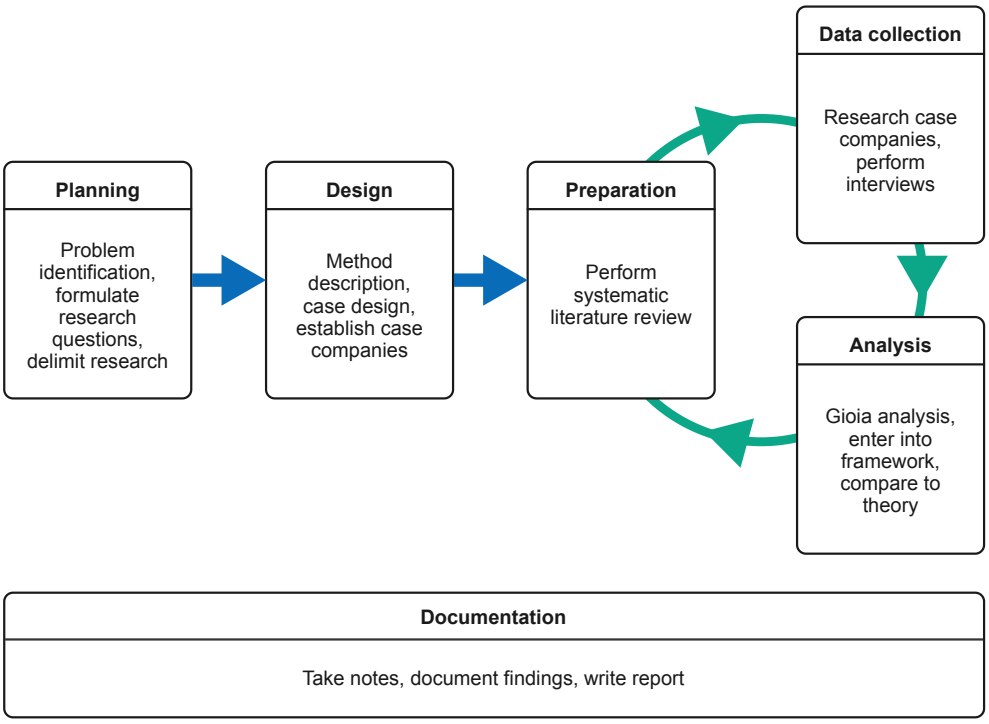

Figure 2.1 Research strategy of the thesis. Modified from Yin (2018).

The problem formulation was finalised in January of 2023, around the same time the general research process was planned followed by designing the literature review and case study in detail. The Preparation phase materialised in a systematic literature review which created a thorough knowledge base before the Collection phase which took the form of a multiple case study. As indicated in Figure 2.1, the preparation, collection and analysis phases are iterative in practice, due to the authors gaining new insights and finding new sources as the work progressed. Thus, previous activities and findings had to be revised several times.

2.1 Research strategy

The choice of research strategy refers to the planning of how to approach a research topic, in part by identifying whether the subject is suited to qualitative or quantitative research. It involves framing the research in the form of objectives, often by formulating one or several research questions. Then, a research method can be decided on (Greener, 2008; Bryman & Bell, 2011). These actions were all made in the Planning phase of the research process.

From the stated purpose of this thesis in combination with the nature of digitalisation as a subject, the authors identified that the topic was suited for a qualitative research strategy. With this as a starting point, it was decided that the research method would be that of a comparative multiple case study, preceded by a systematic literature review.

2.1.1 Research objective

Defining the research questions lays the foundation for the research study. There are two significant demands made of any research question, namely that they should have substance by answering what the study is about and have a clear form in what type of question is being asked (Yin, 2018).

The planning phase began with the authors meeting with AFRY to discuss what questions the company wanted to be answered regarding digitalisation and business innovation. There was consensus between the company and the authors that the results of this study should be of practical use. Therefore, after some deliberation, it was found that the most pressing question(s) that AFRY needed to be answered was: *What are the barriers to digitalisation?* with a natural follow-up question being *What can be done to overcome the barriers to digitalisation?* These were then reformulated for clarity and narrowed to consider the manufacturing industry so that they could be answered utilising the resources provided by AFRY within the timeframe of the thesis. The result became RQ3 and RQ4 in Table 1.1:

Initial research questions

What are the barriers for manufacturers to digitalise their businesses?

How can the potential barriers to digitalisation be overcome?

After the research progressed into the preparation phase, it became evident that the digitalisation of industry is an even more fast-changing subject than initially conceived. Each week more research would surface with new insights. It was found that with such an exceptionally nuanced subject it would be difficult to define a clear starting point for the progression of digitalisation in manufacturing – both as a concept and in specific companies. Because of this, and for not wanting to leave such a relevant knowledge gap unaddressed, the authors formulated two additional research questions. The intention was that answering these would facilitate the analysis of the initial research questions, thus these research questions were put ahead of the initial ones as RQ1 and RQ2:

Prerequisite research questions

What is the state-of-the-art research knowledge on digitalisation in manufacturing?

How far has digitalisation progressed in the manufacturing industry?

2.1.2 Research design

According to Yin (2018), the research design connects the data that will be gathered to the study's research questions as well as the patterns and conclusions that the authors hope to identify and formulate. The overall purpose of this report is to conduct a problem-solving and exploratory research study, which are two typical purposes for a master thesis which were described by Höst, Regnell and Runeson (2006). To fulfil this purpose, one or several well-defined research methods should be formulated. One of Höst's suggestions for a thesis with this stated purposes is a case study, which was ultimately chosen.

2.1.2.1 Choice of research method

The first practical aspect to be considered for this thesis project was what the primary type of research should be. The authors initially suspected that a case study would fit the thesis, as Dul & Hak (2008) describes a case study as a research project in which a small number of cases in their real-life context are selected, and findings obtained from these cases are analysed qualitatively. Yin (2018) provides some additional conditions for when to favour case studies:

The first condition regards the research questions. A case study is most appropriate to study *what*-questions if they are from an exploratory standpoint – which are found in the research questions of this thesis – as opposed to quantitative research methods such as surveys. Additionally, if the research questions are phrased as *how* or *why*, then a case study is also among the top choices, fitting well with the final set of research questions (Yin, 2018).

The second condition considers the definition of a case study, which Yin (2018) describes as twofold:

A case study as an empirical method that

- investigates a contemporary phenomenon (the case) in depth and within its real-world context
    - especially when the boundaries between phenomenon and context may not be clearly evident.
- copes with a situation where there are many more variables of interest than just data points
    - as a result, it benefits from prior theoretical development to guide design, data collection, and analysis,
    - as a result, it relies on multiple sources of evidence, with data needing to converge in a triangulating fashion.

From the beginning, this research would principally be an investigation of currently active companies and digitalisation projects, which fits well in the definition of a contemporary phenomenon. Additionally, as companies make decisions based on both internal and external factors, in researching causalities there indeed is a lack of a clear boundary between themselves and their context. Thus, it became evident that a case study with its prescribed methodologies would be the most appropriate method of research. The second point Yin made also pointed towards the need for prior theoretical research, which was the authors' first indication of the need for a literature review. First, however, the type of case study had to be formulated.

2.1.2.2 Case study type

Dul and Hak (2008) emphasise that their definition of a case study does not limit the types of data collection or measurement techniques used for analysis. However, for this study, it was decided that qualitative data would be utilised to draw conclusions. Qualitative data is generally derived from context and insights from a limited number of sources. In contrast, quantitative data is more appropriate when comparing large datasets with similar aspects, which can be analysed statistically.

The research design chosen for this thesis was a multiple-case study design (Yin, 2018). Dul and Hak (2008) argue that there are different types of case studies, and emphasise two main types: the single case study, in which data from one instance is enough to achieve the research objective, and the comparative case study, which

requires data from two or more instances to achieve the research objective. The authors believed that several instances would need to be investigated to isolate the causes for and draw meaningful conclusions about the barriers to digitalisation. Hence several companies were to be included in the case study, which makes the strategy be that of a practice-oriented comparative case study (Dul & Hak, 2008).

The way a case study is conducted depends, according to Dul and Hak (2008), on the research objective of the study. This study took the form of practice-oriented research, since the general objective of this study is to contribute to the practical knowledge of AFRY and other organisations when implementing digitalisation and associated technologies. Practice-oriented research should be aimed primarily at practitioners, in line with the commissioning of this report, as opposed to theory-oriented research which is rather aimed at the academic community. Even so, the authors hope that this report may still contribute with new knowledge on digitalisation and that the reach of the findings herein is not limited by its primary intended recipient.

2.1.2.3 Preparation by literature review

The main research in this thesis is preceded by a literature review, intended to prepare the authors for the case study by answering the first two research questions. Doing a literature review is suggested by Bryman and Bell (2011), who emphasise its importance towards building a strong knowledge foundation before conducting research.

Yin (2018) states that the purpose of a literature review is to develop sharper and more insightful questions about the topic being researched, but raised some concerns as well, which are addressed in section 2.1.3 regarding Research quality assurance. Meanwhile, Bryman and Bell (2011) put a lot of emphasis on the practical purposes, citing several more: to identify what is already known about the area; if there are any existing theories or concepts that might be of interest; and to uncover if there exists gaps, controversies or inconsistencies between findings already made by previous researchers. Another relevant reason for this paper was to examine what research methods have been employed in previous case studies on the topic and if there may be some insights which could complement the research strategy of this study.

Based on these factors, the authors concluded that a literature review would provide a lot of insight and knowledge into digitalisation and suggest some potential barriers before starting the case study. The decision was made to conduct a Systematic literature review which is elaborated on further in section 2.2.

2.1.3 Research quality assurance

The design quality of the research can, according to Yin (2018), be evaluated based on three specific tests: Construct validity; External validity; and Reliability. These tests were thoroughly used by the authors throughout the entire process in order to maintain credibility in the overall outcomes of this report.

Construct validity refers to the determination of the most appropriate approaches for the topics being examined. Tactics used for this has been to use a variety of sources as well as to evaluate the draft case study report along its progression with the thesis supervisor at LTH and the consultants at AFRY.

External validity means demonstrating the viability of generalising case study results and how to do so. This can be done through replication logic, i.e. by making sure that the cases are sufficiently similar so that conclusions are not made based on researched aspects which can be influenced by the unique circumstances of one single case company.

Finally, reliability proves that a study's processes can be repeated and provide the same outcome over and over. Keeping up a database and evidence chain are valuable tactics to use for this purpose (Yin, 2018), which is why a list of all the literature included in the literature review has been provided in Appendix B.

2.2 Literature review method

It was vital for the authors to have a deep understanding of the theory surrounding the subject of digitalisation in manufacturing before approaching the case study. Without this understanding, there is a risk that essential interpretations or insights are missed when collecting data and information from the cases (Yin, 2018).

The objectives of conducting this systematic literature review were to identify common themes on the subject of digitalisation of industry and to build a solid base of knowledge of what is at the forefront of digitalisation and implementation in manufacturing. Additionally, the authors hope that, by including a systematic literature review in the report, it becomes easier for the reader to understand with what basis the authors are coming to their conclusions. It may also serve as a contribution for other researchers to develop further theories from (Höst, Regnell & Runeson, 2006).

The outline for the literature review is based on *Guidance on Conducting a Systematic Literature Review* by Xiao and Watson (2017) and *Systematic Literature Review in Management and Business Studies* by Al-Tabbaa, Ankrah and Zahoor (2019). The goal was to conduct a descriptive, narrative review as described by Xiao

and Watson (2017), which is a structured, stepwise process divided into three phases (not to be confused with the research phases of the thesis): The planning phase, the conduction phase, and the report phase.

2.2.1 Literature review process

While conducting the review, this outline and the procedures described hereafter served as a protocol, ensuring that the two authors followed the same working principles which allowed for an efficient division of the work. The formulation of this section constitutes phase one of the Systematic literature review, which formally consists of two steps: 1: Formulating the problem, which is the same as the problem formulation of the thesis, and 2: Developing the review protocol, the result of which was a 'Literature review procedure document' which laid the foundation for this section. Chapter 3 of this report constitutes phase three, where the findings from the review are presented.

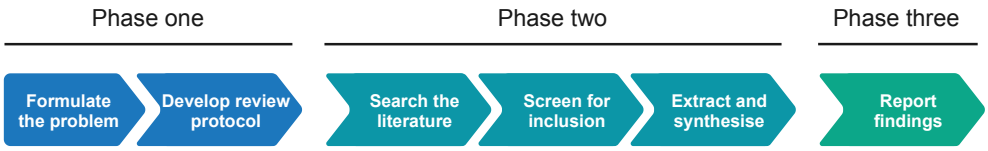

Figure 2.2 The systematic literature review process.

The following sections describe the procedures of the review itself, i.e., phase two. According to Xiao and Watson (2017), this is normally a five-step process where the third step is to assess the quality of identified works, and the fourth and fifth steps are divided between extracting and synthesising data. However, in the case of descriptive reviews, quality assessment is not crucial since this thesis is more concerned with exploring the width of available literature (Xiao & Watson, 2017). Therefore, this step is skipped. Additionally, in the case of qualitative case studies, it is impractical to separate data extraction and synthesis. Thus, inspired by a literature review conducted by Al-Tabbaa, Ankrah and Zahoor (2019), in this review, these steps are combined. The result of these measures is therefore a three-step review process illustrated under phase two in
Figure 2.2 and described in the following sections.

2.2.1.1 Step 1: Search the literature

The primary search for peer-reviewed literature was done through the database Web of Science, chosen because it is considered to be one of the most essential indices while still being restrictive in its inclusion of academic journals (ISU University Library, 2023). At the opposite end, Google Scholar was subsequently used to complete the body of works with articles of special interest, but which might not have been included in Web of Science. Xiao and Watson (2017) express that

"*Depending on the purpose of the review, a search can be exhaustive and comprehensive or selective and representative*", whereas a descriptive narrative review of the present type is often more exhaustive in nature. According to Xiao and Watson (2017), this means that the search shouldn't necessarily be restricted to only peer-reviewed studies. This was the reason for the inclusion of literature from Google Scholar, where more recent articles and reports relating to management and business were expected to appear from less academic sources. However, such articles were included on a case-by-case basis rather than in the extensive literature selection process, because of the index's limitations in restricting search results.

With inspiration from the method used by Al-Tabbaa, Ankrah and Zahoor (2019), the literature search was limited by date to 2016 as the earliest publishing year. This year was chosen based on a literature review by Matt et al. (2022) on Industrial Digitalisation, which found that publications on digitalisation saw a sharp increase from 2016 to 2017, see Figure 2.3. To limit the literature search to only the most recent years is in line with the interest of the authors to capture what is truly the state of the art on the subject, which indeed has seen a very quick pace of development in the last few years and thus works published before this point might already be out of date. However, it is important to note that the author occasionally encountered a subject of particular interest that required additional research before the established limit. In such cases, targeted searches were conducted where the authors deviated from only considering papers from 2016 or later.

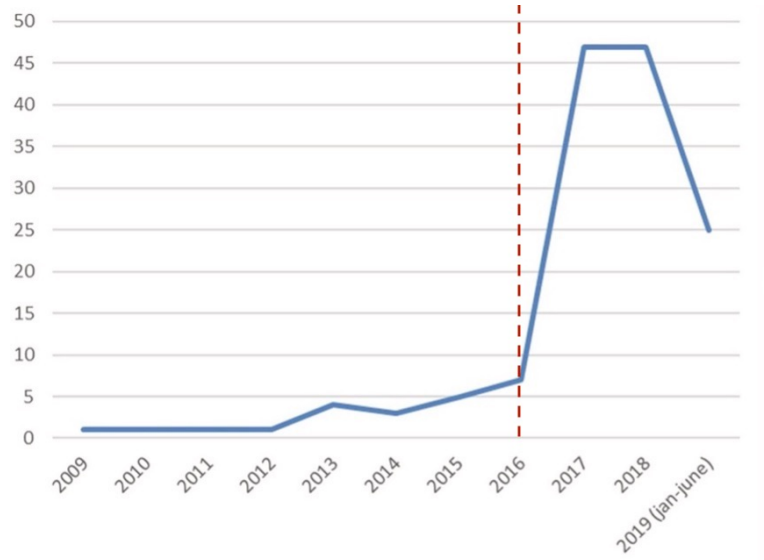

Figure 2.3 Number of publications per year in the literature review by Matt et al. (2022), marked at the cut-off year of the literature review of this thesis.

Before starting the review, trial searches were made with keywords derived from the initial research questions: (*digitalisation* OR *digitalization*) AND (*barriers* OR *implementation*). From the articles in those results, observations were made on the relevance of the search results for the purposes of this review, and the search terms were adjusted to strike a balance between exhaustiveness and precision. The final search terms which were used in the primary search became: (*digitalisation* OR *digitalization*) AND (*barrier** OR *obstacle** OR *challenges*) AND (manufacturing OR *industr**), based on Title, Keywords and Abstract. All articles in the primary search results were exported to a spreadsheet including their titles, keywords, abstracts and other relevant information about the articles, which were reviewed in the next step.

2.2.1.2 Step 2: Screen for inclusion

First, an automated exclusionary scan was carried out on the exported list of works from the primary search, by filtering for occurrences of some initially observed 'Exclusion words'. These were terms which were deemed to coincide with subjects that were not central to the research's focus, such as: *circular economy; servitisation; the covid-19 pandemic; unions; education* as well as specific industries like *tourism, agriculture, naval, construction* etc.

The remaining titles with keywords were divided up and carefully read by the authors, who excluded articles if they fit within one or several pre-developed exclusion criteria which are described in Table 2.1.

Table 2.1 Exclusion criteria for literature review

Shorthand	Reason for exclusion
R	Not relevant regarding the RQs, investigating different topics.
F	Focus on the other aspects of the subject, e.g. not commercial applications.
I	Incompatible or too narrow industry.
G	Geographically distant from the delimitations of the study, study of specific region.
L	Literature review, if not adding new knowledge.

For example, an article containing a case study of the digitalisation of a firm without at least discussing enabling or hindering factors/barriers, nor any description of how at least some challenges were overcome, would thus be excluded according to the R-criteria. However, a guiding principle from the methodological literature urged for inclusiveness when in doubt about the relevance of any individual piece of work (Xiao & Watson, 2017), which was heeded by the authors. However, this did eventually lead to an excessive number of articles being included in the first round, which prompted another pass-over by the authors who then both separately screened

all remaining articles and then jointly reviewed the cases where there was no immediate agreement on whether to include them or not.

The remaining articles were then screened by the authors a final time based on the abstracts, as suggested by Brereton et al. (2007), who also advise that the conclusion section should be read if the abstract does not provide enough information. The articles were assigned an 'interest score' ranging between 0 (not of interest) and 3 (fundamentally important and relevant), where articles with a score of 0 were filtered and articles with a score of 1 meant that only certain relevant parts of the work should be reviewed.

After the review, some articles were added to the list from other sources, some found from Google Scholar and others directly from web searches, like consultant reports. These works were also given an interest score.

2.2.1.3 Step 3: Extract and synthesise data

The final step of the literature review followed a structured method for data extraction which arguably deviates from the often more informal data extraction of most descriptive narrative reviews (Xiao & Watson, 2017).

Simultaneously to the last screening, the articles were coded by assigning overarching themes based on title, keywords and abstract which were then consolidated and developed into overarching primary themes. These were later used to structure the findings of the review. The full texts of each work in the final sample were obtained and the authors read them through fully in order of the themes, meanwhile extracting take-aways and attaching these to the primary themes. Connections were drawn between commonly occurring subjects and the primary themes, such as specific barriers and solutions. These findings are presented in Chapter 3 and create a solid theoretical foundation for this thesis.

2.3 Case study method

As stated, the main research of this thesis was conducted as a comparative multiple case study. There are five crucial elements to keep in mind when designing a case study: The case study's questions; Its propositions (if there are any); The case(s); The logic between the data and the propositions; and The criteria for interpreting the findings (Yin, 2018).

Once the research questions had been outlined, the next step was to determine what data was relevant and should be collected, as well as which methods should be used for data collection and analysis. Secondly, the authors should make some assumptions and propositions that are investigated in the context of the research. The purpose of this element is for the authors to be compelled to advance in the right

direction (Yin, 2018). The authors deemed this to be fulfilled by the outlining of possible barriers found in the literature review.

Thirdly, the case itself and its boundaries should be defined (Yin, 2018). This was done based on the initial research questions and the case materials that AFRY together with the authors found to be relevant for the scope of the report, and the thesis delimitations that were formulated as a result. Furthermore, the data needs to be analysed and linked to the initial propositions, which is the subject of Chapter 5.

Finally, it is important to define what criteria that should be used when determining the significance of the findings of the case study. For example, finding and addressing competing hypotheses is crucial once results and patterns have been identified. This was achieved by triangulating the results, as is addressed in section 2.5.1.

With the stated factors accounted for, and with some inspiration from Dul and Hak (2008) and Fox-Wolfgramm (1997) who advise on a method for conducting a dynamic-comparative case study, the authors developed a process for the case study of this thesis in the form of a flowchart. The process was developed ahead of the case study and was followed with a few adjustments along the way, resulting in the final process as described in Figure 2.4 below.

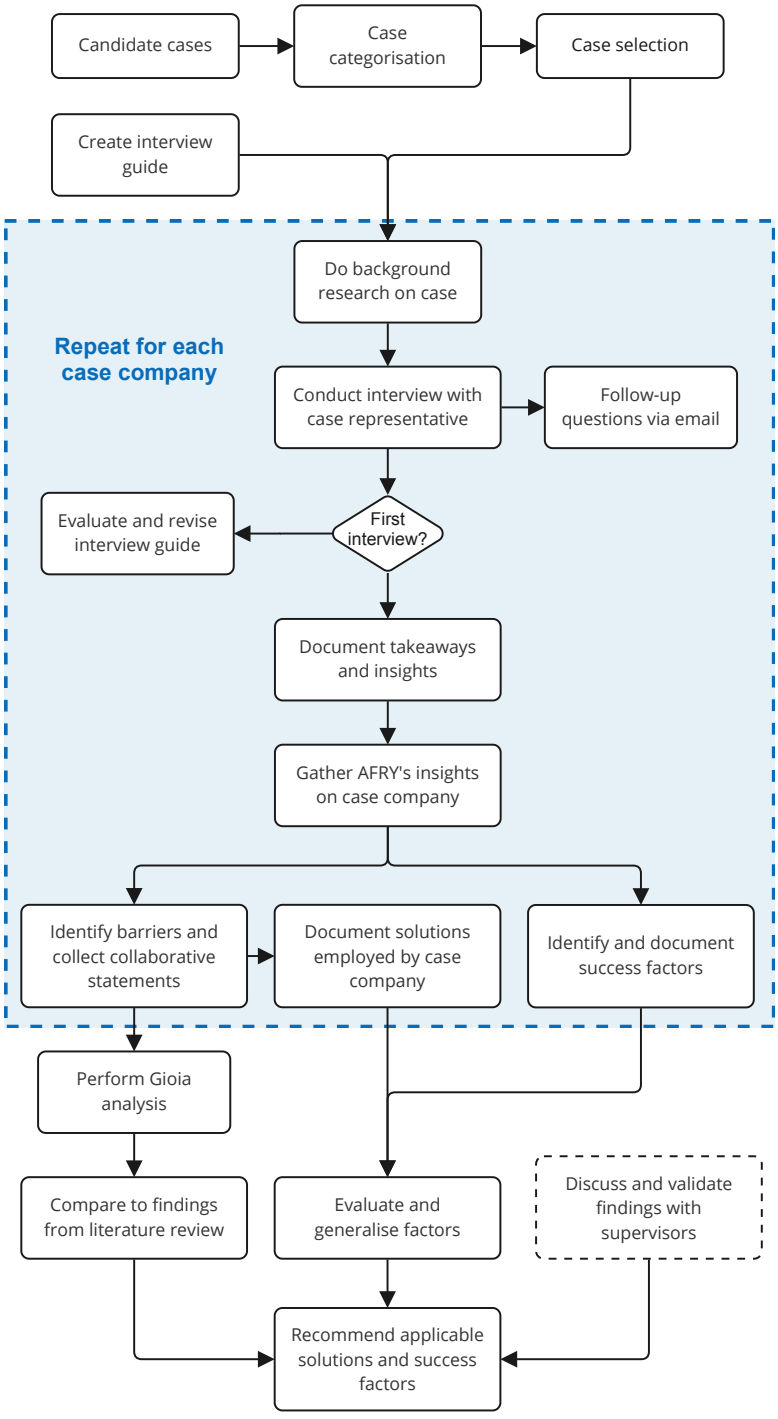

Figure 2.4 Flowchart of the case study method followed throughout this thesis.

2.3.1 Data collection

There are several different ways in which case study data can be collected. For this thesis, interviews are conducted to collect the primary data to answer the research questions and draw conclusions. Several meetings also took place with AFRY to provide supporting data about the case companies and to gain another perspective on the answers provided by the interviewees.

2.3.1.1 Interviews

The interviews were the sources of evidence that lay the foundation for the authors' case analysis. Interviews are a good way to collect data since they can emphasise the topic of the case study directly, as well as provide valuable insights and explanations while simultaneously recording the personal view of the interviewees. However, it is also important for the authors to remember that interviews can be biased both ways or suffer from reflexivity (Yin, 2018). Interviews were chosen as a method of data collection since they are a good way to get different points of view on possible solutions (Höst, Regnell & Runeson, 2006), fitting the purpose of this thesis well.

Four different manufacturing companies, all clients of AFRY, were chosen as an adequate sample for this qualitative research. These companies were seen as good case study candidates among a selection of companies since they were all within the delimitations, while still having vastly different levels of digital maturity, company size and organisational environments when starting their digitalisation journey. The authors were open to the idea of interviewing more companies, hence increasing the sample size, but determined that four were enough to answer the research questions and draw meaningful conclusions within the timeframe of this thesis. This decision was supported by the fact that not much new information could be extracted after the last interview, but that the findings from the later interviews rather supported the patterns which had been starting to form from the previous interviews.

The interviews were held with employees in charge of the digitalisation journey at the four different case companies. A more extensive introduction to the case companies is to be found below. The authors performed an open-ended interview, as explained by Höst, Regnell & Runeson (2006) being an interview type where the goal is to capture the interviewees' experiences of certain phenomena, with the purpose to explore the subject in depth. The questions were open-ended and based on an interview guide, although it did not have to be followed strictly in cases when the interviewees veered the interview in different directions. Questions were prepared beforehand, and a translation of the interview guide can be found in Appendix A. The interviews were conducted either in person or through digital platforms. One of the authors conducted the interview while the other took notes and could interject with the remaining questions at the end. Furthermore, the interviews were taped and partly transcribed for the authors to review later, upon approval by the interviewee.

The purpose of the open-ended interviews was to collect qualitative data in the form of statements and descriptions, in order to get an understanding of the barriers to digitalisation the specific case companies faced and how they could be overcome. Furthermore, the authors hoped to be able to identify patterns between the case companies and subsequently draw more general conclusions.

2.3.1.2 Briefings with AFRY

Before or after each interview with the case company representatives, at least one meeting would occur in which the authors would be briefed by a member of the IDAS team at AFRY, who had worked on the project involving the case company. In these, in-depth conversations were had about why AFRY had been contacted to begin with, what issues had been addressed and what is currently going on at the company in terms of their digitalisation journey. Follow-up emails were also sent to gain the perspective of those employees who had worked with the company on the results from the case interviews.

Besides the informative conversations given in the briefings, the authors were occasionally shown examples of mock-ups which had been created for the customer, along with pictures of the operational environment of the companies. These highlighted what preconditions the company and AFRY had started with, and how far they had progressed during their cooperation. These company-internal resources helped to illustrate the current situation at the companies and where their focus lies currently, which is conveyed in the following sections where a summarising background is provided for each case company.

2.4 Case companies

Key figures and facts about the case companies are shown in Table 2.2. Following this are brief descriptions of each case company and their digitalisation journey so far. All information presented here was obtained through the interviews or subsequent communication with the interviewees.

Table 2.2 Data about the case companies.

Company name	HQ	Number of employees	Total revenue [m.sek]	Number of production sites
IKEA Industry	Malmö, SE	15 000	27 578[a]	18
The Absolut Company	Stockholm, SE	500	7 572	2
Bror Tonsjö	Kode, SE	100	388	1
Manufacturing Company X	– SE	~ 40 000	~ 100 000	12[b]

[a] The revenue of Inter IKEA Group, which IKEA Industry is a part of. Revenue of individual companies are not available.

[b] The number of sites within the division covered by the case study, not the entire company.

2.4.1 IKEA Industry

IKEA Industry AB is a part of the Inter IKEA Group and specialises in manufacturing wooden furniture for IKEA. The company produces more than 100 million pieces of furniture every year, in several different countries, and has around 15 000 employees with the headquarters being located in Malmö, Sweden. In the ISA 95 standard, IKEA Industry's production is categorised as *discrete.*

The company's manufacturing evolution goes back to 1992. In 2016 they introduced their Manufacturing System of the Future (MSF) program, which was the start of their adoption of I4.0. The MSF approach focuses on a smart and connected manufacturing environment through digital technologies. This new approach included features such as data-driven processes, agile planning, and mobile solutions, among others. The MSF concept laid the foundation for successful PLM, Planning, MES/MOM, Data capturing & Visualisation as well as more flexible automation solutions.

The company started exploring Industry 4.0 possibilities back in 2017, where they adopted a *think Big*-mindset. They began development in 2018, rolled out a pilot in

one of their factories in 2019 and then scaled fast with a roll-out to other sites in 2020 and onwards.

The interviewee is Anders Liljewall, CIO of IKEA Industry AB, who was ultimately responsible for planning and implementing the new digital solutions at IKEA Industry.

2.4.2 The Absolut Company

Absolut Company AB is a global spirits company with its Absolut production located in Åhus, Sweden, and its main office located in Stockholm. Since 2008, the company has belonged to the Pernod Ricard group. The company has five brands including Åhus Akvavit, Kahlúa, Malibu, Absolut Elyx, and its world-famous Absolut Vodka. The company is involved in typical *batch production* according to the ISA 95 standard.

The company's current digitalisation journey, which covers the Absolut manufacturing in Åhus, started back in 2018. However, the company started working with some digital tools in their manufacturing as early as 2002. Today, the manufacturing processes are on a high level of automation with five completely automated production lines and one more flexible production line for special product series at the factory in Åhus. Hence, the manufacturing staff is working more with deviations in the processes than with manual labour. The purpose of digitalising has been to enhance and streamline production maintaining the performance despite more articles and smaller batches, all while gathering data for effective decision-making. This goal has included an increased level of flexibility in the manufacturing processes in order to meet changing demands from consumers and allow for smaller batches with different flavours.

During the digitalisation journey, AFRY has helped the company to develop a dashboard prototype for presentation of data, status and production lines. The company has also used consultants to work on other tasks, while still maintaining control of the digital structures and platform by being thorough in their requirement specifications.

The interviewee is Emil Svärdh, Senior Automation Engineer at The Absolut Company and former LTH student, who is working with digitalising the production. Therefore, Emil is working extensively with data flows to and from the machines in the manufacturing process. This work includes creating an architecture that specifies what data points that should be used, which system should own the various data points, and the internal coordination between them and the business systems. Furthermore, Emil develops the digital strategy and reports on digital initiatives within the company.

2.4.3 Bror Tonsjö

Bror Tonsjö AB is a family-owned manufacturing company located in Kode, north of Gothenburg. The company does machining and processing with a focus on cutting processes, and are experts in several areas such as automotive, energy & nuclear, mining & excavation, electric motors and industry. The company is in the *discrete production* category, according to the ISA 95 standard. Furthermore, Bror Tonsjö is a supplier to some of the largest companies in the Swedish industry.

The company started looking into Industry 4.0 back in 2017, looking to create added value for the company and their customers. After an initial screening of the entire company and its digitalisation readiness, their digitalisation journey started. At the start of their digitalisation journey, not a lot of progress towards digitalisation had been made in the industry, and the company had to pioneer many different areas.

The digitalisation journey included a lot of aspects, but the main objective was to connect all the robot cells to the company's different systems to visualise data. Furthermore, the company wanted to connect the whole factory to its business systems as well as its customers. The company thus had to build an industrial IoT platform, with software supplied by Siemens, where AFRY helped them to configure standard applications as well as create new ones and implement them to fit the needs of Bror Tonsjö.

In 2019, Bror Tonsjö won an award for Supplier of the Year, as they were cited to be one of Sweden's leaders in digitalisation. In 2021, the company went on to win Smart Industry 2021 for its work with digitalising its production.

The interviewee from the company is the CEO, Clas Tengström, who has led the change process and the digital implementation in the organisation. Bror Tonsjö and Clas have received around 150 companies visiting their factory to observe their digitalisation progress.

2.4.4 Manufacturing Company X

This company, which requested anonymity, is a global manufacturing company which specialises in producing heavy duty-tools and equipment for mining and extraction. They do this by utilising a mixture of both traditional and advanced technologies for metal processing. The company is in the category of *discrete production* in the ISA 95 standard. In terms of digital maturity, the company has historically been less advanced and for some processes has relied on completely analogue systems. In the last couple of years, however, the company has been catching up through focused efforts where AFRY has been a driving partner during their digitalisation journey.

The digitalisation project for which the company was involved in the case study has so far been limited to a single site which has been focusing on digitalisation for some years, decoupled from central governance in this aspect. The main objective has been to interconnect the existing machines in production to a central platform, which would be able to generate data and visualise the production in real time. A driving factor for the project has been the prospect of minimising machine downtime, creating an obvious cost-saving incentive. The project started some years ago and has progressed incrementally in a cautious yet steady manner.

A key concern for Manufacturing Company X regarding its digital progress has been data security, which has manifested in an isolated system on-site rather than any cloud solutions. In addition, not much mind has been given to integrating their suppliers into their digital platform, rather efforts have been limited to internal processes.

The interviewee who participated in the case research is the technical manager and head of production at the site. He has personally overseen the digitalisation project and has a large mandate to implement changes in the production line. The efforts he has put forth have made him a driving person for digitalisation in other areas of the global organisation as well.

2.5 Analysis methods

After each conducted interview, the authors discussed some key takeaways along with isolating collaborative statements from the interviewee. Following this, the interview notes and recordings were reviewed for additional statements implicating barriers that the company faces, did face and address or managed to avoid throughout their digitalisation journey. Additionally, success factors for each company were collected. This constituted the first part of data extraction.

Then, a method was employed known as the Gioia Methodology, which is a systematic approach in which data collected from informants as part of qualitative research studies is structured to show how the expressions of interviewees and other first-hand data (1st-order concepts) are translated into the researchers' interpretations (2nd-order themes), which may also take prior research and established terms into account. The Gioia method emphasises the importance of maintaining an open and flexible approach to the analysis, allowing themes to emerge from the data rather than imposing preconceived ideas or assumptions. These are then aggregated by the researchers into Aggregate Dimensions which cover major themes throughout the results. The comprehensible structure which emerges, shown as a blank canvas in Figure 2.5, should be easily followed by the reader, thereby at a glance proving that the arguments made by the researchers are backed

up by the conducted research. Thus the research method achieves academic credibility and validity (Gioia, Corley & Hamilton, 2012).

First-order data does not necessarily have to consist of direct quotes. In fact, as shown by Magnani and Gioia (2023), first-order concepts should be quite compact and informative, which quotes from open-ended interviews generally are not. Additionally, in the case of this specific case study, the interviews were conducted in Swedish and thus had to be translated. Still, the authors have attempted to mirror the language and terms used by the interviewees as closely as possible through the translation and consolidation of statements, in order to not make any interpretations, in the first-order concepts as dictated by the Gioia methodology.

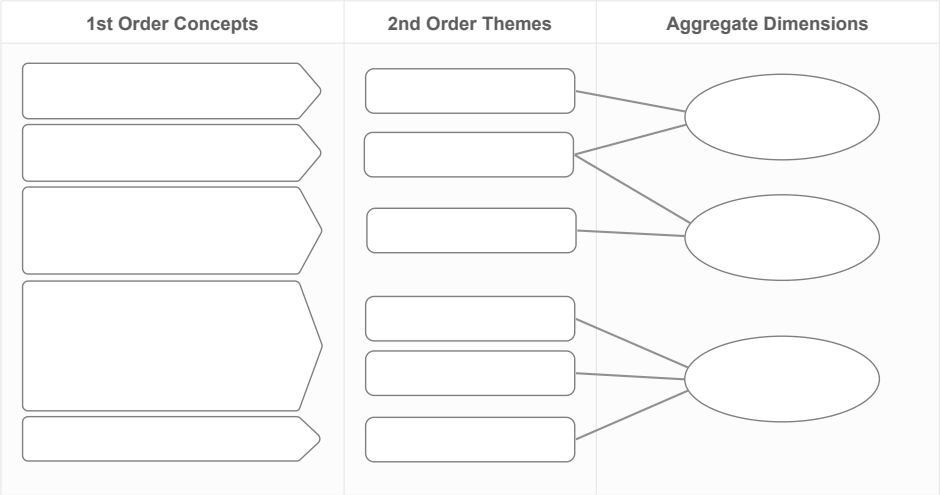

Figure 2.5 Layout of the Gioia framework used analyse the results of the case study.

2.5.1 Triangulating results

Lastly, to ensure the accuracy of the findings, the results from the analysis are triangulated. This means strengthening the validity of the case study through the use of multiple sources of evidence (Yin, 2018). In this thesis, this was achieved by discussing and comparing the findings from the literature review and the case study research with both the thesis supervisor at LTH and the IDAS-team at AFRY. These in turn provided feedback and criticism of the results, prompting the authors to scrutinise their reasoning and strengthen their conclusions with additional proof as required.

3 Literature review findings

This chapter presents the findings from the literature review through several topics, which altogether constitute a solid knowledge base on the state-of-the-art research knowledge on digitalisation in manufacturing.

The chapter begins with a summary of the descriptive findings from the literature review, including the identification of recurring themes among the articles. This provides an overview of the authors' starting point and informs the outline for the rest of the chapter.

The ensuing sections are digests of the identified 'primary themes' from the literature review, which have been enriched with additional sources as needed. These sections address the topics of RQ1 and RQ2 and provide background knowledge for the authors to later address RQ3 and RQ4. The chapter covers five key topics, beginning with a general overview of research on digitalisation in manufacturing and Industry 4.0. This is followed by potential benefits of digitalisation, potential barriers for organisations, and strategies for organisations to achieve change. Lastly, the chapter includes descriptive theoretical models for digitalisation, describing it as a technological paradigm.

3.1 Descriptive findings

This section is a descriptive summary of the literature review and subsequent data coding. A numeric walkthrough of the process is presented along with a quantitative description of what academic literature has been written on the topic of the thesis. Through this, the main themes are uncovered. The methodology which led to these findings was described in detail in section 2.2 and is therefore only very briefly recapped in this section.

Table 3.1 shows the filtering of articles in the several rounds of screenings and the narrowing number of articles in the final selection.

Table 3.1 Changes in number of included articles per step.

Activity	Remaining articles	Change in number of articles
Primary search	1900	
Automated screening	1542	- 358
1st title + keyword screening	256	- 1286
2nd title + keyword screening	115	- 141
Added articles from backreferencing and later discoveries	123	+ 8
Abstract screening	97	- 26

From the initial search on Web of Science, 1900 articles were a match which were exported and went through an automated screening. Out of these, 358 could be rejected by automated filtering of the titles. Then by two rounds of manual screening, a large set of articles were rejected based on the title and keywords set by the authors and excluded within certain predefined categories. The 123 articles which remained were screened by abstract where some were rejected, and the rest rated on a scale of 1-3 based on relevancy to the research questions. The complete list of the selected articles is provided in Appendix B. The distribution of ratings after the full-text review is shown in Table 3.2.

Table 3.2 Distribution of relevance ratings in the final selection of articles.

Relevance rating	number of articles
3 – very interesting and relevant	16
2 – somewhat relevant	41
1 – some interesting points	40
Total	**97**

Out of the selected works, 60 were articles from publications, whereas 25 were proceedings papers and 8 were review articles. The rest were either books, degree projects or early access documents. The 68 articles and review articles were distributed across 46 different journals. The dispersion of journals shows that the topic includes many different perspectives and involves several fields of study.

It was found that a significant portion of sources used surveys or case studies and had consulted industry experts to come to their conclusions, which constitutes a solid foundation for such research (Hoyer, Gunawan & Reaiche, 2020). This proves that there is a robust connection between the results of the reviewed articles and the real-world issues faced by practitioners.

The number of relevant articles distributed per year shows a strong inclination towards more recent articles, as shown in Figure 3.1. 2016 was the earliest publication year from when articles were included in the literature review. However, no articles of sufficient interest were found from 2016 and very few from the following year.

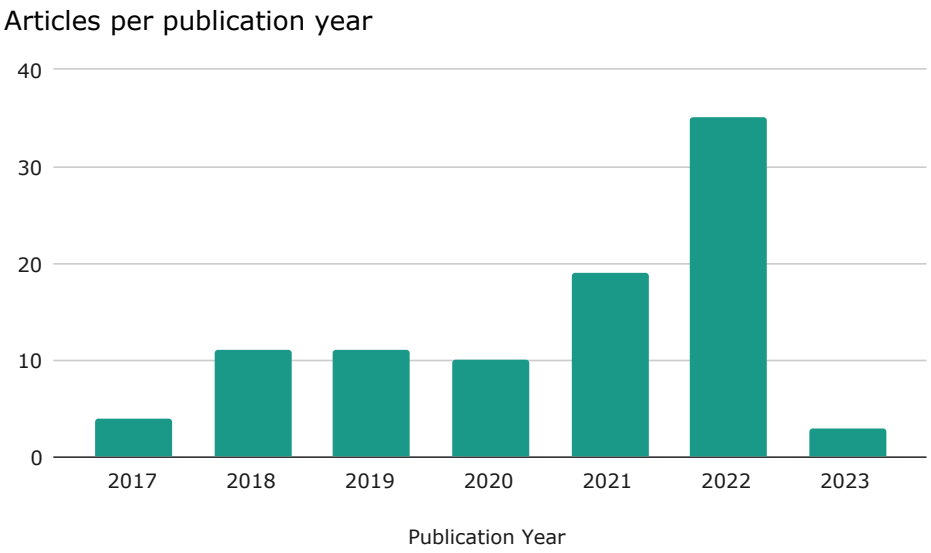

Figure 3.1 Distribution of articles in the literature review per publication year.

All articles in the final selection were read and coded with themes relating to the research of this thesis. On average, five themes were assigned per article. These themes were not determined a priori but were later consolidated and generalised into 'primary themes'. The most commonly occurring primary themes among the articles are presented in Figure 3.2.

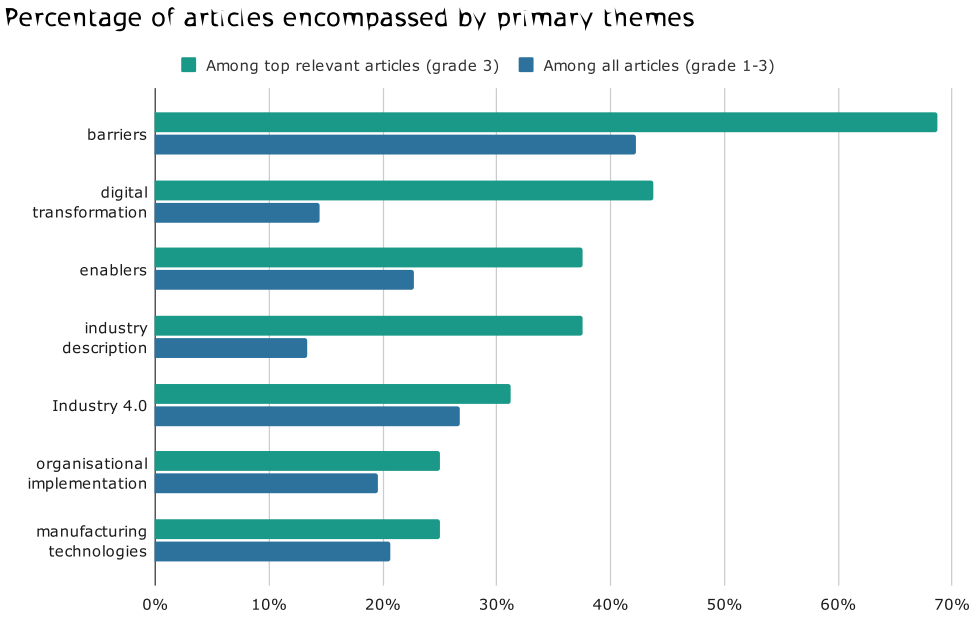

Figure 3.2 Percentage of articles which were encompassed by the seven most prevalent primary themes.

As stated, the authors intended to present an all-encompassing and up-to-date report on topics relating to industrial digitalisation, by presenting the collected research knowledge from the literature. For this reason, the articles were categorised by the primary themes and reviewed as a group, resulting in the following sections in this chapter.

3.2 Digitalisation in manufacturing

In the manufacturing industry specifically, it was found that there are several technologies that have been developed or that are in development, which drive the wave of digitalisation by giving rise to new innovations. Because of the centrality of these to the thesis, a deeper dive into these technologies is of interest.

Unlike many industries, manufacturing is defined by its physical nature and requires large investments in machinery, material handling equipment and factory properties besides staff and digital systems. As such the business models of manufacturers are based around these physical assets for value creation, which carries with it less flexibility in regard to manufacturers changing their business models (Wei, Song & Wang, 2017). Digital transformation has therefore been found to be a less applicable concept for manufacturers than digitalisation, in accordance with the definitions of this thesis. According to Demlehner and Laumer (2020), it has been observed that a notable share of manufacturing firms did not experience big impacts from digital transformation on business models, but are conversely seeing large impacts from digitalisation on its processes, giving rise to I4.0. This is unlike some industries which have already undergone or are currently undergoing radical disruption caused by digital transformation, such as the music industry through streaming or the banking industry through FinTechs (Demlehner & Laumer, 2020).

This is not to say that the adoption of digitalisation, and especially incorporating I4.0 technologies, has not been a major shift for manufacturers. I4.0 technology is often specialised towards precisely such industries where improvements materialise in business process efficiency, with significantly higher productivity and profitability as a result (SAP n.d.). A driving force to digitalise for manufacturers also comes in the form of competitive forces. As companies scramble to adjust to shortened product life cycles and to meet increasing demands for customisation and sustainability, digitalisation makes it possible to effectively generate and utilise production data as well as create an environment in which I4.0 tools can be efficiently incorporated (Demlehner & Laumer, 2020).

3.2.1 Technologies in Industry 4.0

By examination of several works published on I4.0 technologies from both academic and industry sources, 13 distinct I4.0 technologies have been identified that drive innovation in, and the adoption of, digitalisation. These are listed in Table 3.3, along with descriptions of their potential impact garnered from the aforementioned sources (SAP n.d.; Demlehner & Laumer 2020; Rad et al., 2022; Dalenogare et al., 2018).

Table 3.3 Driving technologies for the digitalisation of manufacturing.

Technology	Description of impact on manufacturing
Additive manufacturing (AM) and flexible manufacturing systems (FMS)	AM can transform digital models into physical products. Unlike subtractive manufacturing, additive manufacturing and production involve joining materials layer upon layer to create a physical output from a 3D model. This enables FMS which have a range of applications from rapid prototyping to mass customisation and distributed on-demand manufacturing.
Augmented reality (AR) and virtual reality (VR)	AR is a technology on the rise where digital content is superimposed on the real environment for improved visualisation in various manufacturing and supply chain environments. AR systems allow employees to use smart glasses or mobile devices to view real-time data and digital representations when looking at physical objects, which has major implications for maintenance, service, and quality assurance, as well as for training and safety. VR takes the concept further by immersing the user in a completely digital environment, which can be used by manufacturers in for example training scenarios.
Automated production systems and robots	Automated production systems have seen a rise in the manufacturing industry through the use of robotics and sensor technology, not only enabling data monitoring but also self-conducting manufacturing processes. Autonomous robots play a big role as they are capable of delicate or repetitive tasks with minimal human intervention, and can respond to and interact with other machines. The result is increased efficiency and productivity in manufacturing.
Big data and artificial intelligence (AI)	The collection of vast amounts of diversified data from various sources, such as factory equipment, devices and outside sources, can be analysed in real-time using AI and machine learning for predictive and statistical analysis. From these, knowledge and insights can be generated which improve decision-making in several areas such as manufacturing, logistics and procurement.
Industrial Internet of Things (IIoT)	IIoT, which is considered a subset to the Internet of Things (IoT), is central to Industry 4.0. It enables interconnected devices, machinery, equipment and products to share real-time data about their condition, performance, or location with users and each other. This allows for smoother supply chain operations, rapid modification of procedures, prevention of equipment downtime as well as tracking of products and inventory – for example through the use of incorporating radio frequency identification (RFID). In products, the incorporation of digital services based on IoT platforms also enables new capabilities for customers.

Cloud computing (CC) and storage	Cloud computing and storage is a technology that enables shared data storage, shared computational power, virtual applications and services on *the cloud*, i.e. not singularly located on any one server or computer. CC provides a foundation for many advanced technologies – from AI and machine learning to the IoT. The data resides in the cloud, and cyber-physical systems use the cloud to communicate and coordinate. The application of cloud computing in products thus extends their capabilities and related services.
System integration and monitoring	Industry 4.0 relies on information exchange in production as well as with other business functions. Sensor technology has enabled monitoring through data gathering, which allows for greater control and optimisation of manufacturing processes through what is called Supervisory Control and Data Acquisition (SCADA) software. Meanwhile, Manufacturing Execution Systems (MES) allow remote oversight and control of production as well as enable short-term scheduling. By also integrating data flows horizontally and vertically between business functions and across supply chains, production can be made more responsive to outside events.
Virtual simulation and digital twins	Simulation technologies enable the modelling and evaluation of complex systems and offer the ability to virtually represent objects and flows, allowing for model-based designing of systems. Digital twins are a core component, which are virtual simulations of real-world machines, products, and processes and can receive input from their real-world counterparts. They allow businesses to analyse and improve the performance and maintenance of industrial systems and products, such as identifying specific malfunctioning parts, predicting potential issues, and improving uptime.
Blockchain	Blockchain is a technology platform which allows for the storage and exchange of digital information and transactions, without the need for a centralised party. This technology can be used by manufacturers for cybersecurity applications and to facilitate transparent supply chain management.

3.4 Benefits with digitalisation

The ultimate goal of digitalising is that the organisation will benefit from it in some way. There is, however, a wide range of areas where an organisation can digitalise and attain benefits, so the impact of digitalisation relies heavily on to what extent the organisation commits. There are several different perspectives on how digitalisation can benefit parts of or all of an organisation.

3.4.1 Organisational benefits

When looking at the literature regarding digitalisation and its impact, one should start from a meso-level perspective to get an overview and understanding of the different areas and levels of the manufacturing industry where digitalisation makes an impact, with the support of the literature (Matt et al., 2022).

So far it seems that not a lot of academic research has resulted in quantifiable data on the impact of digitalisation for manufacturing companies specifically. Therefore a 2022 McKinsey report by Gregolinska, Khanam, Lefort and Parthasarathy (2022) is referenced here to provide specific and recent numbers.

All angles listed here are meant to show how digitalisation can benefit implementers are from an organisational perspective, in one way or another. The benefits and impacts of digitalisation have here been categorised into three different levels, as inspired by Parviainen et al. (2017), to facilitate better understanding: internal processes, external opportunities, and disruptive change.

3.4.1.1 Internal processes

Internal processes can be heavily improved when a company successfully adopts digitalisation in the organisation. There are numerous ways in which organisations enhance their internal process performance, such as using digital tools to produce products more efficiently and achieve higher quality. The numbers show that labour productivity can increase by as much as 15 to 30%, while the cost-to-quality numbers show improvement by between 10 to 20% (Gregolinska et al., 2022). Digitalisation can remove time-consuming and inefficient manual steps, thereby saving both money and time while reducing the risk of mistakes. Furthermore, by monitoring and analysing data, one can get a better overview of operations and better understand the process performance, cost drivers, risks, and where faults may appear (Parviainen et al., 2017). As a result, machine downtime can be reduced by 30 to 50% and the accuracy of production forecasts can increase by as much as 85% (Gregolinska et al., 2022). Furthermore, digital technologies in advanced manufacturing can create shorter lead times (both by visualising workflows and using scalable systems) and increase throughput by 10 to 30%, as well as reduce

costs from material stocks (15 to 20%) and from energy usage (Coreynen et al., 2017; Gregolinska et al., 2022). Additionally, internal production information can be utilised to inform customers of the status of their orders and if there are any potential issues.

Matt et al. (2022) argues that there are two main areas where digitalisation has major effects and benefits when looking at the innovating organisation: Knowledge management (KM) and open innovation. The argument regarding KM refers to the possibility of sharing knowledge and documents through digital platforms and thereby decentralising processes. Thus, creating knowledge management systems instead (Matt et al., 2022). Li, Merenda and Venkatachalam (2009) build on this idea, finding that increasing business process digitalisation has a positive impact on new product development, and that one of the reasons for this is that digitalisation makes it cheaper for companies to create information systems that can be accessed by the entire company and also other organisations as required.

For innovating organisations, the combination of open innovation and digitalisation is turning the current innovation methods on its head. We are now seeing digitalised open innovation – where cross-internal functions, suppliers, consumers, and even competitors are all contributing (Frishammar et al., 2019). Digitalisation, therefore, has the potential to completely change the way manufacturing companies innovate, in all areas.

3.4.1.2 External opportunities

External opportunities can appear when digitalisation enables better customer service through, for example, a more rapid response time (Parviainen et al., 2017) as well as better ways of handling Customer Relationship Management (CRM). What is even more important to note is that digitalisation, digital transformation, and new digital technologies help companies to develop options for clients to receive new services or enhanced offers from the company (Parviainen et al., 2017). Manufacturing companies, through digitalisation, can thereby integrate further with their customers and thus create more customised products (Coreynen, Matthyssens & Van Bockhaven, 2017).

One example of a company using digital technologies to enhance its offer to the customer is Nike, which in 2019 launched a new technology where customers can scan their feet through the Nike app. After scanning the foot, the app will recommend the perfect size for the shoe the customer wants to buy by using 13 different measurement points and a machine algorithm. In the future, they plan to manufacture personalised products entirely. Thus, Nike will be able to save a lot of money by reducing rates of return while simultaneously helping them to plan their inventory (Hanbury, 2019).

In reference to interconnected supply chains, Matt et al. (2017) emphasises the consequential effects arising from digitalisation, wherein the avoidance of supply

chain bottlenecks and minimisation of unnecessary transportation are highlighted. Lanz and Tuokko (2017) argue that a key advantage for manufacturing companies is the flexibility and connectivity of the supply chain which digitalisation has enabled.

3.4.1.3 Disruptive change

When talking about disruptive change as a result of digitalisation, it may be in the form of completely new operating environments. Thus, a digitalising company might end up emerging into a completely new industry (Parviainen et al., 2017). Matt et al. (2017) argues, looking from a market-related perspective, that transforming the business model is one of the main impacts of digitalisation. Digitalisation can enable a manufacturing company to identify and expand into completely new markets while also developing entirely new products and/or services, which is often referred to as *digital transformation* (Parviainen et al., 2017).

An example of a company making such a drastic transition is Netflix, which started a DVD-by-mail subscription service soon after it was founded in 1997. Through the utilisation of digital technologies, the company launched its streaming service in 2007. By doing so it started operating in a new environment, heavily relying on digitalisation (Clark, 2022).

3.4.2 Sustainability benefits

One cannot discuss digitalisation's impact on manufacturing without mentioning sustainability benefits. Given that the frequently assumed increases in resource efficiency can be realised, the digitalisation of industrial manufacturing has the potential to spearhead a greener, more sustainable and less wasteful world. More efficient use of resources such as energy, water and raw materials can be reached through the usage of smarter processes, which reduces waste (Gregolinska et al., 2022). Lower emissions can also be made possible from employing new technologies in the production processes. A greater use of renewable energy overall may also be made possible through digital tools and greater production flexibility. There are also hopes that digital technologies can push companies to use more renewable materials (Beier et al., 2017).

3.5 Potential barriers to digitalisation

Many different barriers were identified from the literature, stemming from a broad range of origins which have been explored by different authors. In this section, the aim has been to summarise all possibly relevant barriers found throughout the literature review. At this stage, these may be seen as *potential* barriers to digitalisation for manufacturers within the delimitations of the thesis. This is to say, that while not all of the barriers do necessarily pose a threat to any one single entity, outlining these possible barriers creates a registry to study when identifying which barriers *could* be impacting manufacturers.

A note on enablers:
It seems clear to the authors that by eliminating a barrier one might instead create the inverse; an enabling factor or "enabler". An example would be to rectify a lack of external funding opportunities by introducing financial incentives at an institutional level. Such incentives might then promote more digitalisation efforts than those which initially prompted the action. Theoretical enablers to digitalisation could however be the topic of a whole additional report. For this reason, and because many other enablers are principally the inverse of the barriers which are listed here, possible enablers are not discussed here in any great detail.

3.5.1 Theoretical framework for barriers

In the context of this thesis, the term 'barriers' include all factors whose presence might have a negative impact on organisations' ability to digitalise, even if some authors might not necessarily term these as barriers but rather as general factors to consider, such as the skill level of employees.

Most articles in which an examination of barriers is conducted have attempted to categorise different types of barriers. Hoyer, Gunawan and Reaiche (2020) in their article divided the factors they found to impact the implementation of I4.0 into external factors and internal factors, as well as a third category they call company characteristics. Matt et al. (2022) chose to classify barriers in their literature review into organisational, market, institutional and social/ethical. Ancillo et al. (2022) chose to divide the barriers they identified into Technological, Training, Economic and Contextual. This is to say, that even as all of these works were authored quite recently there still seems to be little consensus between authors on how such barriers should be categorised.

Lammers, Tomidei and Trianni (2019) created a framework for the specific purpose of categorising barriers to digitalisation in industry, which the authors ultimately chose to adopt for this thesis. Their framework, shown in Table 3.4, is a structured framework which considers both the nature (category) of the barriers in question as

well as their origins: *Intra-level* originates from within the frame of the company or organisation (compare to internal factors). The *meta-level* concerns policy-makers, the general public and global markets (compare to external factors). Between those is the *inter-level,* which concern the relationships of the organisation and its collaborators, competitors and the supply chain (Lammers, Tomidei & Trianni, 2019).

Table 3.4 Lammers' framework, by Lammers, Tomidei & Trianni (2019).

	Level of origin		
Categories	**Intra-level**	**Inter-level**	**Meta-level**
Financial			
Knowledge & skills			
Regulatory			
Technological			
Contextual			
Organisational			
Cultural			

The authors chose this framework, from this point referred to as *Lammers' framework*, based on the perception that it is best suited for a wide investigation of all areas of a company. The framework can therefore also be utilised by practitioners to ease the identification of barriers, avoiding the risk of overlooking certain areas. For this reason, the framework is also continuously used in the latter discussion of this report.

3.5.2 Potential barriers to digitalisation by category

Out of the articles with the highest relevance rating from the literature review, ten were found to have listed barriers of interest to digitalisation. The most commonly identified barriers were about the knowledge and skills present in the organisation, as well as technological and organisational factors on the intra-level. The barriers as described in the literature are presented in the following sections, in order of the categories within Lammers' framework. The potential barriers are then summarised in section 3.5.3 by placing them into Lammers' framework, forming 55 distinct barriers all-in-all.

3.5.2.1 Financial barriers

In all corporations, financial barriers present probably one of the biggest factors to change projects, and rightly so. All entities are subject to financial constraints where projects with short-term yields are often prioritised. Meanwhile, both digital systems infrastructure and I4.0 technologies are very costly. At the same time, calculating the return on investment (ROI) in digitalisation and I4.0 might be difficult (Hoyer, Gunawan & Reaiche, 2020).

At the inter-level, large financial projects may sometimes be undertaken by several cooperating actors which can spread the financial burden and associated risk. This might be especially beneficial if suppliers' systems may be integrated with those of the company (Matt et al., 2022). However, a lack of interest from collaborators may instead pose as a financial barrier to the exploitation of new technologies due to the risk of wasted research efforts on behalf of the first mover, in an otherwise collaborative environment.

On a larger scale, industries and entire markets may face financial barriers stemming from a lack of available external funding, both in the form of grants from public institutions and venture capital from private actors. This issue may also be exacerbated by the lack of demonstrated successful business cases in relevant industries which might be needed to justify the investment (Lammers, Tomidei & Trianni, 2019).

3.5.2.2 Knowledge and skill barriers

Another set of barriers which many authors identify concerns the knowledge and competencies of the staff in an organisation. Most such barriers act not in an obviously deterring way, like financial barriers which create hesitation from stakeholders, but rather as substantial obstacles to the implementation process that must be overcome for digitalisation projects to move forward.

Internally, IT and other technological competencies must be sufficient to implement and support the systems required for I4.0 and digitalisation. This is often a challenge, as has been observed in many studies (Gadekar, Sarkar & Gadekar, 2022). As a result, qualified staff must be recruited from a labour market where competition for IT talents can be very high. Even, people with such capabilities might not be available in the workforce at all (Lammers, Tomidei & Trianni, 2019).

While having expertise is important to digitalise, another factor which must be addressed is that the general staff might have little experience working digitally in the capacity which would be required, a factor often referred to as employee readiness. It is vital that skill development programs are introduced to equip workers with the skills necessary to adapt to their new working environment, where developing adequate training programs presents an additional barrier (Hoyer, Gunawan & Reaiche, 2020; Gadekar, Sarkar & Gadekar, 2022).

Another issue concerns the knowledge and awareness of relevant opportunities with digitalisation from management. A lack of awareness is especially detrimental regarding what digitalisation might mean for the business and its processes (Ancillo et al., 2022).

To effectively surmount the barriers to digitalisation, or indeed to execute any changes in the organisation, change management has risen to become a key skill which managers need to possess. However, it is also an area where many companies find their own capabilities insufficient and may require outside expertise to work in the organisation (Gupta, 2018).

3.5.2.3 Regulatory barriers

Regulatory barriers are predominantly on the meta-level and originate from governments or inter-government organisations which create laws and regulations as well as from non-governmental organisations (NGOs) that might formulate industry standards, such as the ISO (Lammers, Tomidei & Trianni, 2019). These may form barriers when inconsistencies arise between regulations or when regulatory developments are uncertain (Ancillo et al., 2022; Gadekar, Sarkar & Gadekar, 2022) as well as when legislation is outdated (Matt et al., 2022).

One area of special interest concerns intellectual properties and data security, where outdated or insufficient regulation might make it impossible for certain businesses to establish themselves in a region (Matt et al., 2022; Borovkov et al., 2021).

3.5.2.4 Technological barriers

Technology, as has been discovered, is what drives the I4.0 paradigm. Barriers in this category are among the most commonly cited throughout the literature review and may concern either challenges with specific technologies or, more commonly, the supporting IT infrastructure of an organisation.

One big challenge lies in that I4.0 technologies are very complex and require significant levels of integration with existing systems. This leads to high implementation costs which for practitioners may surmount the perceived benefits (Ancillo et al., 2022). The ability to manage such complex systems also requires significant employee allocation from the IT department, a barrier which can be difficult to overcome with a shortage of skilled staff. In production environments, existing equipment with low levels of automation takes a lot of effort to integrate with new manufacturing technologies, again requiring both resources and skills (Borovkov et al., 2021).

Strategically, preparing an organisation for digitalisation puts significant demands on data compatibility and secure protocols, which require a considerable amount of effort and expertise to formulate. This challenge may also involve outside actors in the case of integrated supply chains, where there may be a maturity gap (Borovkov et al., 2021).

3.5.2.5 Contextual barriers

Contextual barriers to digitalisation refer to issues in the external environment of organisations. The main challenges are often supply chain related, particularly the lack of cooperation among partner companies (Lammers, Tomidei & Trianni, 2019). This may create difficulties for individual actors who rely on information from collaborators, the exchange of which may be limited (Matt et al., 2022). This challenge is even more pronounced for companies operating in market segments where changes occur often due to regulations, trends, or habits, making adaptation to I4.0 processes even more challenging (Ancillo et al., 2022).

3.5.2.6 Organisational barriers

The adoption of digitalisation in a company may require changes in strategy, policy or structure to overcome. One of the primary organisational barriers is therefore a lacking implementation strategy. Without defined goals and a vision for implementation, companies may struggle to identify the necessary steps and realise the benefits of digitalisation (Gupta, 2018). This is often compounded by the inability of an organisation to align its digital strategy with its overall business strategy, leading to bureaucratic inefficiencies and underutilisation of digital technologies (Hoyer, Gunawan & Reaiche, 2020).

Another barrier arises from a lack of analysis on the correlation between the performance of different business processes, the result of which is company functions implement changes in assumed isolation. This can have unexpected widespread consequences which later hampers digitalisation efforts (Ancillo et al., 2022). Limited communication is also an important factor especially concerning the involvement of human resources (HR) in change management, highlighting the importance of having sufficient HR support to prepare the workforce and workplace for digitalisation (Gupta, 2018).

Moreover, a shortage of time allocated to planning and preparation can be a significant barrier to digitalisation efforts, especially when the organisation aims to digitalise within a short time frame. The complexity of a company, often related to its size, can also pose challenges in managing change. Therefore doing pilot projects and streamlining data flows is crucial to overcoming such barriers. (Lammers, Tomidei & Trianni, 2019)

Most organisational barriers occur internally or within company partnerships. However, one external organisational barrier which is difficult to address is a lack of relevant proven frameworks, which is still a factor in some industries (Hoyer, Gunawan & Reaiche, 2020).

3.5.2.7 Cultural and psychological barriers

Lastly, cultural and psychological barriers may be shared within an organisation or sometimes throughout society. However, unlike organisational barriers, these

emerge from mindsets and norms rather than from formal structures and policies. One barrier which might keep some organisations from even attempting to digitalise is poor motivation and attitudes; towards either digitalisation as a concept, its related technologies or consequences, or towards change overall (Hoyer, Gunawan & Reaiche, 2020). Scepticism towards the benefits as well as the fondness of existing business models may not necessarily hinder digitalisation outright but can act as a barrier to effective implementation. In such cases, it must be clearly understood and communicated what digitalisation actually means for the organisation and how it will be beneficial (Matt et al., 2022).

From a societal perspective, citizens may be reluctant to associate or do business with companies that deal with certain digital technologies. For example regarding big data, where there may be concerns about the ethical handling of private information. Or automation and its potential for eliminating blue-collar jobs (Matt et al., 2022). Such issues are important to consider by the organisation and to convey how they are to be addressed.

3.5.3 Summary of potential barriers to digitalisation

Table 3.5 Lammers' framework of potential barriers to digitalisation found throughout the literature.

	Level of origin		
Categories	**Intra-level**	**Inter-level**	**Meta-level**
Financial	• High implementation cost • Lack of internal funding • Profit uncertainty, risk aversion • Pressure to deliver short term ROI	• Lack of opportunity for shared research, thereby risk of wasted research efforts	• Lack of successful business cases • Lack of accessible public and private funding • Uncertain future market conditions • Aversion to reliance on loans and subsidies

Knowledge & skills	• Insufficient IT and tech competence • Lack of previous organisational change knowledge • No or inadequate employee training programs • Top management misalignment • Lacking leadership capabilities • Personnel lack awareness; of process, impacts, technology • Personnel lack interest	• Skill gap for cooperation with partners and institutions • Challenging to provide necessary training to customers and suppliers	• Lacking skilled workforce to recruit • Not able to hire competent personnel • Lack of qualified implementation specialist, consultants
Regulatory	• Misunderstanding of regulatory terms	–	• Lack of or insufficient business standards and frameworks • Hindering policies and regulations • Absence of privacy and security regulations • Absence of intellectual property rights • Regulation uncertainty and inconsistency
Technological	• I4.0 tech is too complex • Lack of required tech (It- and automation infrastructure, internet connection stability, outdated manufacturing tech) • Lack of data security measures • Lack of I4.0-compatibility in existing tech	• Lack of industry software standards • Data security concerns with partners' systems • IT maturity gap between cooperating participants • Incompatible standards • Absence of technology meeting special requirements	• Privacy and security concerns • Absence of available secure infrastructure solutions

Contextual	–	• Unreadiness of customers and suppliers • Technology governing norms • Lack of integration between partners • Market segments are changing constantly	• Lack of standardisation: Compatibility in com-protocols, tech, laws • Lack of political support
Organisational	• Unable to align digital strategies with overall strategy • Lack of HR support • Not enough managers to implement change • Company inertia due to size or complexity, i.e. lack of flexibility • Lack of clear vision/goal for implementation • Not enough time / expecting things to move more quickly • Lack of documented implementation plan • Departments are isolated from each other	• Lack of established common practices • Risk for occupational health and safety	• Lack of organisational frameworks specifically suited for companies
Cultural & psychological	• Poor organisational attitude towards digitalisation or innovation • Company sluggishness, poor motivation to change • Individuals sceptical towards advantages of digitalisation • Devotion to conventional, existing business models	–	• Poor social acceptance for digitalisation • Ethical/moral issues with digitalisation and private information access

3.6 Organisational change

The need to adopt digital solutions in organisations is becoming more urgent as a result of the benefits made possible as well as the new problems ushered in by the new era of digitalisation (Martinez, 2019). It is said that the implementation of digital technologies within an organisation will inevitably change that organisation at its core (Parviainen et al., 2017). However, it is difficult for organisations to succeed with transformation in general, and the success rate has so far been rather low (McKinsey, 2018). Even more difficult is when organisations attempt transformation connected to digitalisation and digital technologies. Still, according to McKinsey (2018), more than eight out of ten surveyed organisations have in one way or another tried to transform their organisation into a more digital one.

It can be argued that it is digital strategy, which is ingrained in the organisational culture, rather than advancements in technology that drives digitalisation (Kane et al., 2015). A digital strategy, in general, incorporates a company's ambitions toward digitalisation with that of the overall business goals of the company. However, to start the process of digitalising an organisation, it is crucial to understand where the organisation stands in digital maturity. This includes understanding one's available digital capabilities and what actions that need to be taken to address shortcomings. The goal of understanding the digital maturity of the organisation is to know where the organisation is today compared to where it needs to be in order to be ready to persuade a successful digitalisation process (Schallmo & Tidd, 2021). In other words, it is a measure of how ready the organisation is to commit to digital change. Deimler and Reeves (2012) argue that current trends point towards the creation of a new business environment, thus an organisation's ability to adapt is key to competitive advantage. Other factors for an organisation to succeed in a world defined by transparency, new technologies, and globalisation include curiosity to try new products, services, strategies, and business models, a capability to inspire colleagues as well as a capacity to handle multiple stakeholders simultaneously (Deimler & Reeves, 2012).

3.6.1 Accelerating change

How can an organisation effectively implement change and excel in change management? In 1996, John P. Kotter published an 8-step process for leading change. The 8-step process was developed for a hierarchical organisation where the main focus was to achieve goals over time in a linear way (Kotter Inc., 2018).

In 2012, Kotter wrote about his new ideas for organisations to better keep up with the rapidly changing environment around them. These ideas included a second operating system working completely differently, in an agile network-like structure,

with a focus on the design and execution of strategy. This system is supposed to continuously evaluate the organisation and its surroundings, and be able to work with innovation, agility, and pace. The new operating system was not supposed to replace traditional ways of working but rather support the existing organisation and ways of working. At this time, Kotter also presented eight accelerators (some similar and some different compared to the original 8 steps) that function as processes for the new operating system, see Figure 3.3 (Kotter, 2012).

Figure 3.3 The Eight Accelerators for organisational change (Adapted from Kotter, 2012)

In conclusion, in a rapidly changing world, pushing an organisation to be agile and focus on change management through implementing dedicated frameworks, is to prepare it for success. Of extra relevance to this thesis, working proactively with change management and having an organisation prepare before diving straight into implementation means that an organisation can bypass many unnecessary problems that they otherwise may face.

3.7 Industry development

3.7.1 Technological paradigm

One of the most famous academics who has written about paradigm shifts is Thomas Kuhn (1922-1996). His book *The Structure of Scientific Revolutions* is one of the most widely referenced academic texts ever (Bird, 2022). Kuhn (2012) talks about paradigm shifts as a major shift in a specific scientific discipline's underlying ideas and methods. According to Riemer and Johnston (2016), Kuhn questioned the widely held belief that science tells a linear tale of advancement. Instead, he showed how times of continuity, or "normal science", are frequently punctuated with disruptive eras of revolutionary research. Riemer and Johnston (2016) divide Kuhn's description of a revolutionary paradigm shift into four stages: "1) normal science, 2) emergence of anomalies, 3) paradigm change and crisis, 4) post-revolutionary normalisation" (Riemer & Johnston, 2016). Furthermore, it is suggested that Kuhn's explanation of how scientific areas develop might shed light on how disruptions affect enterprises and how the development of new technologies can generate transformations. Reimer and Johnston (2016) try to translate Kuhn's 4 stages of a paradigm shift in science into 4 phases of a paradigm shift in a specific industry to see the parallels between industry disruptions and scientific revolutions: 1) "Business as usual", 2) "Emergence of anomalous competition", 3) "Industry disruption", 4) "Post-disruptive normalisation". All in all, scientific and industrial progress were found not to be linear but rather consists of numerous revolutions where new theories or anomalous competition replace existing ways of thinking, resulting in a transformation of the way scientific theory, technology as well as industry are thought of.

Although Kuhn largely limited his use of paradigm shifts to its use in sciences, the idea can still be used in situations outside of academia to denote a significant transformation in a core belief system or way of viewing the world, as mentioned above. Someone who has built on the ideas of Kuhn is Carlota Perez. Perez (2009) is discussing both techno-economic paradigms and technological revolutions and refers to Giovanni Dosi, who originally introduced the term *technological paradigm* in 1982 (Dosi, 1982). Both authors have had Kuhn in mind when introducing their theories. So, at the point where technical potential, relative costs, market acceptance, functional coherence, and other factors coincide, a paradigm is a logic that is broadly accepted. Perez puts a lot of emphasis on the importance of incremental innovations after a radical innovation resulting in a paradigm shift (Perez, 2009). Hence, a paradigm doesn't start and end with a radical innovation, but rather numerous new innovations that transform the way a certain industry works, digital technologies in manufacturing for example. The path of a singular innovation, such as a new revolutionary technology, can be seen in Figure 3.4.

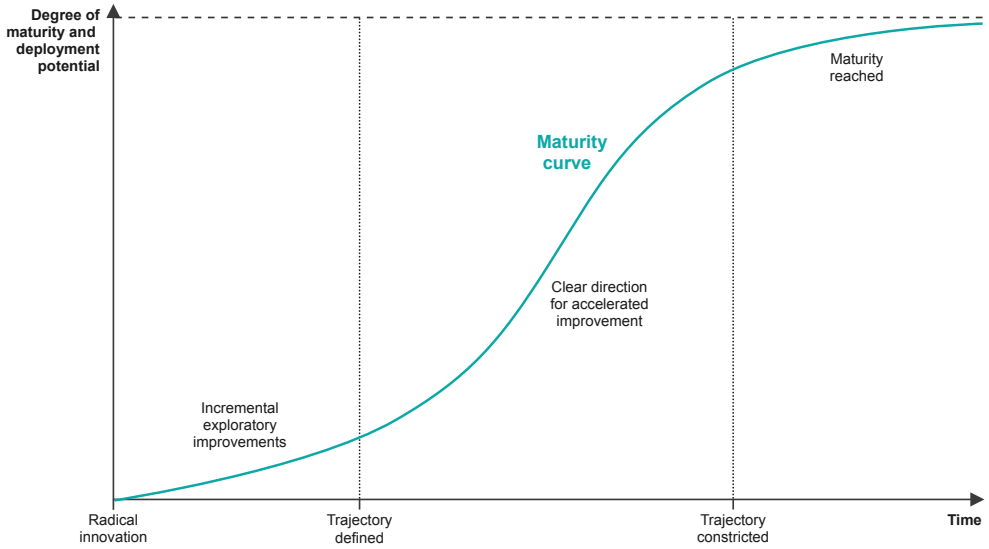

Figure 3.4 The adoption trajectory of an individual technology (Adapted from Perez, 2009)

According to Perez (2009), individual innovations do not just appear at random but rather link with one another and frequently pop up close to other developments. When innovations are fundamental enough, they have the potential to change entire industries. The idea of *technology systems* implies this type of interconnectivity between technologies. Technology systems thus have the ability to change businesses, industries, and even cultures. Furthermore, together with specialised training, new standards, and other institutional enablers, new laws and regulations may also necessarily follow. Perez (2009) further develops on the idea by saying that technological revolutions consist of interconnected technology systems (just as technology systems consist of individual innovations). She defines a technological revolution as "a set of interrelated radical breakthroughs, forming a major constellation of interdependent technologies; a cluster of clusters or a system of systems", and argues that the revolutions consist of "strong interconnectedness and interdependence of the participating systems in their technologies and markets" as well as "the capacity to transform profoundly the rest of the economy (and eventually society)" (Perez, 2009).

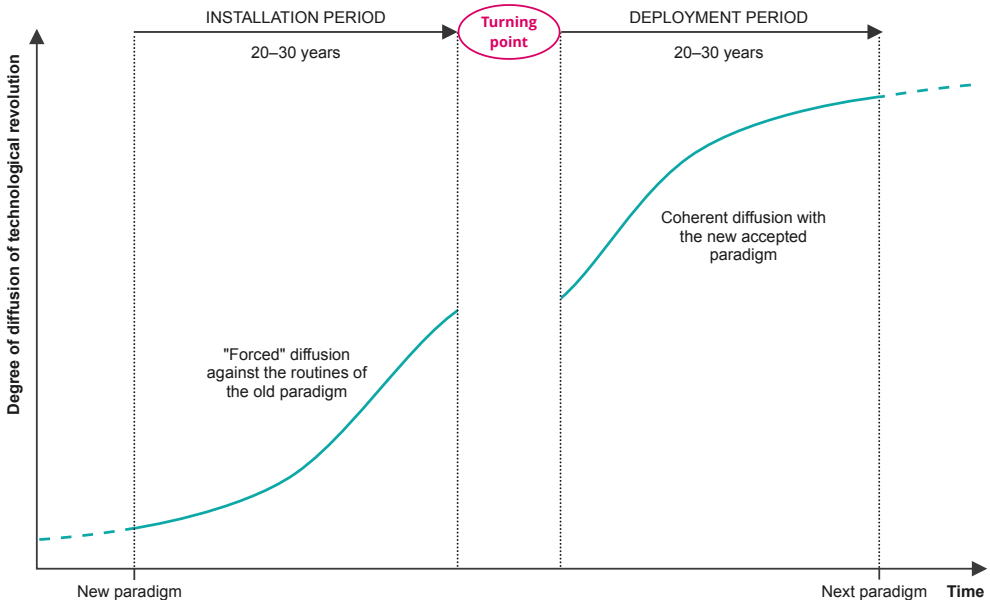

Figure 3.5 Time periods in the diffusion of technological revolutions (Adapted from Perez, 2011)

As seen in Figure 3.5 the diffusion of technological revolutions consists of two different periods known as *installation* and *deployment*. The *installation period* is characterized by the battle of new entrepreneurs to overcome the deeply embedded resistance of the old paradigm, with leadership increasingly shifting to the hands of financial capital to back emerging paradigms. Between the two phases, there would typically be a recession of varying length during which all the negative social and economic effects of the bubble that is the old paradigm would come to light and there would be great demand for drastic reform. In this pivotal moment, institutional frameworks are to be changed in ways that allow for more production capital, often represented by new firms and industries that take control of the financial capital. The following period, referred to as the *deployment period*, is when the freshly created paradigm becomes further ingrained in all facets of society. Both new and old companies then control the production capital and the economic processes. It is also important to note that technological revolutions overlap each other, hence no technological revolution reigns alone (Perez, 2011).

3.7.2 Adoption of new technologies

When it comes to organisations adopting new technologies, in this case manufacturing companies adopting digital technologies, one theory of particular interest is the diffusion of innovations theory, originally launched by Everett M. Rogers. He defined diffusion as "the process by which an innovation is communicated through certain channels over time among the members of a social system" while an innovation is "an idea, practice or object perceived as new by an individual or other unit of adoption" (Rogers, Singhal & Quinlan, 2019). Some authors claim that technologies are adopted the same way as innovations are over time and that technologies should be seen as innovations (Swan, 2020; Fleiter & Plötz, 2013).

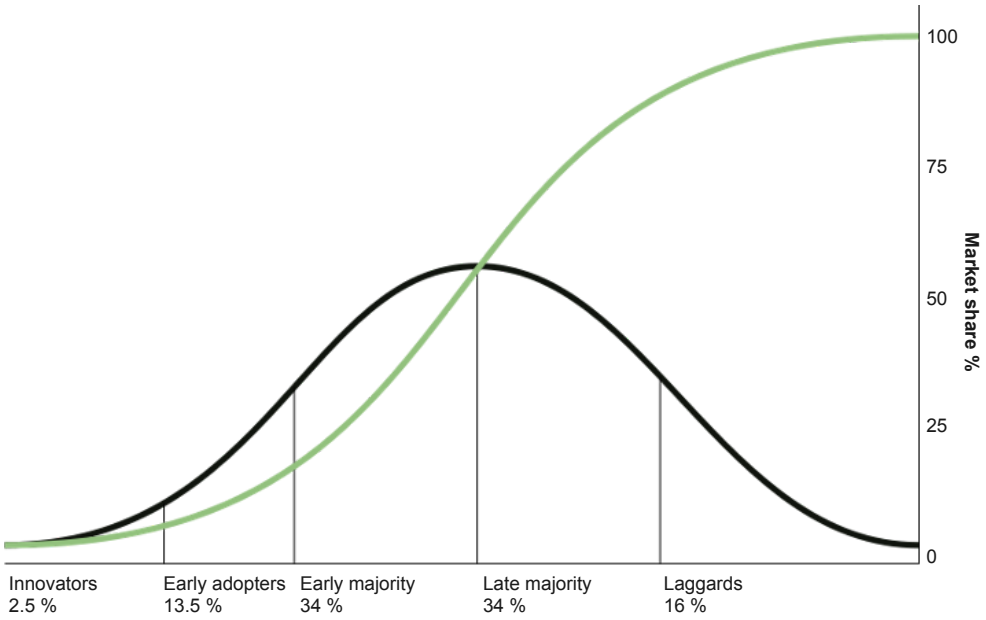

Figure 3.6 The Diffusion of Innovations according to Rogers (1962)

In Figure 3.6, one can see how Rogers illustrated one curve (black) based on the relative time of adoption of a certain innovation/technology (Rogers, 1962), and one curve (green) showing the rate of adoption of the innovation/technology (Rogers, Singhal & Quinlan, 2019). It is important to note that adopters can be anyone, people as well as companies and organisations. As one can see in the graphs, there is a point where the rate at which an innovation is adopted is increasing at its highest rate. This happens for all innovations and results in the "S-curve of diffusion" (Rogers, Singhal & Quinlan, 2019).

3.7.3 Statistics on the progression of industrial digitalisation

When looking at I4.0 and the adoption of digital technologies in manufacturing, some authors claim that we in fact are seeing a new paradigm take place in the manufacturing business (Zangiacomi et al., 2020; Mesa et al., 2022). If this is the case, then how far has the manufacturing industry come in its transition?

A survey of 230 senior manufacturing decision-makers shows that already in 2021, 91% of companies increased their investments in digital technologies while 77% simultaneously claim that the increase was significant (Fictiv, 2021). Another survey from 2022 performed with manufacturing leaders says that 58% of manufacturing companies have started their digital transformation journey (Maw, 2022). A global survey by PwC Germany from 2022 claims that 64% of manufacturing companies are either still developing a roadmap, beginning the transformation, or in an initial progress phase when it comes to the implementation of digital factories. Furthermore, 28% of the manufacturing companies are halfway through their digitalisation journey, 7% are ¾ done and 3% are fully transformed (PwC Germany, 2022).

In Sweden, out of 300 responding companies within production/manufacturing from 2017 to 2019, 28% said that they hadn't come far on their digitalisation journey while 29% said that they were just starting and 43% said they were working intensively. In 2022, 33% of the respondents said that they had come very far on their digitalisation journey while only 25% said that they were either just starting or hadn't come far at all and the rest were somewhere in between (IVA, 2022). Hence, the transition among Swedish manufacturing enterprises was moving forward rapidly. Meanwhile, when looking at Italian companies for example, 13% hadn't started their digitalisation journey in 2021, while 66% were at an analytical stage or early adoption stage and 21% had adopted digitalisation or even fully integrated it into their business processes (Truant, Broccardo & Dana, 2021).

From a macro perspective, the market of smart manufacturing is expected to be worth around 651.5 billion U.S. dollars in 2029 compared to 277.8 billion U.S. dollars in 2022 (Fortune Business Insights, 2022). Furthermore, 100% of surveyed chief economists say that Europe will experience weak or very weak economic growth during 2023, and 63% say that there is somewhat likely or very likely that there will be a global recession in 2023 (World Economic Forum, 2023).

4 Research results

In this chapter, the results of the conducted interviews and subsequent thematic analysis are exhibited. These results are the authors' observations and deductions from the open-ended interviews, yielding apparent barriers and success factors for the digitalisation of manufacturing based on the studied cases.

The barriers which were discovered through the interviews were analysed using a Gioia framework, which is presented below. Following this are the authors' insights on the identified barriers and their impact, based on both literature, the case study results and various discussions with consultants at AFRY. Solutions that the case companies employed to the barriers are also presented, both in cases where they were encountered and in cases where they could be avoided. Finally, several overall success factors are presented, as contributed by the interviewees themselves. These success factors have applied to one or several of the case companies and convey part of what the interviewees think has made their company achieve success in their digitalisation journey. These success factors along with the solutions contribute to the final recommendations of the thesis.

4.1 Apparent digitalisation barriers

Statements from the performed interviews and subsequent Gioia analysis are presented below in Figure 4.1a-c. In it, 1st order concepts in the form of condensed interviewee statements enforce 2nd order themes, which are stated in the form of barriers which were deducted from the cases. These barriers are then consolidated under five aggregate dimensions, representing general areas of the companies where barriers were found. Then, Lammers' framework has been used to summarise the identified barriers in Table 4.1.

In the text contained in this chapter, the authors have provided some directly translated quotes from the interviewees to exemplify the highlighted issues. It should be noted however that the quotes provided are not directly referenced to the source. This is because the interviewees were promised anonymity when quoted, as the purpose of this thesis was not to examine the specific case companies in any way. Therefore, while the quotes are attributed to the interviewees, they should not be considered to be tied to any of the specific case companies.

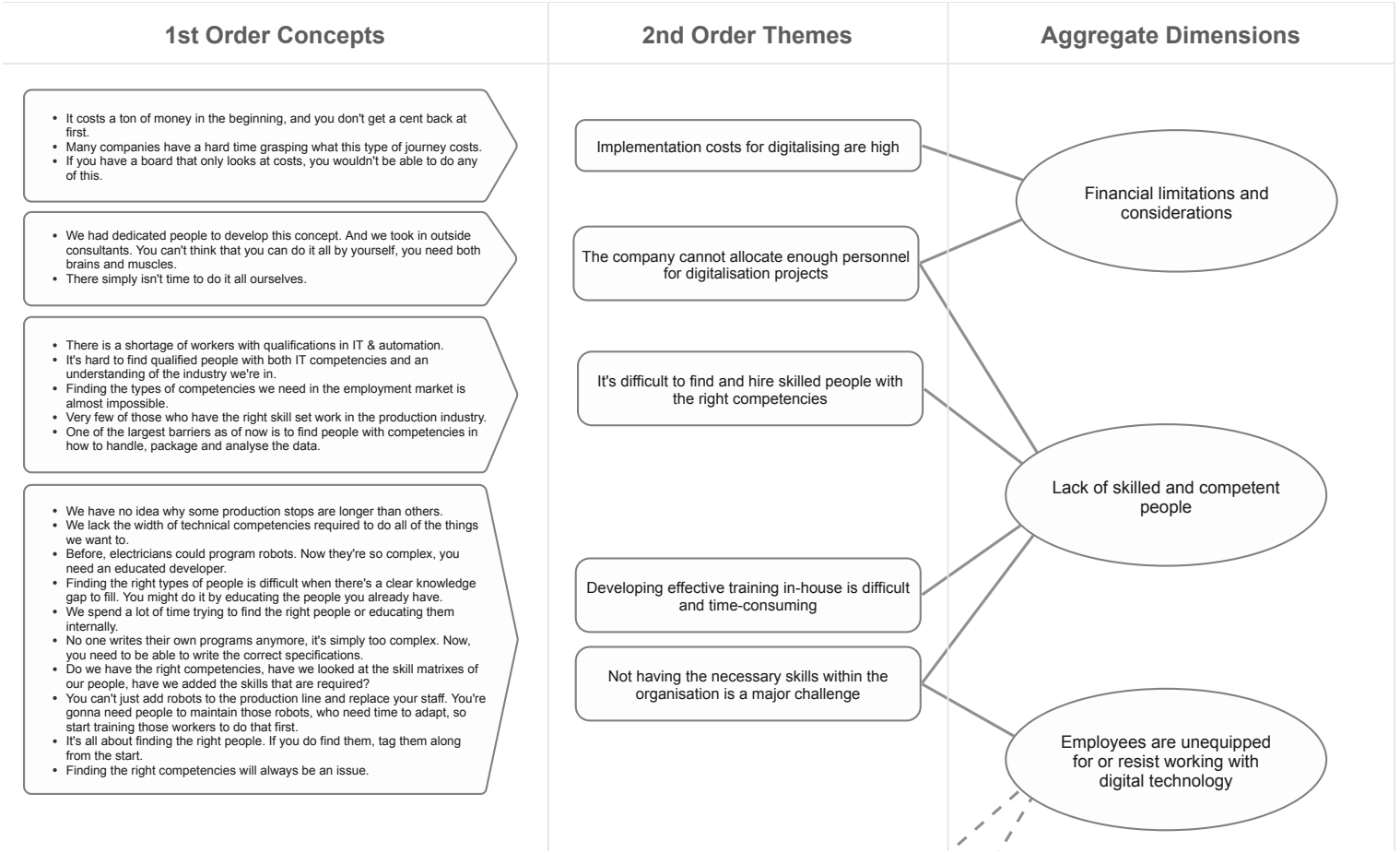

Figure 4.1a Gioia analysis of identified barriers from the interviews, page 1/3.

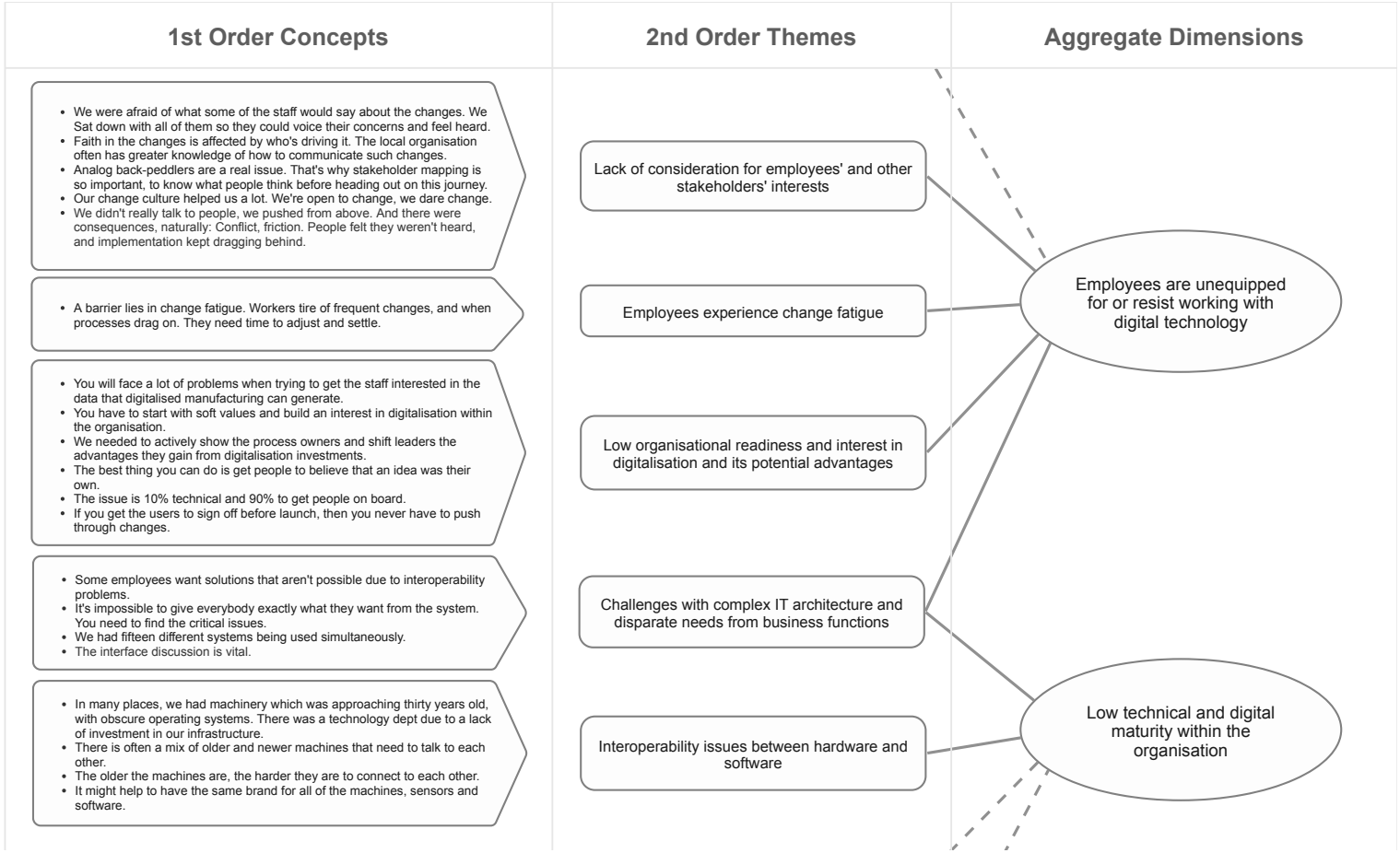

Figure 4.1b Gioia analysis of identified barriers from the interviews, page 2/3

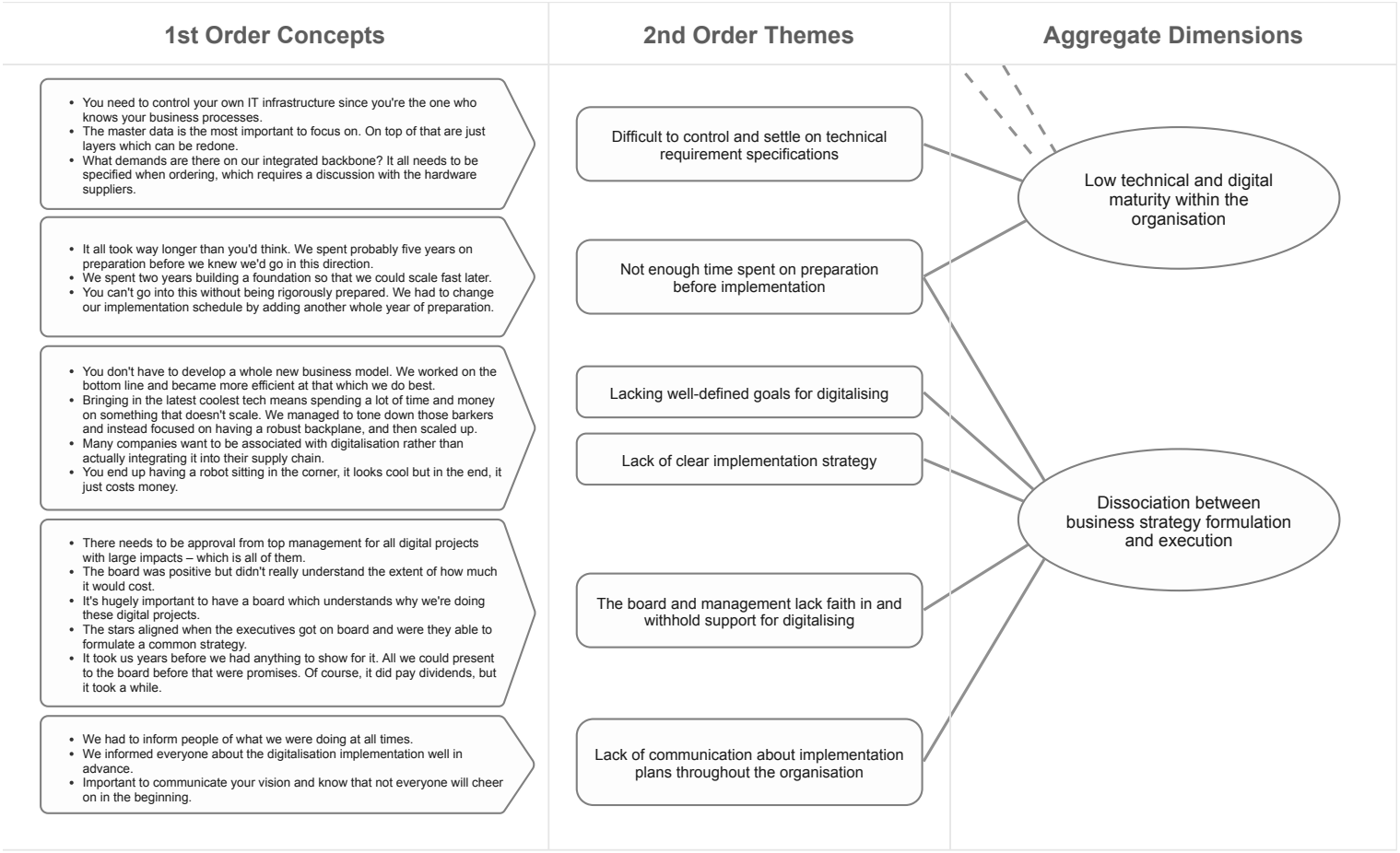

Figure 4.1c Gioia analysis of identified barriers from the interviews, page 3/3

Table 4.1 Lammers' framework summarising the case study results.

	Level of origin		
Categories	**Intra-level**	**Inter-level**	**Meta-level**
Financial	• Implementation costs are high • Company cannot spare personnel resources for digitalisation initiatives		
Knowledge & skills	• Lacking the necessary skills • Difficult to develop effective training programs		• Difficult to hire competent staff • Not enough skilled people available in the labour market
Regulatory			
Technological	• Complex IT infrastructure • Interoperability issues between hardware and software • Difficult to formulate technical specifications		• Incompatible hardware and software standards
Contextual			
Organisational	• Low digital maturity within the organisation • Lack of clear implementation strategy and goals • Lack of understanding from the board and/or management • Disparate business processes • Not enough time spent on preparations • Lack of communication towards employees • Employees experience change fatigue	• Low readiness of suppliers and partners	
Cultural	• Lack of consideration for employees' interests • Lack of interest in digitalisation • Scepticism towards digitalisation		

4.1.1 Financial limitations and considerations

One of the areas that the interviewees touched on when discussing barriers was financial limitations and considerations. Barriers on this theme include high implementation costs for digitalising the manufacturing processes, as well as costs for employing outside technical expertise to assist in digitalising. The high implementation costs are extra significant since it is often very hard at the start of the process to understand the benefit of the hardware and/or software that is acquired compared to the initial cost of it. “It costs a ton of money at the beginning, and you don’t get a cent back at first”, one interviewee said. The problem of not initially being able to see the benefits may also result in withholding of funding from decision-makers, forming a barrier before even starting the actual development phase. Furthermore, it was found that it is generally hard to calculate the total costs of the digitalisation journey for a manufacturing company since the process is often iterative and not fully planned out from the start.

The solutions, or possible solutions, mentioned by the interviewees include being extremely diligent when doing the necessary financial calculations, both when it comes to the costs and ROI. This means taking the time during the preparation phase to explore all possible costs and monetary savings that might be the result of the planned implementation of digital technologies and systems in the manufacturing processes, which requires knowledge of their impacts. Having the necessary key figures is crucial to substantiate the credibility of the investment and facilitate decision-making. Hence, having performed all the calculations, created a budget, and mapped its returns makes it easier to justify the investment towards the board and investors, as well as to avoid unexpected expenses.

4.1.2 Lack of skilled and competent people

A common barrier regarding skills and competencies concerns the fact that most companies have a hard time identifying what total skillset their employees possess. Following this, a barrier often lies either in knowing who their most skilled and suited employees are, or, that they simply do not have the required skills in-house to address their own digital needs. Hiring consultants can alleviate this issue to an extent and can certainly help start the implementation process and facilitate further development. Introducing skill development programmes is another solution which some companies have seen success with, either by utilising experts internally (if they exist) or by bringing in outside counsel. Two of the case companies lifted how a wide mapping of their current competencies helped them identify their own strengths and shortcomings. This enabled them to combine the skills of people from different

teams with different responsibilities and utilise them as an expert unit, moving them around as different production areas or sites started digitalising.

A long-term solution to the lack of necessary skills is naturally to hire more people. However, the case companies all consider this a major challenge. Hiring staff with the right skills and competencies, for example in areas such as robotics and automated manufacturing, is currently very difficult. The interviewees indicated that people possessing such skills from university, in academic specialisations that haven't existed all that long, are quite rare in combination with having experience and interest in working with manufacturing. Additionally, many who do have this set of prerequisites are often unwilling to switch jobs. This means that there is high demand for skilled and competent employees, often leading to a situation where a few large and attractive companies employ a majority of such sought-after people. Some manufacturing companies also face the issue of being geographically situated in places that are not very appealing to move to for potential employees, exacerbating their difficulties in hiring staff from other places.

4.1.3 Employees are unequipped for or resist working with digital technology

For some of the case companies, it became clear that getting their employees on board with digitalisation should be a top priority and posed a significant challenge. This was particularly true for employees whose job assignments would be significantly impacted by the changes brought about by digitalisation. One interviewee, a technical expert, even said that "the issue is 10% technical, 90% getting people on board". This being the case was perhaps more expected in traditional manufacturing companies where employees may be more hesitant to change. However, the authors were surprised to find this issue to be evident even in case companies where the company had already invested significant resources in modernising and digitalising their operations for quite some time.

It was understood that the issues that were encountered didn't have so much to do with singular "traditionalists" (except in some instances). Most companies had pre-emptively tried to address that potential barrier. Instead, the companies disclosed that the barrier of resistant employees could be handled through proper change management and clear communication early on. For companies with a typical hierarchical governance structure, this meant having production floor managers act as representatives and mediators between upper management and the factory employees, actively demonstrating to them their new capabilities and de-dramatising the concept of digitalisation. They could at the same time listen in to the workers' worries and have them brought up through the proper channels. Finally, such trusted individuals could advocate the proposed changes for their co-workers and communicate the benefits that the changes would mean for them specifically. A

message which wouldn't be as convincing coming from "outsiders" such as higher-ups.

Lingering issues with the readiness of personnel beyond the above factors are more difficult to solve. Employees might not have enough experience working with digital tools, especially complex cross-functional platforms which entail trade-offs in desired functions – which might have been in place in previous systems. General wide-use platforms might be conceived as inferior to legacy systems for this reason, for certain tasks. But the issues might also originate on the systems-side. Frustration over difficult user interfaces leads to resistance, which is understandable and was lifted as an issue for several companies. This barrier may sometimes be disguised as employees resisting change, but in reality, might be an issue of inadequate application software.

4.1.4 Low technical and digital maturity within the organisation

The introduction of new technologies often creates barriers due to technical complexity or implementation issues. Such barriers are often the result of cumbersome and outdated networks consisting of several redundant systems, or unwieldy ill-formatted data flows.

Modifying existing data flows and reducing redundancy is advised, even if this might require significant rework of multiple business processes. However, the authors found that most case companies had already made some effort to harmonise their IT infrastructure and reduce reliance on different software for different business functions. As a result, when these companies interconnected their manufacturing and business systems as part of their digitalisation journey, compatibility and interconnectivity were much less of an issue. It is worth noting, though, that this process took those companies quite some time.

Some of the case companies encountered another barrier: their production machinery couldn't be made compatible with their new systems without significant investments in sensors and interface modifications. In some cases, such investment would be worth it, in other cases the only viable options were typically to leave out such machines from the process entirely or upgrade to more advanced machinery.

In the context of managing data, ownership and control of the data infrastructure is an important factor that can impact a company's ability to service and modify their own systems. Some companies prioritise knowing their IT infrastructure in detail to be able to accurately deliver technical specifications. This helps them to have a better understanding of their own technical requirements and to communicate their needs more effectively to hardware and software suppliers, avoiding confusion and time wasted. However, all companies recognise that this can be a challenging task which requires preparation and research.

From the interviews, the participants recommended that companies prioritise attaining high-level competencies when faced with limited resources. For more specialised skills, they suggested seeking assistance from consultants in areas such as application design and integration. This way, companies can maintain their knowledge of the digital backbone while still being able to tap into specialised skills as needed. Despite the difficulties associated with acquiring such high-level expertise in-house, all companies view ownership and control of the IT infrastructure as an important aspect of their business which therefore needs to be managed properly.

4.1.5 Dissociation between business strategy formulation and execution

During the interviews, barriers were found due to a disconnect between a company's business strategy and execution. These challenges arise when a company lacks clear goals for digitalising or adopts digitalisation for the wrong reasons.

Success often hinges on overcoming multiple obstacles which can only be overcome with a well-formulated digitalisation strategy. Therefore, board and management support are crucial for any manufacturing company to embark on a successful digitalisation journey. To make it easier to get decision-makers invested, clear goals, a well-structured implementation plan, a carefully calculated budget, and a strong business case are important. In one interview, it was noted that "it's hugely important to have a board which understands why we're doing these digital projects", underscoring the need for their support.

One possible and straightforward goal for digitisation might be to improve existing processes, instead of trying to transform the entire business model right away. This approach allows the organisation to achieve more realistic and measurable goals to present to decision-makers. Meanwhile, the implementation plan should be detailed, to avoid the problems that arise when managers only have a vague implementation strategy to go by.

To overcome the barrier of a lack of communication about implementation, it is essential for the management team to be transparent and inform everyone affected within the organisation about upcoming changes well in advance. It's important to understand that not everyone will be on board instantly. One potential solution mentioned was to map all the stakeholders, talk to them and get their point of view, thus anticipating what the response will be from all parts of the organisation.

In conclusion, the success of a digitalisation journey relies on having support from the board and management. Overcoming this barrier is fundamental for all manufacturing companies.

4.2 Success factors

From the interviews, a number of success factors were discussed which the case company representatives attributed as factors which helped them implement digitalisation in the organisation. Such factors were found to not have been primarily employed as a solution to any specific barriers, even though some barriers might have been negated by these in practice.

These success factors represent some of the most promising practices in the manufacturing industry, and can be mimicked by other practitioners to achieve their own digitalisation goals. It should be noted that these were uncovered from the same interviews as the barriers, however because of the smaller data set they could be generalised directly and were thus not included in a Gioia analysis. It should also be noted that these factors are often not necessarily specific to manufacturing companies, and could be appropriate for any organisation undergoing digitalisation.

4.2.1 Develop a positive change culture

Cultivating a change-positive work culture and encouraging active participation can make it easier for companies to implement digital solutions. To encourage participation, companies can create a sense of ownership for initiatives, offer training and development opportunities, and foster a culture of innovation. When employees feel supported and valued, they are more likely to support change like those brought about by digitalisation, even though the changes are introduced from high up in the hierarchy.

To promote employee creativity and innovation, companies should establish clear communication channels for submitting ideas and feedback. This can include regular dedicated meetings, suggestion boxes, and online forums. It is then important to make a real effort to attempt the suggested improvements and acknowledge employee contributions, to reinforce a culture that is positive towards change.

4.2.2 Integrate suppliers

Some of the case companies have seen significant benefits from digitalising their operations especially when integrating their suppliers into their digital ecosystem. By collaborating closely with their suppliers, applying pressure where needed and offering assistance when necessary, these companies have been able to integrate the supply chain into their manufacturing process, effectively making theirs and the suppliers' manufacturing process act as one.

While not something that was within the scope of all the case companies, those that were able to involve their suppliers in the digitalisation journey found that this approach not only improved the reliability and accuracy of deliveries but also achieved a streamlined manufacturing process, making it more efficient and cost-effective. Additionally, by collaboratively developing digital solutions with their suppliers, these companies developed stronger relationships and built more valuable partnerships, positioning themselves well for long-term growth and success.

4.2.3 Visualise the advantages of digitalising

Developing a visual roadmap, highlighting the change areas as well as the specific benefits digitalising would bring has shown to be a success factor for some of the case companies. This has advantages both in terms of creating a story of why, how, and when changes are happening from the point of view of the employees, but also creates a narrative which can be used to convey the significance of the project to the board, to managers and investors.

Some employees, especially on the production floor, may initially fear being replaced or having to learn new complex technology when hearing that there are plans to digitalise the manufacturing processes. If the benefits of the digitalisation journey can be visualised for them at an early stage, unnecessary resistance or hesitation can be avoided. Since there often are benefits for the employees resulting from the digitalisation of for example manual processes, such as less ergonomic stresses, visualising these advantages can prove to be a success factor at an early stage.

4.2.4 Incremental progress and pilot projects

Several of the case companies have adhered to implementing digital aspects into their manufacturing organisations in incremental steps, addressing the most vital needs one at a time and focusing on getting those right. Along the way, one can adjust the implementation strategy while receiving inputs on the things being done, thus being able to revert when something doesn’t turn out as intended.

This approach is not always feasible, however, as different parts of the manufacturing processes may likely be too dependent on each other. In such cases, some companies instead chose to do limited pilot projects by digitalising only one production area or production line at a time. Typically, this means implementing, testing, and refining the processes several times over the pilot project, ironing out any potential issues before scaling up the implementation to reach the rest of the manufacturing organisation.

5 Discussion

This chapter contains discussions on the most significant results from the literature review, along with an analysis which contrasts the results from the literature with those of the case study. The chapter also discusses some limitations of the conducted research.

The thesis has resulted in several interesting findings. Section 5.1 summarises the authors' key insights on the *state-of-the-art research knowledge* from the literature, which are most relevant for answering the research questions. Following this is a discussion which draws from both theory and the case study on the progress and way forward for digitalisation in the manufacturing industry. Finally, an analysis is presented of the differences between the findings of the literature review and the case study results. Both verified barriers which weren't extensively covered in the literature and gaps between the literature review and case study results regarding barriers and solutions.

5.1 Theoretical findings

5.1.1 State-of-the-art research knowledge from literature

As revealed in the literature review, digitalisation has the potential to bring significant benefits to manufacturers in their internal processes, such as up to 30% increase in labour productivity and up to 30% higher production throughput. There's also the possibility for enhanced customer offerings through production transparency and customisability, as well as sustainability benefits. It also presents the opportunity to capture external opportunities. Numerous innovative technologies are accompanying the advent of Industry 4.0, many of which provide the potential for advances in manufacturing, offering unprecedented competitive advantages to those who master them.

However, there are a plethora of potential barriers facing incumbents to industrial digitalisation, and there is no single determinant of which barriers will appear and which ones will be most significant. The literature implies that the specific context of an organisation is hugely important and that organisations should attempt to

identify what specific challenges face them and the severity of their consequences. The authors suggest using Lammers' framework to map out potential barriers to a specific organisation for this reason. Examination of the focus areas in the framework in each category and level of origin ensures that no part of the organisation or its context is overlooked. There are several generally recognised barriers from various sources presented in this thesis that should be specifically, but not exclusively, considered.

Another prominent insight from the literature was that successful digitalisation requires wider organisational changes than just incorporating new technologies. This is because digitalisation is a new paradigm for the manufacturing industry that is as much if not more strategic than technical. It should be treated as such by having a clear vision and a plan for achieving that vision, along with a solid change strategy in place. The intention should also not be limited to streamlining current operations and adapting to outside requirements but should be in line with the authors' provided definition of *Digital Transformation*: To innovate new and better manufacturing techniques, develop entirely new types of products, expand the business offering to include customisation and services, and ultimately achieve entirely new business models.

5.1.2 Progression of digitalisation in manufacturing

Part of the aim of this thesis was to explore how far manufacturing companies have come in the journey to adopt digital technologies in their manufacturing processes. When comparing the statistics which were presented in section 3.7.3 to the literature, one can see that anomalies have emerged where some companies have adopted new digital technologies in manufacturing while others stay in the old ways, which could point towards a paradigm shift and crisis. One can also compare the diffusion of technological revolutions by Perez (2011) in Figure 3.5 and the adoption of technologies by Rogers (1962) in Figure 3.6, and with the help of the statistics see that we are somewhere in the middle of both of them. Hence, there might be a correlation between the two where Perez's turning point is reached at a point where the adoption rate of digital manufacturing technologies is at its highest.

The arguments that we might be at what Perez calls *the turning point* are that the investments in digital technologies in manufacturing are accelerating while chief economists argue that we might face a recession. All in all, we are seeing an industry disruption and turning point at the moment where manufacturing companies are focusing their investments on digital technologies. If the theories presented previously hold true, then there will come a deployment period and post-disruptive normalisation phase where a majority of companies will have adopted digital factories while the new technological paradigm is becoming established in society.

To gain a different perspective on how far the progression of digitalisation in manufacturing has gone, one can compare the case results with the digital paradigms supporting the industrial revolution (see Figure 1.2) and the theory related to the figure. The results from the case study, where all the companies were at a stage where they were implementing digital technologies in their manufacturing processes rather than revolutionising their entire business models, confirmed what the consulted experts at AFRY had said. That is, the manufacturing companies that have progressed furthest are well situated in the industry 4.0 paradigm, where they are in the later stages of digitalisation with yet to step into the world of digital transformation, as per the author's definition of the terms.

5.1.2.1 Development opportunities

Drawing on the literature, the case results and performed triangulation with the co-supervisor at AFRY confirmed the necessity for viewing digitalisation as an organisational change in order to exploit the development opportunities. To be able to successfully implement digital technologies is essential since digitalisation and digital transformations unavoidably will change all organisations at their core. Hence, the need for the members of an organisation to understand its digital maturity is crucial to make the changes necessary to succeed in a digitalisation journey. As identified in the literature, current trends in the business environment suggest that an organisation's ability to rapidly adapt to change is key to gaining a competitive advantage. In addition to agility, other factors for success in a world defined by transparency, new technologies, and globalisation include curiosity, inspiration, and the ability to handle multiple stakeholders. The findings emphasise the importance of organisations embracing change and being agile to remain competitive.

However, enabling an organisation to accelerate change and to be more agile and prepared for a rapidly changing world through proactive change management can be a challenge. We know from the literature that Kotter (2012) proposed innovative solutions to enable organisations to keep pace with the rapidly changing business environment. His proposals centred on putting into place a second operating system that would function in a flexible network-like layout. In addition, he emphasised the need of developing and implementing a plan to guarantee the organisation and its surroundings are continuously evaluated, as well as the capability to operate with creativity, agility, and pace. Since it is crucial that the new operating system isn't intended as a replacement for traditional ways of working but rather as a complement, Kotter identified eight accelerators that could function as processes for a new operating system (see Figure 3.3).

Whether or not an organisation follows change management processes by Kotter or from elsewhere, management must be prepared, open-minded and ready to lead their company through a process of digital adoption. The concept of having a positive change culture is also one of the results from the case interviews that a lot of

emphasis was put on due to its heavy impact on the outcome of the digitalisation journey.

Furthermore, there is a development opportunity in the fact that companies no longer should see tasks such as adopting digital technologies as a project the company can complete and then move on from. If they keep seeing it as individual projects, there are imminent risks that produced knowledge goes to waste once the project is finished and handed over to some other function within the organisation. The function within the organisation receiving the finished project won't focus on developing it further, resulting in it eventually becoming obsolete and another project being initiated. Instead, companies need to shift away from project-based thinking when it comes to digitalisation and rather see it as an agile development process where the same people are responsible for the whole cycle. Hence, avoiding the issue of having to start over and instead focusing on maintaining and continuously developing the adopted digital technologies within the manufacturing processes.

To conclude, there is an apparent development opportunity where manufacturing companies, with the right management, in an effective way can implement and accelerate change to successfully embark on their digitalisation journey. To do this, they need to embrace a positive change culture and have a clear strategy for how to accelerate change processes within the organisation. Moreover, they need to change the way they view their digitalisation journey from project-based thinking to an agile development process.

5.2 Contrasting literature and research

Several similarities as well as some discernible differences were found between the potential barriers towards digitalisation from the literature review and the results from the case study. Some barriers which were verified through the interviews were stressed by the interviewees as more or less significant than had otherwise been indicated in the literature and are therefore elaborated on in the following section. Other barriers were not encountered in the case study and can thus be considered rare or insignificant within the scope of the thesis, even if they cannot be ruled out completely. Additionally, some barriers were dismissed as irrelevant by interviewees when asked about them specifically, as revealed in the following gap analysis.

In order to compare the research results with the barriers found in the literature, refer to Table 4.1 – *Lammers' framework summarising the case study results*. Contrasting this to Table 3.5 – *Lammers' framework of potential barriers to digitalisation found throughout the* literature, some notable aspects stand out: few barriers were found which originate at the Meta-level, and barely any at the Inter-level. Additionally, the

results from the case study indicate no presence of regulatory or contextual barriers. This suggests that there are few significant barriers for practitioners to encounter outside of the organisation's influence, which provides a positive outlook for companies to be able to solve the subsisting barriers.

5.2.1 Analysis of verified barriers

The one inter-level barrier which was verified from the literature review was the low readiness of suppliers and partner companies. This factor was acknowledged by most of the interviewees in the case study. However, they did not find it to be a barrier outright as much as an affirmation that they acted as pioneers in their immediate environment. The integration of partners within the scope of the companies' digitalisation efforts was largely seen as an extra incentive and a success factor when done right, as was covered in 4.2.2, and was otherwise considered as an unattended possibility.

Between the literature and the research, emphasis was put on technical complexity. While technical difficulties were certainly an issue which was discussed by all case companies, the findings from the research also suggest that this was not a highly debilitating barrier. This might be partly attributed to the generally high skill level of those who are responsible for driving the digitalisation projects, but also to the progression of suppliers in developing more compatible and easily configurable solutions. It should also be noted that the availability of skills-for-hire through consultants with relevant experience has been cited to alleviate some of the technical difficulties.

Unexpectedly, much more significance was attributed to barriers resulting from a lack of commitment and willingness to participate from employees. This means that there is a severe shortage of people who are willing and capable of driving change projects, especially from mid-level positions and on the production floor, which is problematic considering the finding that digitalisation should be considered an organisation-wide change.

Contributing to this issue might be the lack of opportunities to be creative, and the organisation not being willing to give ownership of solutions despite the high level of accountability that comes with engaging in change management. This makes participating and accepting responsibility unrewarding, resulting in demotivated employees. It is essential to recognise that without individuals who are willing and capable of driving change projects, it becomes extremely challenging to implement digitalisation initiatives. Therefore, companies must prioritise the development of individuals with the necessary skills and, above all, mindset. Doing so creates a culture that values progress and continuous improvement, leading to long-term success.

Another contributing factor towards employee resistance was found to be fear of change for varying reasons, a factor which was not extensively covered in the literature. Some employees seem to fear that digitalisation may affect and eventually eliminate their jobs, while others fail to see how digital initiatives improve their jobs and consider it something that adds complexity, difficulty, and more work. Effective communication from leadership is therefore crucial in communicating the benefits of digitalisation, the plans for current employees' roles, and in de-dramatising the *digital* aspect of the process which many workers might not be very comfortable with.

5.2.2 Gap analysis

Barriers which were not found in the case study, but which were identified in the literature review are of interest. These might indicate differences for practitioners in what barriers face Swedish or Nordics-based manufacturers as opposed to other regions. Highlighting these differences can provide valuable insights for organisations with similar contexts who are looking to digitalise.

To explain the absent regulatory and contextual barriers from the case study, one should consider the scope covered by each. The case study focused on the digitalisation of manufacturers which had their headquarters located in Sweden, while the literature review covered the broader manufacturing industry, still with some consideration to the origins of articles by excluding work which focused on parts of the world where the preconditions for businesses were deemed significantly different because of cultural differences, geographical challenges, or political instability. Still, the lack of identified regulatory or contextual barriers remained.

The authors do not claim that such barriers do not exist at all for Swedish-based or similar manufacturing companies, since the research population of case companies is much too small for such definite conclusions. However, their absence from the results indicates that there do not seem to be widespread issues from regulators, competitors or stakeholders acting as barriers in the researched industry. If there are, then perhaps the majority of companies have already managed to avoid these barriers before starting their digitalisation journey, enough so that they aren't considered barriers when digitalising.

5.2.2.1 Gaps in specific barriers

Looking at the barriers from the case study and comparing those to the ones found in the literature review point by point, some gaps merit further discussion:

Firstly, it was theorised that worries about the viability of digitalising could be apparent and would make stakeholders pull the breaks on certain projects. However, while the board sometimes lacked a complete understanding of the scope of the

changes they were undertaking, no lack of faith or support was apparent in the case companies.

Difficulty in financially estimating the value of digitalisation and making calculations on ROI was often encountered as a potential barrier in the literature. However, when asked, the interviewees said that while not always straightforward, the financial calculations they had made had proven to be sufficient and fairly accurate. One explanation for this might be the more obvious savings which digitalisation enables for manufacturers specifically, such as from reducing production downtime. Another explanation might be that they all had help in the early stages of their digitalisation journey from consultants who had foreseen these potential barriers.

Data security was expected to be a vital concern when referencing the literature. While data security had clearly been considered a factor by most of the case companies, its prioritisation varied widely and was mostly not regarded as a challenge which stood in the way of continued development by the case companies. One possible explanation for this might be the maturity of the available systems in the case companies, thus placing this concern out of the hands of singular practitioners.

Public acceptance of digitalisation, with moral and ethical dilemmas which go along with a more digital society and the mass availability and storage of data, is a relevant factor in several industries at the point of this thesis. However, it was found that for the manufacturers this was not considered a barrier, nor did the interviewees say that they had received concerns for its impact on the well-being, privacy or security of their employees.

It should be noted that these gaps are all subject to the limitations of the conducted research. All of the case companies had progressed in their digitalisation journey at the point of the interviews. Some barriers which might have reasonably been encountered early on might therefore have been overcome long ago, and since considered to a lesser extent.

5.3 Limitations of research

In section 2.1.3, the authors described the steps taken to assure that the research maintains its quality based on three tests. Even though the authors have done their best to ensure the quality of the research, any thesis will inevitably have its limitations on the conducted research, and this thesis is not an exception to that. Thus, discussing the limitations of the findings from this research study is of utmost importance.

First of all, to *construct validity*, a variety of sources have been consulted and drafts of the report have been continuously evaluated together with the main informants. However, if a greater number of sources had been used during the literature review phase or if the sample size had been increased to include more than four interviewees and case companies, more gaps between the literature and the findings from the case study might have been identified. Additionally, more possible barriers, solutions, and success factors could have been found while simultaneously identifying any conflicting findings and alternative paths. The authors also acknowledge that other methods of data collection might have resulted in different findings.

Secondly, the issue with *external validity* should be addressed. That is, whether the authors' findings can be generalised to other settings and contexts. The researchers intended to address external validity by performing replication logic, meaning studying multiple cases and drawing cross-case conclusions. However, since the sample was limited to customers of AFRY, it is worth reflecting on whether including non-customers of AFRY among the case companies would have led to different findings. The limitation of only researching AFRY's customers could potentially cause risks of bias that could otherwise have been avoided. Hence, the reader must keep in mind that this study is limited to manufacturing companies that are customers of AFRY and therefore that the same conclusions might not necessarily have been drawn if the same methodology was applied in another context.

Furthermore, the authors aimed to ensure the *reliability* of the study by constantly documenting the progress while sharing all the steps of the study with the reader. The objective was to ensure that anyone conducting the same study would achieve the same results. However, there are limitations as to whether that would be the case, since even though the authors have attempted to verify their conclusions, qualitative results are nevertheless interpreted subjectively.

Finally, it is vital to mention the research ethics described in section 1.4.5. The authors have taken all necessary steps to guarantee that the research maintains its integrity based on ethical, legal, and professional standards. By following the four research principles described in 1.4.5, the authors have done their best to ensure that no further limitations have arisen due to research integrity issues.

6 Conclusions and final recommendations

In the final chapter, the conclusions related to the research questions are presented, along with final recommendations for manufacturers to overcome the barriers they encounter and steer their digitalisation efforts in the right direction. The chapter also presents the authors' thoughts on appropriate related research topics for future research.

6.1 Concluding results

Four research questions were chosen to be addressed in this thesis based on the problem description and stated purpose. The concluding results and answers to these questions are presented below.

RQ1: What is the state-of-the-art research knowledge on digitalisation in manufacturing?

The literature review helps to provide knowledge about the current state-of-the-art research knowledge on digitalisation in the manufacturing industry. In summary, digitalisation offers manufacturers numerous benefits, both in their external and internal processes, and those that grasp and utilise those benefits have the possibility to gain significant competitive advantages. Such competitive advantage could be, for example, more time-efficient manufacturing processes with less waste of resources compared to if the processes weren't digitalised. With the help of prominent Industry 4.0 manufacturing technologies, companies may greatly improve their production processes.

However, one prominent factor is the numerous barriers that need to be identified and overcome in order to succeed on a digitalisation journey. Organisations need to realise that embarking on a digitalisation journey means implementing change across the wider organisation, while simultaneously adopting new digital technologies. Digitalisation should be regarded as a new paradigm for the manufacturing industry, necessitating a well-thought-out plan, clear goals, and a supporting change strategy.

Finally, one can conclude that the state-of-the-art research acknowledges digitalisation both as a megatrend in manufacturing and the context of sustainability. The report finds that digitalisation is significantly influencing companies' growth as well as the development of several industries. On the topic of sustainability, one conclusion is that many issues relating to the sustainability of society and manufacturing specifically can be solved through product and process innovation, enabled by digitalisation.

RQ2: How far has digitalisation progressed in the manufacturing industry?

It has been concluded that some manufacturing companies have adopted new digital technologies, while others remain in their old ways. This points towards an occurring paradigm shift and crisis in the manufacturing industry. The statistics presented suggest that we've reached a point where the adoption rate of digital manufacturing technologies is at its highest and the diffusion of digital technologies are now pushing the industry in line with the new paradigm. Hence, manufacturing companies are focusing their investments on digital technologies, and we are seeing an industry disruption and turning point at the moment. A conclusion can be drawn that the manufacturing companies that have progressed furthest are well situated in the industry 4.0 paradigm, where they are in the later stages of digitalisation with yet to step into the world of digital transformation, as per the definitions used in this thesis. That is, this thesis has found nothing that implies that a manufacturing company has completely changed its business model, but the statistics indicate that there is a rapid increase of manufacturing companies adopting and utilising digital technologies, situating them in the Industry 4.0 paradigm.

However, in order to progress even further and exploit the opportunities of digitalisation, companies should no longer see tasks such as adopting digital technologies as individual projects but rather as a continuous process that requires ongoing agile development and improvement. It is also essential to view digitalisation as an organisational change. There exist several different strategies to accelerate change and keep pace with the constantly changing business environment, such as Kotter's eight accelerators. What is essential is that management must be prepared, open-minded, and ready to lead their company through the process. Developing a positive change culture is therefore vital to the outcome of the digitalisation journey.

RQ3: What are the barriers for manufacturers to digitalise their businesses?

This report describes several potential barriers to digitalisation in manufacturing. The case study identified financial, skill-related, people-related, technical, and strategic barriers, but found no regulatory or contextual barriers.

One of the most prevalent barriers is a lack of skilled and experienced employees to manage the technical challenges involved in digitalisation. Such individuals may be

difficult to locate and utilise within large organisations and are rare and highly sought after within the labour force.

A substantial barrier comes from employee resistance and pushback, which can be rooted in people not seeing the benefit of digitalisation at their level of the organisation, lacking experience working with digital tools, or generally being disinterested in change. Such barriers were encountered more often than technical challenges, which are relatively easy to foresee and therefore to pre-emptively tackle.

Companies may also face major issues and delays if they fail to allocate sufficient time to prepare the organisation, eliminate redundant systems, unify data flows and define their technical specifications.

Finally, the absence of a well-conceived plan, strategy, and objectives for digitalising results in companies expending time and resources on efforts that serve no clear and practical purpose for the organisation, yielding no benefits.

RQ4: How can the potential barriers to digitalisation be overcome?

The authors conclude that overcoming the barriers to digitalisation is an involved endeavour where proper change management is key. The support and mandate of management is absolutely crucial for successful implementation. A strategy for digitalisation should be formulated, including clear, common goals and a plan for how to get there. Potential barriers should be investigated and planned for as part of this plan, where stakeholder mapping is an important activity to identify barriers.

Manufacturers should ensure their employees possess the necessary skills to meet the technical requirements for the digitalisation of their manufacturing operations as well as the necessary supportive functions. Additionally they should ensure that leadership at all levels of the organisation is dedicated and engaged in this process. Efficiently utilising skilled and experienced people is vital for bringing along the rest of the company on the digitalisation journey. Providing staff with a roadmap of the changes to come, and the benefits they will bring, and addressing any concerns while constantly seeking input on the progression of implementation is also crucial. Additionally, companies should provide training for staff to work with digital tools, which helps to de-dramatise digitalisation and is necessary to complement the challenge of hiring enough people with expertise in all required areas.

6.2 Final recommendations

Digitalisation is a journey which should be embarked on without expecting it to have a definite ending. Like waves on an ocean, there will be periods of more or less activity, however there should always be an underlying current of continuous improvement.

Companies should be ready to allocate ample time for preparation before implementing technologies which are considered new for the organisation. As a consequence, for manufacturing companies who have not officially started researching digitalisation – it is high time.

Before getting underway, extra care should be given towards acquiring and cultivating the skills which are most necessary for the digitalisation of one's specific operations.

As digitalisation is an organisational change, getting the individuals who make up a company row in the same direction is one of the most difficult things to get right. Management must for this reason find proponents within the ranks at all levels, who can advocate for the employees as well as pass along their inputs on the changes once they are implemented.

Finally, digitalisation requires a strategic and flexible approach. Companies need to be aware of potential barriers and develop a culture that values progress and constant improvement. By doing so, they position themselves to take advantage of the many potential benefits of digitalisation and remain competitive in the long term.

6.3 Future research

In considering future research based on this thesis on crossing the digitalisation chasm, it may be valuable to further explore the concept of enabling factors to digitalisation, as the authors noted in Section 0. While many enablers may be the inverse of the barriers discussed in this report, it could be worthwhile to investigate theoretical enablers in a separate study. It may further be feasible to develop a framework that aids industrial organisations in investigating and implementing digital technologies by looking at the function that these enablers play in supporting digitalisation. This framework might be used to direct decision-making, pinpoint important investment areas, and create plans for effective execution. Hence, additional research may be necessary to fully understand the impact of each of these enablers and how they interact with one another. By building on this existing research about barriers to digitalisation, it may be possible to create a more

comprehensive understanding of the process and develop effective strategies for overcoming obstacles and promoting change.

Furthermore, in addition to possibly further exploring the enablers to digitalise manufacturing, it may also be valuable to investigate the impact of the specific digital technologies on manufacturing and their correlation to company performance. Even though they are presented briefly in Table 3.3, it might be worth digging further into some or all of them. By examining the relationship between these enabling technologies and their impact on the manufacturing process, cost savings, efficiency, new product development (NPD), and innovation, it may be possible to identify key areas for investment and develop strategies for successful implementation. In comparing the impact of these technologies, it may be necessary to consider factors such as the availability and compatibility of digital infrastructure with existing systems, the potential for automation or optimisation of manufacturing processes, as well as the impact on user experience.

To further understand the barriers to digitalising manufacturing companies, it may be useful to further study the specific conditions and characteristics of the case companies. In this thesis, all case companies were customers of AFRY with headquarters in Sweden and similar digitalisation and manufacturing processes. By broadening the scope and using a more diverse sample of case companies, internal and external factors such as company size, type of manufacturing process, geographic location, economic conditions and government policies could be further investigated since they likely play a significant role in the challenges companies face when adopting digital technologies. By taking a more holistic approach to the study of digitalisation in manufacturing, it may be possible to gain a deeper understanding of the process and develop more effective solutions for promoting change. Thus, using a bigger and more diverse sample of case companies might give potential future researchers the chance to look more into and analyse the companies' characteristics and conditions, and how they affect the success of the adoption of digital technologies.

Finally, exploring different methodologies could be another alternative approach to conducting future research on the subject. The thesis strategy has been to conduct open-ended case interviews with emphasis put on qualitative research to achieve the research objectives. If one wanted to build on the research presented in this study, an alternative methodology would make it possible to develop a more comprehensive picture of the topic. For example, a more quantitative research approach could facilitate the assessment of which barriers are more vital to address than others. It would enable reaching out to more case companies in a similar time frame achieving a larger sample size, generating more quantitative and/or statistical data through structured interviews or surveys which could complement the qualitative results found through this thesis.

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Appendix A – Interview guide

Introduction questions

- Can you tell us about yourself and your role in the company?
- How do major changes occur within the company? Do you have the ability to influence the company's strategic direction?
    - What would you say are the most important business operations for you to digitalise?
    - Are there any specific technologies of particular interest to incorporate into your operations?

Digitalisation process

- What does digitalisation mean in the context of your company and your industry as a whole?
- Can you tell us about the projects you have undertaken as part of your digitalisation process?
    - How involved have you been in the digitalisation projects undertaken by your organization?
        - In what way have you provided expertise in the process?
    - How long have the different parts of the projects taken?
    - Were there any notable milestones in the process?
- How high of a priority has your digitalisation journey been in terms of resources allocated? What kind of resources have you allocated?
- How has digitalisation affected your business and your employees?
    - What benefits have you seen from the digitalisation of your company?
    - Have you encountered any negative consequences of digitalisation?
- What role has management played in your digitalisation process?
    - Arguments?
        - What has been the ROI (Return on Investment)?
        - Acquired data?
- Which individuals have been involved during your digitalisation process, and what roles have they had?
    - What role did AFRY and your own staff play in this process?
- What were the company's goals for your digitalisation journey?
    - Were these goals well-defined from the beginning?

Success factors

- Regarding the digitalisation projects you consider successful, what do you believe contributed to their success? What are the success factors?
- Are there any technical competencies you have acquired that have been crucial to the success?
- Have you needed to change anything in your organisation or corporate culture to succeed with digitalisation?

Barriers

- What barriers and challenges have you encountered during the digitisation process?
    - Have you had any problems of a technical or competence-related nature?
        - Compatibility?
        - Data security?
        - Data ownership?
            - Maintenance?
    - Have you encountered any problems related to corporate culture or organisational structure?
    - Have you encountered obstacles from external actors such as suppliers or partners?
    - How did you overcome these barriers?
- Are there any barriers that were easier or more difficult to overcome?
- Are there any barriers/problems that you have not yet fully resolved?
    - How do you work to solve those problems?
- What role do you believe management plays in relation to digitalisation barriers?
- What have you learned during the process?

Future

- What are your future plans regarding the digitalisation of your organization?
    - What do you hope to achieve in such cases?

Conclusion

- What advice would you give to other companies considering digitalising their processes?
- Is there anything else you would like to add?

Appendix B – Selected articles in the literature review

Author(s)	Publication Year	Title
Demlehner, Q; Laumer, S	2020	Why Context Matters: Explaining the Digital Transformation of the Manufacturing Industry and the Role of the Industry's Characteristics in It
Borovkov, A; Rozhdestvenskiy, O; Pavlova, E; Glazunov, A; Savichev, K	2021	Key Barriers of Digital Transformation of the High-Technology Manufacturing: An Evaluation Method
Calabrese, A; Dora, M; Ghiron, NL; Tiburzi, L	2022	Industry's 4.0 transformation process: how to start, where to aim, what to be aware of
Okreglicka, M	2020	Barriers in the Technological Innovation Implementation and Digital Entrepreneurship Development
Birkel, H; Wehrle, M	2022	Small- and Medium-Sized Companies Tackling the Digital Transformation of Supply Chain Processes: Insights From a Multiple Case Study in the German Manufacturing Industry
Gadekar, R; Sarkar, B; Gadekar, A	2022	Model development for assessing inhibitors impacting Industry 4.0 implementation in Indian manufacturing industries: an integrated ISM-Fuzzy MICMAC approach
Rad, FF; Oghazi, P; Palmie, M; Chirumalla, K; Pashkevich, N; Patel, PC; Sattari, S	2022	Industry 4.0 and supply chain performance: A systematic literature review of the benefits, challenges, and critical success factors of 11 core technologies
Lammers, T; Tomidei, L; Trianni, A	2019	Towards a Novel Framework of Barriers and Drivers for Digital Transformation in Industrial Supply Chains
Ancillo, AD; Gavrila, SG; Diez, JRFD; Beseler, JC	2022	LATAM and Spanish SME barriers to Industry 4.0
Hoyer, C; Gunawan, I; Reaiche, CH	2020	The Implementation of Industry 4.0-A Systematic Literature Review of the Key Factors
Matt, T; Pedrini, T; Bonfanti, A; Orzes, G	2022	Industrial digitalization. A systematic literature review and research agenda
Dmitry Plekhanov, Henrik Franke, Torbjørn H. Netland	2022	Digital transformation: A review and research agenda
Gupta, S	2018	Organizational Barriers to Digital Transformation

Parviainen, P; Kääriäinen, J; Tihinen, M; Teppola, S	2017	Tackling the digitalization challenge: how to benefit from digitalization in practice
Daniel R. A. Schallmo, Joseph Tidd	2021	Digitalization - Approaches, Case Studies, and Tools for Strategy, Transformation and Implementation
Andersson, P; Movin, S; Mähring, M; Teigland, R; Wennberg, K	2018	Managing Digital Transformation
Mesa, D; Renda, G; Gorkin, R; Kuys, B; Cook, SM	2022	Implementing a Design Thinking Approach to De-Risk the Digitalisation of Manufacturing SMEs
Arora, AK; Rathi, P	2019	An Analysis of Implementation of Digitalisation in SMEs in India
McFarlane, D; Ratchev, S; de Silva, L; Hawkridge, G; Schonfuss, B; Angulo, GT	2022	Digitalisation for SME Manufacturers: A Framework and a Low-Cost Approach br
Truant, E; Broccardo, L; Dana, LP	2021	Digitalisation boosts company performance: an overview of Italian listed companies
Queiroz, MM; Pereira, SCF; Telles, R; Machado, MC	2021	Industry 4.0 and digital supply chain capabilities A framework for understanding digitalisation challenges and opportunities
Carlsson, L; Olsson, AK; Eriksson, K	2022	Taking Responsibility for Industrial Digitalization: Navigating Organizational Challenges
Ghobakhloo, M	2020	Determinants of information and digital technology implementation for smart manufacturing
Thun, S; Bakas, O; Storholmen, TCB	2022	Development and implementation processes of digitalization in engineer-to-order manufacturing: enablers and barriers
Machado, CG; Winroth, M; Carlsson, D; Almstrom, P; Centerholt, V; Hallin, M	2019	Industry 4.0 readiness in manufacturing companies: challenges and enablers towards increased digitalization
Chauhan, C; Singh, A; Luthra, S	2021	Barriers to industry 4.0 adoption and its performance implications: An empirical investigation of emerging economy
Di Sabato, V	2021	Challenges of the Fourth Industrial Revolution for Companies and Employees
Zangiacomi, A; Pessot, E; Fornasiero, R; Bertetti, M; Sacco, M	2020	Moving towards digitalization: a multiple case study in manufacturing
Pessot, E; Zangiacomi, A; Battistella, C; Rocchi, V; Sala, A; Sacco, M	2021	What matters in implementing the factory of the future Insights from a survey in European manufacturing regions
Marques, M; Agostinho, C; Zacharewicz, G; Jardim-Goncalves, R	2017	Decentralized decision support for intelligent manufacturing in Industry 4.0
Favoretto, C; Mendes, GHD; Godinho, M; de Oliveira, MG; Ganga, GMD	2022	Digital transformation of business model in manufacturing companies: challenges and research agenda

Amaral, A; Pecas, P	2021	SMEs and Industry 4.0: Two case studies of digitalization for a smoother integration
Bolte, S; Dehmer, J; Niemann, J	2018	Digital Leadership 4.0
Lodgaard, E; Torvatn, H; Sorumsbrenden, J; Knutstad, GA	2021	Barriers Hindering an Efficient Implementation Process of Digital Technologies; a Case Study at Norwegian Manufacturing Companies
Ghobakhloo, M; Iranmanesh, M	2021	Digital transformation success under Industry 4.0: a strategic guideline for manufacturing SMEs
Bencsik, A	2020	Challenges of Management in the Digital Economy
Grooss, OF; Presser, M; Tambo, T	2022	Balancing Digital Maturity and Operational Performance - Progressing in a Low-digital SME Manufacturing Setting
Stocker, A; Rosenberger, M; Schmeja, M; Schneider, G	2021	Key Success Factors for the Implementation of Digital Technologies in the Context of Industry 4.0
Carcary, M; Doherty, E; Conway, G; Crowley, C	2017	Transforming to a Digital Enterprise - an Empirical Investigation
Kumar, A; Agrawal, R; Wankhede, VA; Sharma, M; Mulat-weldemeskel, E	2022	A framework for assessing social acceptability of industry 4.0 technologies for the development of digital manufacturing
Dieste, M; Sauer, PC; Orzes, G	2022	Organizational tensions in industry 4.0 implementation: A paradox theory approach
Soluk, J; Kammerlander, N	2021	Digital transformation in family-owned Mittelstand firms: A dynamic capabilities perspective
Ghobakhloo, M; Iranmanesh, M; Vilkas, M; Grybauskas, A; Amran, A	2022	Drivers and barriers of Industry 4.0 technology adoption among manufacturing SMEs: a systematic review and transformation roadmap
Zangiacomi, A; Sacco, M; Pessot, E; De Zan, A; Bertetti, M	2018	A perspective for the implementation of a path towards the Factory of the Future: the Italian case
Jain, V; Ajmera, P; Davim, JP	2022	SWOT analysis of Industry 4.0 variables using AHP methodology and structural equation modelling
Leitao, P; Pires, F; Karnouskos, S; Colombo, AW	2020	Quo Vadis Industry 4.0? Position, Trends, and Challenges
Can, O	2021	The Role of Leadership in Digital Transformation: A Review and Suggestions for Future Research
Butschan, J; Heidenreich, S; Weber, B; Kraemer, T	2019	Tackling Hurdles to Digital Transformation - The Role of Competencies for Successful Industrial Internet of Things (IIoT) Implementation
Glass, R; Meissner, A; Gebauer, C; Sturmer, S; Metternich, J	2018	Identifying the barriers to Industrie 4.0
Krajcik, V	2021	The readiness of Small and Medium-sized Enterprises (SMEs) for the digitalization of industry: Evidence from the Czech Republic
Telukdarie, A; Buhulaiga, E; Bag, S; Gupta, S; Luo, ZW	2018	Industry 4.0 implementation for multinationals

Turkes, MC; Oncioiu, I; Aslam, HD; Marin-Pantelescu, A; Topor, DI; Capusneanu, S	2019	Drivers and Barriers in Using Industry 4.0: A Perspective of SMEs in Romania
Wang, YR	2022	Analyzing the mechanism of strategic orientation towards digitization and organizational performance settings enduring employee resistance to innovation and performance capabilities
Gromova, EA; Koneva, NS; Titova, EV	2022	Legal barriers to the implementation of digital industry (Industry 4.0) components and ways to overcome them
Saniuk, S; Caganova, D; Saniuk, A	2021	Knowledge and Skills of Industrial Employees and Managerial Staff for the Industry 4.0 Implementation
K. Schwertner	2017	Digital Transformation of Business
Jimmy Bumann, Marc K. Peter	2019	Action Fields of Digital Transformation - A Review and Comparative Analysis of Digital Transformation maturity Models and Frameworks
Arica, E; Powell, D	2021	Digitalization in Manufacturing: Trends, Drivers, Challenges, and Research Areas in Norway
Sharma, M; Raut, RD; Sehrawat, R; Ishizaka, A	2023	Digitalisation of manufacturing operations: The influential role of organisational, social, environmental, and technological impediments
Schonfuss, B; McFarlane, D; Hawkridge, G; Salter, L; Athanassopoulou, N; de Silva, L	2021	A catalogue of digital solution areas for prioritising the needs of manufacturing SMEs
Martinez, F	2019	Process excellence the key for digitalisation
Bickauske, D; Simanaviciene, Z; Jakubavicius, A; Vilys, M; Mykhalchyshyna, L	2020	Analysis And Perspectives Of The Level Of Enterprises Digitalization (Lithuanian Manufacturing Sector Case)
Szalavetz, ANDREA	2022	Digitalisation-induced performance improvement: Don?t take it for granted!
Buttner, R; Muller, E	2018	Changeability of manufacturing companies in the context of digitalization
Macias-Aguayo, J; McFarlane, D; Schonfuss, B; Salter, L	2022	A catalogue of digital solution areas for logistics SMEs
Wiesner, S; Gaiardelli, P; Gritti, N; Oberti, G	2018	Maturity Models for Digitalization in Manufacturing - Applicability for SMEs
Mihajlovic, I	2022	International Visegrad Project: Possibilities And Barriers For Industry 4.0 Implementation In Smes In V4 Countries And Serbia
Dogea, R; Stolt, R	2021	Identifying Challenges Related to Industry 4.0 in Five Manufacturing Companies
Gomes, N; Rego, N; Claro, J	2022	Supply Chains' Digitalization: Boosters and Barriers
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