SCHOOL OF BUSINESS AND SOCIAL SCIENCES
AARHUS UNIVERSITY

Navigating Digitalization in SMEs:

A Focus on Maintenance and After-Sales Service

PhD dissertation

Oliver Fuglsang Grooss

Aarhus BSS
Aarhus University
Department of Business Development and Technology
2024

Thesis submitted: 30 January 2024

PhD supervisor: **Associate Professor Mirko Presser**

PhD co-supervisor: **Associate Professor Torben Tambo**

PhD committee: **Associate Professor Martin Olsen**
Aarhus University, Department of Business Development and Technology

Professor Ole Madsen
Department of Materials and Production, Aalborg University, Denmark

Professor Dr.-Ing. Sven Tackenberg
Technische Hochschule Ostwestfalen-Lippe, Germany

PhD Series: Department of Business Development and Technology
Aarhus BSS, Aarhus University, Denmark

Preface

This thesis is submitted as a summary of a collection of scientific articles. Therefore, it is not a monography but a presentation of three published or publishable journal papers. This presentation describes the relation between these publications and how they each contribute to the overall PhD project, as described by the "Rules and guidelines for the PhD degree programme" of 15/11/2023 by Aarhus BSS Graduate School, Aarhus University[1].

As the included papers must be able to stand on their own, the reader of this thesis is likely to encounter repeating points and positionings, especially in the introducing parts of the papers.

Please notice that the final papers have been peer-reviewed by editors and reviewers of different journals. In this process, the papers have been shaped to adhere to these journals' requirements, customs, and formats.

[1] https://bss.au.dk/en/research/phd/rules-and-regulations

Acknowledgment

I would like to extend my gratitude to everyone who have in any way supported me in process of writing this thesis:

My girlfriend and best friend, Magdalena. Thank you for coping with me. Thank you for always supporting me, for encouraging me to do better, and for asking me to sometimes "take a chill pill". Thank you for offering helpful and constructive advice when I have been struggling (whether I have asked for it or not). I often joke and say that "I love you, most of the time", which I know you hate, but please know that I always do. This PhD thesis would not have been started nor completed without your support. Thank you for celebrating the wins with me and thank you for telling me that it was "totally not my fault" when something didn't go as planned (even when it clearly was my fault).

My family for their support. My parents for teaching me to strive for high standards in my work. Thank you for not letting me drop out of high school in my first year - I don't think I would have written a PhD if that would have happened. My younger sister, for helping me pass my statistics course on my first bachelor semester.

All my friends who have listened regretfully after mistakenly asking how it has been going "with that PhD thing". Thank you for all the fun experiences we share.

Mirko Presser, my primary supervisor. Thank you for always helping me out, whether it has been with reading and providing feedback to my work, or kindly requesting me to pull myself together. Thank you for patiently dealing with my biweekly identity crises and rebooting me into operational state. Also, thank you for the beers. They were seriously needed at the times.

Torben Tambo, my secondary supervisor. Thank you for helping me navigate my project, both from academic and industrial perspectives. Thank you for teaching me how to publish my work. The literature review would still be desk-rejected, had you not helped me with that.

Emilie Mathilde Jakobsen, my office roommate. Thank you for the talks, coffee runs, and side quests that kept me sane during office hours.

All other colleagues at BTECH for sparring on different projects and for listening to my dumb jokes and silly ideas.

All the companies that I have met, visited, studied, interviewed, disturbed and/or borderline harassed during my studies.

Thank you all.

Oliver

Table of Contents

Figures and tables

Executive summary

This executive summary presents a concise overview of a thesis examining the challenges and opportunities for SMEs in the context of Industry 4.0 and digital transformation. Since 2011, these concepts have gained considerable attention, focusing on integrating digital technologies in various industries. While larger corporations are adapting to this new industrial paradigm, SMEs often struggle due to limited financial resources and digital expertise. This hesitation often stems from a risk-averse mindset and uncertainty about the return on digital investments. However, in the future, digital technology implementation will be a prerequisite to deliver on customer expectations and operational efficiency. Therefore, this thesis focuses on how SMEs can leverage data and data technologies to enhance their operational efficiency.

The thesis is guided by five research questions:

RQ1: What are the current recommendations for adopting Industry 4.0 technology in SMEs based on contemporary research?

RQ2: What are the main organizational and technology factors that describe the maturity stages of maintenance activities in Small and Medium-sized Enterprises (SMEs)?

RQ3a: What are the needs for technical development competencies within information systems for supporting after-sale service processes in SMEs?

RQ3b: How do SMEs manage data collection and analysis in after-sales service processes from a human perspective?

RQ3c: How do SMEs utilize low-code tools for digitalization of after-sales service processes?

The thesis answers these questions over three chapters (2-4), each representing a published or submitted journal paper. Before these are presented, Chapter 1 introduces the thesis structure, provides background to the problem, presents research gaps, and positions the thesis.

Chapter 2 addresses the first research question through a systematic literature review of 50 scientific publications. It identifies 11 key focus areas across three domains: Technology, Organization, and Environment, and concludes with three specific recommendations in these areas. This chapter is encapsulated in the paper *"Surround yourself with your betters: Recommendations for adopting Industry 4.0 technologies in SMEs",* published in Digital Business by Elsevier.

Chapter 3 tackles the second research question, focusing on the maturity stages of maintenance activities in SMEs. It utilizes four in-depth case studies in Danish SMEs, adopting a participatory research approach. The outcome is a conceptual framework and maturity model highlighted in the paper *"Digitalization of maintenance activities in small and medium-sized enterprises: A conceptual framework",* published in Computers in Industry by Elsevier.

Chapter 4 delves into the remaining research questions, further investigating the underperforming aspects identified in Chapter 3. It narrows the focus to after-sales service, conducting multiple case studies with six Danish companies. The chapter culminates in a model outlining the interplay between skill location, solution process, and data maturity, aimed to assist human resource allocation for digital initiatives. This work is presented in the paper *"Digitalization of After-Sales Service Processes in SMEs—Perspectives of Skill Location, Solution Processes, and Data Maturity",* submitted to Computers in Industry by Elsevier.

The thesis concludes with Chapter 5, which reflects on the findings, methodologies, and their relevance to both industry and academia. This final chapter synthesizes the insights gained and their implications for future research and practical application in the realm of digitalization in SMEs.

This thesis introduces several novel elements in the field of SME digitalization. Firstly, it presents a structured literature review identifying 11 focus areas for SME digitalization, from which three specific recommendations are derived to direct future research. This review notably advocates for a pragmatic approach in digitalization research for SMEs, aiming to fill gaps in current research with a practical, future-oriented agenda. Secondly, the thesis develops an innovative framework designed for SMEs' digital initiatives, emphasizing resource scarcity. This framework is unique in its focus on underutilized data resources within SMEs, demonstrating how these can be effectively leveraged to enhance digitalization. It stands as one of the first studies to conceptualize the use of these resources in conjunction with technology aspects like system integration and digital data collection. Thirdly, the thesis offers insights into managing digitalization from a human perspective, suggesting that SMEs should allocate human resources towards co-creation and prototyping, while outsourcing technical development. Fourthly, the research combines practical case studies with theoretical insights, bridging the gap between industry practice and academic theory. Lastly, it delves into the less explored areas of maintenance and asset management within SMEs, shedding light on these vital yet overlooked aspects of digitalization, and thus adding a unique dimension to the field.

Resumé

Dette resumé præsenterer et kortfattet overblik over en afhandling, der undersøger udfordringerne og mulighederne for små og mellemstore virksomheder (SMV'er) i forbindelse med Industri 4.0 og digital transformation. Siden 2011 har disse koncepter fået stor opmærksomhed, hvilket signalerer et skift i retning af at integrere digitale teknologier i forskellige industrier. Mens større virksomheder tilpasser sig dette nye industrielle paradigme, kæmper SMV'er ofte på grund af begrænsede økonomiske ressourcer og digital ekspertise. Denne tøven udspringer ofte af en risikovillig tankegang og usikkerhed om afkastet af digitale investeringer. Derfor fokuserer denne afhandling på, hvordan SMV'er kan udnytte data og datateknologier til at øge deres operationelle effektivitet.

Afhandlingen er styret af fem forskningsspørgsmål:

RQ1: Hvad er de nuværende anbefalinger for at indføre Industry 4.0-teknologi i SMV'er baseret på moderne forskning?

RQ2: Hvad er de vigtigste organisatoriske og teknologiske faktorer, der beskriver modenhedsstadierne af vedligeholdelsesaktiviteter i SMV'er?

RQ3a: Hvad er behovene for tekniske udviklingskompetencer inden for informationssystemer til at understøtte eftersalgsserviceprocesser i SMV'er?

RQ3b: Hvordan administrerer SMV'er dataindsamling og analyse i eftersalgsserviceprocesser fra et menneskeligt perspektiv?

RQ3c: Hvordan bruger SMV'er "low-code" værktøjer til digitalisering af eftersalgsserviceprocesser?

Afhandlingen besvarer disse spørgsmål over tre kapitler (2-4), der hver repræsenterer en offentliggjort eller indsendt tidsskriftsartikel. Inden disse præsenteres, introducerer kapitel 1 strukturen for afhandlingen, giver baggrund for problemstillingen, præsenterer uafklarede spørgsmål i den eksisterende litteratur og positionerer afhandlingen.

Kapitel 2 behandler det første forskningsspørgsmål gennem en systematisk litteraturgennemgang af 50 videnskabelige publikationer. Kapitlet identificerer 11 nøglefokusområder på tværs af tre domæner: Teknologi, Organisation og Miljø, og afsluttes med tre specifikke anbefalinger på disse områder. Dette kapitel består af artiklen *"Surround yourself with your betters: Recommendations for adopting Industry 4.0 technologies in SMEs"*, publiceret i Digital Business af Elsevier.

Kapitel behandler det andet forskningsspørgsmål, der fokuserer på modenhedsstadierne af vedligeholdelsesaktiviteter i SMV'er. Den anvender fire dybdegående casestudier i danske SMV'er gennem en deltagende forskningstilgang. Resultatet er en begrebsramme og modenhedsmodel fremhævet i artiklen *"Digitalization of maintenance activities in small and medium-sized enterprises: A conceptual framework"*, publiceret i Computers in Industry af Elsevier.

Kapitel 4 dykker ned i de resterende forskningsspørgsmål og undersøger yderligere de underpræsterende aspekter identificeret i kapitel 3. Kapitlet indsnævrer fokus til eftersalgsservice, der udfører flere casestudier med seks danske virksomheder. Kapitlet kulminerer i en model, der skitserer samspillet mellem færdighedsplacering, løsningsproces og datamodenhed, med det formål at optimere allokering af menneskelige ressourcer til

digitale initiativer. Dette arbejde er præsenteret i artiklen *"Digitalization of After-Sales Service Processes in SMEs—Perspectives of Skill Location, Solution Processes, and Data Maturity"*, indsendt til Computers in Industry af Elsevier.

Afhandlingen afsluttes med kapitel 5, som reflekterer over resultaterne, metoderne og deres relevans for både industrien og den akademiske verden. Dette sidste kapitel syntetiserer den opnåede indsigt og deres implikationer for fremtidig forskning og praktisk anvendelse inden for digital transformation i SMV'er.

Denne afhandling introducerer flere nye elementer inden for SMV-digitalisering. For det første præsenterer den en struktureret litteraturgennemgang, der identificerer 11 fokusområder for SMV-digitalisering, hvorfra der er udledt tre specifikke anbefalinger til at lede fremtidig forskning. Denne gennemgang går især ind for en pragmatisk tilgang til digitaliseringsforskning for SMV'er med det formål at udfylde huller i den nuværende forskning med en praktisk, fremtidsorienteret dagsorden. For det andet udvikler afhandlingen en innovativ model designet til SMV'ers digitale initiativer, der understreger ressourceknaphed. Denne ramme er unik i sit fokus på underudnyttede dataressourcer inden for SMV'er, der viser hvordan disse effektivt kan udnyttes til at forbedre digitaliseringen. Afhandlingen står som en af de første undersøgelser, der konceptualiserer brugen af disse ressourcer i forbindelse med teknologiske aspekter som systemintegration og digital dataanalyse. For det tredje giver afhandlingen indsigt i styring af digitalisering fra et menneskeligt perspektiv, og foreslår, at SMV'er bør allokere menneskelige ressourcer til co-creation og prototyping, mens de outsourcer teknisk udvikling. For det fjerde kombinerer forskningen praktiske casestudier med teoretiske indsigter, der bygger bro mellem industripraksis og akademisk teori. For det femte dykker den ned i de mindre udforskede områder af vedligeholdelse og asset management inden for SMV'er, og kaster lys over disse vitale aspekter af digitalisering og tilføjer dermed en unik dimension til feltet.

Chapter 1. Introduction

This chapter introduces the topics and research gaps of this thesis, presents the research questions and methodology, and finishes with an overview of the conducted research.

1.1. Background, research gaps, and positioning

The following sections are structured as follows. First, an introduction of key concepts is provided to understand the theoretical scope of the thesis. This is not meant as a comprehensive review of all the literature on the topics but as a reader's guide, that provides context to the thesis. More detailed literature can be found in the paper chapters. Based on this presentation, a series of research gaps will be presented. Lastly, a short section clarifies some specific positionings related to the introduced literature and research gaps.

1.1.1. Industry 4.0 and digital transformation

Industry 4.0, or The Fourth Industrial Revolution, was introduced in a short paper in 2011 by (Kagermann et al., 2011). The paper presented a new paradigm driven by digital technologies and intelligent systems and how they would transform traditional manufacturing and production processes. Shortly after the publication, German Chancellor Angela Merkel used "Industry 4.0" in her opening speech for the 2011 Hannover Fair, which virialized the term to a point where it is now as recognizable as the word "autobahn" (Kagermann & Wahlster, 2022).

Despite this, the concept of Industry 4.0 has been difficult to define, and several definitions exist (Horváth & Szabó, 2019; Moeuf et al., 2018a). However, the concept describes the increasing digitalization of the entire supply chain by integrating innovation and technologies with various devices and machinery to create intelligent factories and processes (Bakkari & Khatory, 2017; Decker, 2017; Horváth & Szabó, 2019).

The primary goals are increased efficiency, flexibility, and customization in manufacturing processes, enhancing productivity while reducing costs and environmental impact (Masood & Sonntag, 2020). High-quality data, efficient data flows, and data technologies have become necessities to remain competitive as more and more product offerings and enterprise solutions are built around data. Therefore, it seems imperative for companies to collect, structure, and utilize data in their daily operations, as this will be the future prerequisite for delivering on customer expectations and operational efficiency (OE) (Ghobakhloo & Ching, 2019; Horváth & Szabó, 2019; Matt et al., 2020; Sevinç et al., 2018; Xu et al., 2018).

Industry 4.0 is characterized by the integration of various digital technology concepts, such as the Internet of Things (IoT), Cloud computing, Cyber-physical systems, and Artificial Intelligence (AI) (Masood & Sonntag, 2020; Moeuf et al., 2020). These technologies and their immediate implications in business have been well documented. For the past ten years, Industry 4.0 has been the topic of more than 1.000 project consortia, 10.000 conferences, and 100.000 publications, which have discussed its implementation from technical and scientific perspectives (Kagermann & Wahlster, 2022).

In the broader context of these technological advancements, the concept of digital transformation emerges as a critical strategic initiative for organizations across various sectors. Unlike Industry 4.0, which is predominantly focused on manufacturing and industrial applications, digital transformation represents a holistic shift in organizational operations and strategies (Battistoni et al., 2023; Schlegel & Kraus, 2023; Skare et al., 2023). This shift encompasses the adoption of digital technologies to transform services and business models, enhancement of customer experiences, and streamlining of operations (Skare et al., 2023; Vial, 2019). Digital transformation not only complements the specific advancements of Industry 4.0 but also extends its benefits beyond the industrial sector, impacting everything from small businesses to large corporations and public services (Battistoni et al., 2023; Ghobakhloo & Iranmanesh, 2 021).

The projects and research within digital transformation and Industry 4.0 cover both technical engineering and implementations of digital technology solutions to specific real-world problems and fuzzy assessment models for assessing Industry 4.0 maturity across different technology, business, and social science domains (Castelo-Branco et al., 2022; Colli et al., 2019; P. Senna et al., 2023; Pacchini et al., 2019, 2019; Putnik et al., 2021).

1.1.2. Small and medium-sized enterprises in the European economy

Small and Medium-sized Enterprises (SMEs) are fundamental to the European economy. In 2022, about 24.3 million SMEs were active within the EU-27, comprising 99.8% of all enterprises in the non-financial business sector (NFBS) (Di Bella et al., 2023). These SMEs collectively employed approximately 84.9 million people, representing nearly two-thirds of the total employment in the EU-27 NFBS (Di Bella et al., 2023). This significant contribution to employment highlights the role of SMEs as major employers across the continent. By providing jobs to millions, SMEs play a crucial role in driving economic growth, fostering social stability, and contributing to the development of human capital.

In terms of economic output, SMEs accounted for slightly more than half of the value added in the EU-27 NFBS (Di Bella et al., 2023). This contribution demonstrates that these enterprises are not just numerous but also impactful in terms of their economic productivity.

The importance of SMEs in the European economy is not just in their numbers but also in their diversity and flexibility. They are often more nimble than larger corporations, able to adapt quickly to changing market conditions and customer needs (Mittal et al., 2018; Rassool & Dissanayake, 2019; Ulas, 2019).

1.1.3. Industry 4.0 and digital transformation in SMEs

Apart from innovative start-ups and tech-savvy SMEs, there's a sizable group of industrial SMEs that are lagging in adopting digitalization (Doyle & Cosgrove, 2019; Horváth & Szabó, 2019; Masood & Sonntag, 2020; Matt et al., 2020; Sommer, 2015). For such SMEs, Industry 4.0 technologies have been criticized for being too theoretical, often described as "presenting many ideas but not enough results" (Sommer, 2015). Moreover, there have been increasing complaints about the growing lack of interest in digitization among SMEs (Mittal et al., 2018; Sommer, 2015). This holds significant importance, as SMEs form the cornerstone of the European economy (Andulkar et al., 2018; Bidan et al., 2012; Bouwman et al., 2019; Crupi et al., 2020; De Marco et al., 2020; Masood & Sonntag, 2020; Matt et al., 2020; Ulas, 2019), and because the success of an industrial revolution relies on its implementation across both large corporations and SMEs, ensuring it's more than just a superficial label (Horváth & Szabó, 2019; Kergroach, 2020; Sommer, 2015). The deficiency of digitalization in SMEs is not attributed to a lack of willingness but rather to a lack of clarity on where to start (Ganzarain & Errasti, 2016; Sommer, 2015). Several factors make it challenging for SMEs to kickstart innovation and digitalization projects, with the most substantial obstacles being limited resources and competencies (Masood & Sonntag, 2020). These shortages often lead SMEs to be cautious about taking risks, as wrong investment decisions can have significant repercussions. Consequently, this tends to result in SMEs opting to maintain the status quo, adhering to their usual business practices (Bidan et al., 2012; Rassool & Dissanayake, 2019; Sommer, 2015). In the context of digitalization, this is a major curtailment of potential, as SMEs are otherwise known for their agility and organic structure (Mittal et al., 2018; Rassool & Dissanayake, 2019; Ulas, 2019).

1.1.4. Research gaps

This thesis is built on several specific research gaps that have been identified in the literature.

First, the existing body of research largely overlooks the specific needs of SMEs (Masood & Sonntag, 2020; Matt & Rauch, 2020; Mittal et al., 2018) Although there is an abundance of studies discussing digitalization strategies, they fail to address the fundamental comprehension required by SMEs within their unique operational contexts (Brodny & Tutak, 2022; Mittal et al., 2018; Sommer, 2015). Concepts like IoT and AI are often developed with large automotive companies in mind and do not readily translate to the more modest scale of SMEs (Hansen & Bøgh, 2021; Masood & Sonntag, 2020; Sommer, 2015). The approach of Industry 4.0 proves insufficient for these enterprises, highlighting a critical research gap in understanding and addressing the resource constraints typical for SMEs (Brodny & Tutak, 2022; Masood & Sonntag, 2020; Mittal et al., 2018; Sommer, 2015; Stentoft et al., 2021)

Second, the existing literature often falls short in offering an interdisciplinary perspective. The digital transformation in SMEs is not just a technological challenge; it is deeply intertwined with business and organizational dynamics. Much of the current research tends to either focus on the technical aspects, such as the development of statistical models, without fully considering their impact on business operations or emphasize the business side without adequately understanding the technological implications. There is a need for research that bridges this gap, providing insights into how technology affects business processes and vice versa, and understanding the organizational changes that accompany technological upgrades in SMEs.

Third, there is a lack of publications and research activities that relate to how to adapt and utilize digital concepts and technologies in SMEs (Masood & Sonntag, 2020; Matt et al., 2020; Mittal et al., 2018; Nowotarski & Paslawski, 2017; Oliff & Liu, 2017; Sommer, 2015). Here, there is a need for pragmatic research that takes participatory approaches to study how SMEs, and industry in general, best approach digital technology implementation as they occur (Amaral & Peças, 2021; Colli et al., 2019; Ghobakhloo & Ching, 2019).

Lastly, it should be noted that studies should not only focus on practical problem-solving. While exampling through case studies can generate powerful inspiration for others (Flyvbjerg, 2006), much digitalization research has been criticized for being developed using only single case studies or data points (Sundberg et al., 2019; Williams & Lang, 2019). This suggests that theorizing should be done based on multiple case studies to strengthen the validity of the outcomes.

1.1.5. Specific positioning

This thesis defines and employs a clear distinction between the concepts of digitalization, complete digital transformation, and Industry 4.0. While the latter two are often regarded as the pinnacle of technological and operational advancement (Genest & Gamache, 2020; Moeuf et al., 2018b), this research positions digitalization as a critical steppingstone towards achieving these objectives. It considers that for SMEs to successfully transition into the Industry 4.0 paradigm and realize the full spectrum of digital transformation, they must first proficiently navigate the digitalization of individual business facets. The focus of this thesis is to explore and clarify the initial pathways through which SMEs can embark on this transformative journey, laying the groundwork for a future full digital integration.

With this in mind, it is also imperative to underscore that the objective of this project is not simply to insert digital technologies and information systems into SMEs in an attempt to force them towards Industry 4.0. Instead, it is to understand how SMEs can incrementally convert their current business processes and digital technology landscape to something that accommodates a future-oriented Industry 4.0 mindset. This means that this project will not exclusively focus on employing the latest Industry 4.0 technologies but will comprehend the context in which these future technologies will operate and learn how to adapt to this context. This positions the project in relation to the presented scarcities of SMEs.

To facilitate this and guide the research for this thesis, the following definition has been developed as a steering point for discussing digitalization: *Digitalization represents the introduction of one or more digital technologies to business processes, with the intent to decrease analog/manual labor and automate data collection and/or information flow.*

1.2. Research questions

Based on the background and motivation, The following question guides this thesis:

How can SMEs combine data and data technologies to increase their operational efficiency?

This overarching question frames this thesis and sets the scene for the completed work. The objective of this thesis is not to answer this question directly but to use it to guide the research efforts. Based on this question, a series of specific research questions has been developed. These research questions are empirically driven and have been developed sequentially based on the accumulated research in the project. By so, these were not completely defined at the beginning of the project but have matured as the research progressed.

To provide an academic foundation for the project, it was relevant to research the existing body of knowledge on the topic of digitalization and Industry 4.0 in SMEs. As the topic is already well-researched, it was decided to focus on extrapolating direct recommendations on how SMEs can adopt digital technologies. Therefore, the following research question was proposed.

RQ1: What are the current recommendations for adopting Industry 4.0 technology in SMEs based on contemporary research?

From answering RQ1, two things were clear. First, as **Error! Reference source not found.** will describe, there is a strong relationship between technological and organizational factors when introducing digital technologies in SMEs. This suggests that these should be treated and studied with respect to this relationship and that they should not be considered as individual aspects of digitalization. Second, the topical broadness of digitalization suggested that to fully understand how SMEs can successfully introduce digital technologies, there was a need to scope out future research in the project. Therefore, it was decided to scope forward-going research to focus on digitalization of maintenance activities in SMEs, as this topic has received limited attention, which **Error! Reference source not found.** will further describe. Based on this, the following research question was proposed.

RQ2: What are the main organizational and technology factors that describe the maturity stages of maintenance activities in Small and Medium-sized Enterprises (SMEs)?

Answering RQ2 led to the development of a conceptual framework and maturity model for identifying low and high-performing aspects of digitalization of maintenance activities in SMEs. With this came the identification of several low-performing elements in the included case studies. From these, the following research questions were developed for Chapter 4.

RQ3a: What are the needs for technical development competencies within information systems for supporting after-sale service processes in SMEs?

RQ3b: How do SMEs manage data collection and analysis in after-sales service processes from a human perspective?

RQ3c: How do SMEs utilize low-code tools for digitalization of after-sales service processes?

1.3. Methodology

The following section will describe the methodology of this thesis. To explain the structure of the thesis, the overall methodological considerations for the project as an entirety will be presented. This will be followed by a brief introduction to relevant research methodologies. Next, a general research design is presented. The specific methodology of each chapter is further described in the respective papers. The section ends with an overview of the conducted research.

1.3.1. Overall methodological considerations.

The overall methodological considerations were rooted in the introduced research gaps, which initially framed the methodology for the project.

First, it should address the need for interdisciplinary research, as this requires a special positioning among research methodologies. In the context of digitalization in SMEs, it was clear from the beginning that understanding only technology or business could not provide the necessary insights. Instead, the purpose of this project was to understand the development and management of technologies in specific business contexts. From this, it was evident that this required an ability to delicately balance between engineering research and business and social science research. From an engineering perspective, it was necessary to understand the technical complexity of digital technologies and how these can influence business. On the other hand, from a business and social science perspective, it was imperative to grasp the organizational and human complexity of the studied organizations to fully understand the influence of digital technologies.

Second, the distinct need for pragmatic research directly invited research methods that minimize the distance between the researcher and the researched phenomena. With this, it was not only necessary to immerse into the operational contexts of the SMEs, but the research also had to be of relevance to them. Practically, it was essential to understand the specific requirements and expectations to digital technologies, which could be achieved through complete immersion into the studied SMEs.

Thirdly, the research design also had to facilitate theoretical synthetism that contributes to the collective development of SMEs. Leading back to the previous point about pragmatic research, it was essential that the output of this research contributes back to the research community and addresses the shortcomings of the existing work.

Lastly, the overall methodology should be adaptable. From the beginning, it was obvious that this project should be empirically driven. By so, the project should be able to go in whatever direction the empirical data would suggest. From a practical perspective, this meant that insights from one part of the project should be able to change the scope of the next part - and so on. To avoid locking into a direction that was influenced by initial assumptions and incomplete knowledge, the research design had to be flexible and support agility.

1.3.2. Design Science Research and Action Research

The nature of the presented research gaps and the methodological considerations suggested two specific methodologies: Design Science Research and Action Research.

1.3.2.1. Design Science Research

Design Science Research (DSR) is a research methodology used primarily in the fields of information systems and software engineering (Hevner et al., 2004), although its principles can be applied to other disciplines as well (Collatto et al., 2018). DSR focuses on the development and performance of artifacts with the goal of understanding the problems addressed by these artifacts and the solutions they offer. The artifacts created through DSR can be constructs, models, methods, or instantiations (Hevner et al., 2004).

(Hevner et al., 2004) provides a framework for understanding and conducting design science research in information systems. It emphasizes the importance of both relevance and rigor in DSR and identifies three cycles of activity: the relevance cycle (connecting the research to real-world problems), the rigor cycle (connecting the research to existing scientific knowledge), and the design cycle (iterating between problem understanding, artifact design, and evaluation) (Hevner, 2007; Hevner et al., 2004). A key aspect of DSR is the strong focus on contributing to the general knowledge by solving problems (Collatto et al., 2018). DSR should add to the existing knowledge base while at the same time improving a practical situation of in the organization (Collatto et al., 2018). Despite this problem-solving perspective, the objective of DSR is not to provide a perfect solution to a problem, but to make a meaningful improvement to an existing solution (Collatto et al., 2018).

1.3.2.2. Action Research

Action Research is an emergent, iterative process of inquiry designed to develop solutions to real organizational problems through participative and collaborative methods (Collatto et al., 2018; Saunders et al., 2016). It's a strategy that begins within a specific context, with an initial research question and evolves through several stages. This evolution often leads to the refinement or even change of the initial question as new insights are gained (Saunders et al., 2016).

The uniqueness of Action Research lies in its requirements of research, action, and participation (Coghlan & Brannick, 2005; Collatto et al., 2018; Saunders et al., 2016). It necessitates organizational members' cooperation, allowing their work practices to be studied and improved upon. Participation is not passive but requires active collaboration in every iterative cycle of the research process. With this, organizational members are not just subjects of study but co-researchers, contributing their skills and knowledge to the process (Coghlan & Brannick, 2005).

Action Research follows a cyclical process that typically includes four main stages: diagnosing, planning action, taking action, and evaluating action (Coghlan & Brannick, 2005), but variations exist (Azhar et al., 2010; Saunders et al., 2016). These stages represent a spiral of iterative cycles within any action research project, with each stage building upon and influencing the next, ensuring a dynamic and responsive approach to research and problem-solving (Coghlan & Brannick, 2005).

Action Research is informed by both theoretical knowledge and the experiential knowledge of participants (Collatto et al., 2018). It integrates propositional knowledge (abstract, theoretical knowledge) with experiential knowledge (everyday lived experiences) and knowing-in-action (knowledge derived from practical application) (Coghlan & Brannick, 2005; Collatto et al., 2018).

1.3.3. Research design

Based on the presented methodologies and guidelines, a research design was developed. The project employed a DSR methodology as the overarching methodology. This research design was developed to ensure practical relevance for SMEs by making a tangible contribution to industry practices. Concurrently, it was underpinned by theoretical knowledge, allowing it to also contribute to academic discourse. A visualization of the research design can be found in Figure 1.1.

The project was divided into three parts based on the research questions, each of which contributes to the outcome of the project. The first part conducted a structured literature review, using only established literature. This provided an academic foundation for the project, which in return delivered insights back to the knowledge base.

In the second part, immersive case studies were conducted. These case studies represent the majority of the empirical work for the project. These were individual case studies that each attempted to solve a practical problem through an action research approach, as it is appropriate when the purpose is to cooperate to understand how an intervention can help solve a problem in practice (Collatto et al., 2018). The case studies were conducted sequentially, where learnings from each case study carried on to the next. Insights from all the case studies culminated in a conceptual framework. Each of the case studies were conducted by developing artifacts as well. In the case studies, existing data and resources was explored to build prototypes and improve processes, which required some degree of innovation to existing processes or systems. By extension, this describes the development of an artifact which advocated for DSR methodology. The success of the artifact depended on the interaction with the case companies to gain the proper contextual domain knowledge. Yet, the objective was not the design of the artifact itself but the learnings that came with its development, which was more rooted in action research. Furthermore, the evaluation of the achieved improvements were manifested by the cyclic and continuous data collection concepts of action research (Collatto et al., 2018).

In the third and last part, specific components from the developed framework were selected for further investigation based on what stood out in the results.

The research was contextualized within the environment of SMEs, which provided the practical backdrop for the study. As the project progressed, the scope of this practical context was further scoped based on the accumulated findings. The knowledge base contributed with knowledge from previous research. As with the environment, this context was scoped as the project progresses.

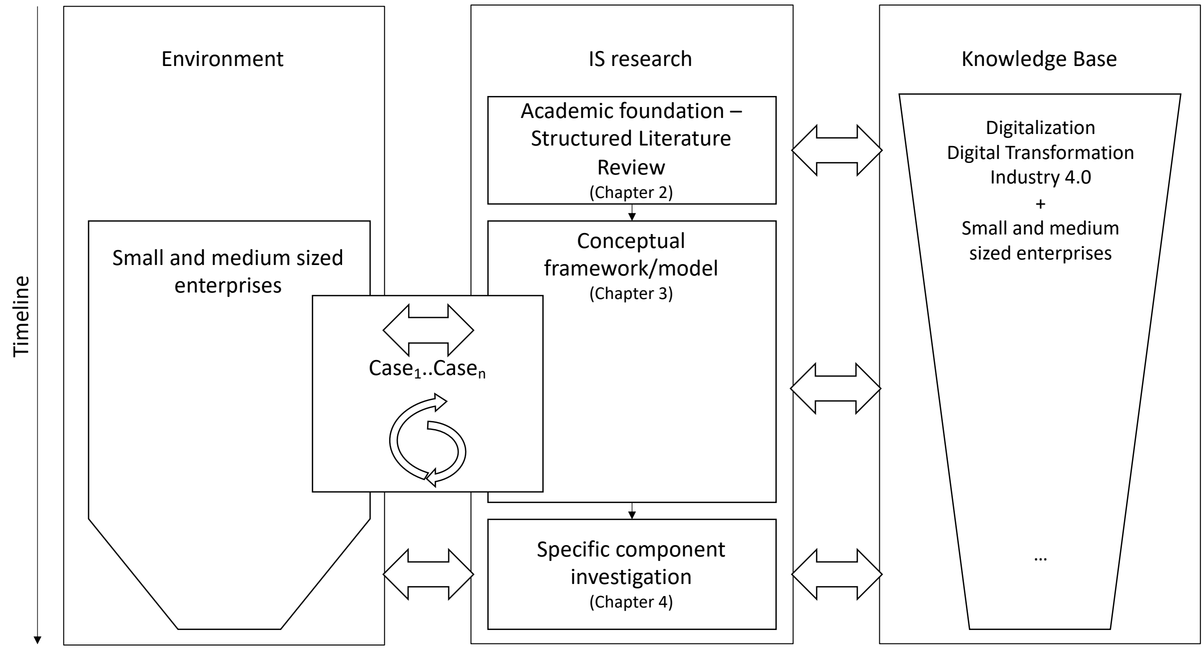

Figure 1.1: Visualization of the research model, built on DSR and action research methodology.

1.3.3.1. Sampling

Some selective recruitment was necessary to ensure the relevance of companies involved in the case studies for the project.

The definition of an SME by the European Commission specifies that an SME is a company that has less than 250 employees, has a yearly profit of less than 50 million euros, or a balance sheet of less than 43 million euros (Lookanen, 2003). By this definition, the pool of potential companies was huge and diverse, which required further scoping.

The focus was on SMEs with a workforce ranging from 50 to 250 employees. This size range was explicitly chosen to include companies of substantial size while excluding very small businesses. The primary targets were companies with a mixed workforce of both blue-collar and white-collar employees.

Financial stability was another key factor in the selection process. Companies showing profitability in their annual financial reports were targeted. Profitability was used as an indicator of the availability of financial resources for potential projects, serving more as a guiding parameter than a strict selection criterion. This was chosen as any initiative would be associated with costs, which is why companies with a yearly profit of less than 1 million DKK were discarded.

The age and history of the companies were also considered. The study aimed to include companies that had been in business for a considerable period, specifically those established before 2005. This cut-off was based on the likelihood that such companies would have undergone IT system upgrades or investments around significant technological shifts, such as the mobile and cloud revolution. This criterion was intended to identify companies with functional but potentially outdated technology, indicating a need for digitalization.

Additionally, the internal IT resources of these companies were assessed. The selection favored organizations that traditionally depend on external partners for technological expertise rather than maintaining extensive in-house IT resources. This approach was used to pinpoint companies that were not inherently tech-savvy, suggesting their potential readiness and need for digital transformation.

The research design for this study involved recruiting participants for two distinct components: immersive case studies and specific component investigations. Due to time constraints, it was anticipated that only four to five immersive case studies could be conducted, with each expected to take approximately three months. Ultimately, four such case studies were completed. The approach to specific component investigations was more open-ended, with no predetermined number of studies. The decision to engage with new companies for these investigations was made with the understanding that this aspect would evolve based on findings throughout the project.

While the number of case studies (four to five) might seem limited for generalization purposes, this aligns with the study's objectives. According to (Flyvbjerg, 2006), case studies need not always be used for generalization. They can serve as illustrative examples, offering valuable insights in place of statistical generalizations. This approach is particularly effective in qualitative research, where depth and detail can provide significant understanding.

Furthermore, (Flyvbjerg, 2006) emphasizes that the quantity of case studies and their potential for generalization is less critical than creating a representation that resonates with the realities SMEs recognize. This study attempts to do this by focusing on the depth and relevance of each case to present a comprehensive understanding of the digital transformation processes within SMEs.

Practically, the sampling was heavily influenced by convenience and snowball sampling. The research is contingent on the willingness of companies to grant access to their organization and confidential data. Not all companies are comfortable with allowing an external researcher, who is essentially a stranger, to access their comprehensive data. Consequently, the pool of potential case studies was limited to companies that exhibit a certain level of trust and openness. This restriction inherently influenced the selection of cases, as it was not always able to work with companies that perfectly fit the predefined criteria. The research, therefore, relied on the cooperation of companies that are agreeable to collaboration. Complementing convenience sampling, snowball sampling played a crucial role in the recruitment process. Participating companies were requested to refer the research project to other potential companies. This method served two purposes: it allowed for the identification of companies similar to the ones already studied, and it provided a 'stamp of approval' from a known and trusted source. Being referred by an existing participant eased the process of recruiting new companies, as it helps to establish a baseline of trust and credibility with potential new participants.

1.3.3.2. Data collection

The data for this project was extracted from multiple sources and consists of both primary and secondary data. The primary data originates from the interaction with the companies that participated in the project. For the immersive case studies, primary data has been collected through several methods. As the immersive case studies were built around a participatory approach, where a significant amount of time was spent in the company, a considerable amount of data comes from interacting with the organization and the digital technologies.

The development of artifacts for the participating companies was not only a means of engagement but also a vital primary data collection method. The process of creating and refining these prototypes provided a unique opportunity to gather first-hand information by being directly involved in the companies' operations. This hands-on experience was crucial in collecting primary data, as it allowed for a deeper understanding of the companies' processes, decision-making practices, and cultural dynamics. The interactions and discussions that arose during the prototyping process were rich sources of primary data, offering insights that were integral to the research findings. Moreover, the emphasis on the prototyping process served a dual purpose. It not only facilitated a deeper immersion into the organizational environment, making the research presence more relatable and justified, but it also ensured that the data collected was directly reflective of the companies' real-world scenarios.

The focus was on the journey of development and the interactions it fostered rather than solely on the solution. This approach reinforced that the value of prototyping lay in its ability to generate meaningful and context-rich primary data, crucial for understanding the nuanced aspects of organizational behavior and technology adoption. Here, a lot of the knowledge of business processes comes from training sessions, meetings, and participation in work. Furthermore, a part of the organizational context comes from informal meetings and "water-cooler talks." The organic emergence of this knowledge made it challenging to formally document why this has mostly been done through post-notetaking and/or the topics that have been brought up in later interviews.

Semi-structured interviews have also played an enormous role in this project. Where mere participation has allowed for exploratory research of the nature of the daily operations of the company, semi-structured interviews have made it possible to uncover more profound knowledge about specific topics. This has provided an explanatory aspect of the data collection while still maintaining the possibility for exploration. Semi-structured interviews were all audio recorded when in-person, and audio/video recorded when online.

Beyond primary data, secondary data has also been used in this project, namely through business data and established literature. Business data from the immersive case studies plays a prominent role in this project. Business data is structured and unstructured data that can be found in the companies' information systems. The data can come from business processes related to production, accounting, finance, purchasing, service, and/or maintenance. This data plays a vital role in the prototype development and is a necessary prerequisite. Related to this, information from business documents was used. This includes, but is not limited to, strategic documents, standard operation procedures, organizational visualizations, and/or other documentation. Company data was accessed on-premises, dictated by the case companies, with respect to internal policies for cyber security and data governance. This also means that company data, in many instances, is not available after the case study is finished, as access to this has been revoked.

Lastly, a big part of the secondary data comes from existing literature. Through this project, the literature has been constantly revisited to understand existing work from different areas as the research has progressed. The approach to finding literature has differed. In some cases, it has made the most sense to review literature closely related to specific topics, which may have been sparsely available. In one case, rigorous, and structured literature review methodologies have been developed to ensure a complete scan for the most relevant research. This has been thoroughly described in Chapter 2. What is common for any literature search process in this project is that only literature from acknowledged, peer-reviewed journals and proceedings has been included. This is to ensure that only high-quality research has been analyzed. An active choice has been made also to include papers from conference proceedings, to also include the newest research.

1.3.3.3. Analysis

In the analysis of data collected from the case studies, a methodical cross-case analysis was undertaken. This approach was designed to identify patterns and themes that repeat across the individual cases. The established literature played a central role in this process, serving as the foundation for the analysis. This was achieved by employing the literature as a lens through which the data was examined. More specifically, integral themes, concepts, and variables was identified in the literature, which formed the basis for a coding scheme that categorized the data, enabling systematic comparisons across different cases. The coding process was both deductive, guided by pre-existing theoretical constructs, and inductive, allowing for emergent themes to be captured.

The cross-case analysis also involved the triangulation of data sources to reinforce the validity of the findings. By comparing and contrasting data points from various sources within and across different cases, a more robust and multifaceted portrayal of the subject matter was achieved. This triangulation aided in uncovering convergent evidence that reinforced the identified patterns and themes. The analysis culminated in the synthesis of findings, integrating the individual and collective learnings from the case studies that highlights commonalities and differences.

1.4. Research overview

This thesis is composed of a series of published and submitted papers and makes up the following chapters. All papers are published in or submitted to acknowledged, peer-reviewed journals. The journals have been selected based on their relevance to the individual paper topics. An overview of the included papers can be found in Table 1.1.

Table 1.1: Directly included papers in this thesis.

Chapter	**Title**	**Journal**	**Reference**
Chapter 2	Surround yourself with your betters: Recommendations for adopting Industry 4.0 technologies in SMEs	Digital Business (Elsevier)	(Grooss et al., 2022c)
Chapter 3	Digitalization of maintenance activities in small and medium-sized enterprises: A conceptual framework	Computers in Industry (Elsevier)	(Grooss, 2024)
Chapter 4	Digitalization of After-Sales Service Processes in SMEs - Perspectives of Skill Location, Solution Processes, and Data Maturity	Computers in Industry (Elsevier	Submitted

Furthermore, a substantial amount of work has been completed to support the chapters in the form of smaller paper submissions to relevant conferences. These papers are not included in this thesis but are merely supporting work that can be used to get a better understanding of the included work. It is not necessary to read these papers to understand the thesis. An overview of these papers can be found in Table 1.2.

Table 1.2: Supporting papers published during the PhD project but not directly included in this thesis.

Title	**Journal**	**Reference**
Balancing digital maturity and operational performance progressing in a low-digital SME manufacturing setting	Procedia Computer Science	(Grooss et al., 2022a)
Advancing maintenance strategies through digitalization: A case study		(Grooss, 2022)
Essentials for Digitalizing Maintenance Activities in SMEs		In press (see Appendix 1)
Comparison between data maturity and maintenance strategy: A case study	Procedia CIRP	(Høj Brasen et al., 2021)

Chapter 2. Surround yourself with your betters: Recommendations for adopting Industry 4.0 technologies in SMEs

The following journal article answers RQ1:

Grooss, O. F., Presser, M., & Tambo, T. (2022). Surround yourself with your betters: Recommendations for adopting Industry 4.0 technologies in SMEs. *Digital Business*, *2*(2), 100046. https://doi.org/10.1016/j.digbus.2022.100046

The published version of this paper can be found at this link: https://www.sciencedirect.com/science/article/pii/S2666954422000266

The content of this chapter is directly copied from this paper.

Abstract: The purpose of this paper is to review the state-of-the-art literature on Industry 4.0 and digitalisation in small and mid-sized enterprises (SMEs). The paper aims to extrapolate and organise recommendations for how to progress in these disciplines from a substantial number of studies. This is accomplished by a systematic literature review on publications within the period 2018–2021. For this purpose, a rigorous metadata analytics process is deployed to retrieve, filter, and structure large amounts of metadata to increase inclusiveness and transparency. The findings consist of 11 focus areas that are developed by extrapolating recommendations from the reviewed literature. These focus areas are structured using the technology-organisation-environment (TOE) framework, which is divided into subcategories. From these, three specific technology-focused recommendations are developed. Furthermore, the paper identifies some concerns with the current research methods due to the overall low implementation of Industry 4.0 in SMEs. This leads to suggesting that future research should engage in pragmatic research methods with attention to how digital technologies are applied in SMEs.

Keywords: Industry 4.0, Digitalization, SME, TOE, Digital Technology

2.1. Introduction

Industry 4.0 has been central to industrial digital transformation (DT) since 2011, discussing new ways of connecting devices and systems, resulting in new data insights, customisable products, and technological autonomy (Horváth & Szabó, 2019; Matt et al., 2020; Sevinç et al., 2018; Xu et al., 2018). This industrial revolution has introduced many new digital technologies and, by extension, vast amounts of possibilities for new business development opportunities. Industry 4.0 describes the DT of manufacturing, in which interconnected processes and equipment allow the mass customisation of products and responses to market demands (Bakkari & Khatory, 2017; Decker, 2017; Horváth & Szabó, 2019; Karki et al., 2022). DT, inspired by Industry 4.0, is vital in many industries where it is especially important for small and medium-sized enterprises (SMEs) not to be excluded from such opportunities, as these companies make up 99% of the companies in Europe (Andulkar et al., 2018; Bidan et al., 2012; Bouwman et al., 2019; Crupi et al., 2020; De Marco et al., 2020; Masood & Sonntag, 2020; Matt et al., 2020; Ulas, 2019).

However, several authors have raised concerns about the engagement of SMEs in the Industry 4.0 paradigm. This is highlighted by (Sommer, 2015), who finds that smaller SMEs may become victims of Industry 4.0, as they do not possess the necessary resources to participate in comprehensive digitalisation initiatives. (Holopainen et al., 2022) similarly find that most of the studied companies struggle with adjusting their operations in DT. Furthermore, both (Ganzarain & Errasti, 2016; Sommer, 2015) highlight that SMEs simply do not know where to start their DT. Numerous papers have already investigated the barriers to implementing Industry 4.0 in the context of SMEs. Generally, they find that unlike larger corporations, SMEs experience grave shortcomings when it comes to financial resources and availability of technical competences (Bidan et al., 2012; Rassool & Dissanayake, 2019; Sommer, 2015).

These issues are not new, and throughout the literature, authors have proposed future research directions that should be explored to help SMEs implement Industry 4.0 technologies. For example, (Menon & Shah, 2020) suggest creating an extensive master plan for digitalisation for SMEs. Similarly, (Coleman et al., 2016) request a mechanism that can assist SMEs in getting started. (Ghobakhloo & Ching, 2019) conclude that there is a need for research that addresses the identification of the key determinants that make SMEs adopt and implement digital technologies. (Matt et al., 2020; Sommer, 2015) highlight the need for further research on action plans that can support SMEs when introducing Industry 4.0 initiatives. (Veile et al., 2020) brings learnings from 13 interviews with Industry 4.0-experienced automotive companies in Germany, thereby providing practical insights into how to implement Industry 4.0 initiatives.

However, as these insights originate from large corporations, it remains unclear how SMEs can achieve the same given their resource restraints. Furthermore, the authors suggest broadening these aspects to other industries. Similarly, (Ortt et al., 2020), who discuss 11 papers on the implementation of Industry 4.0, call on research on specific methods and insights for introducing Industry 4.0 initiatives in different types of companies. This suggests that there is a lack of research that targets specific focus areas and recommendations for SMEs that can help them enter the Industry 4.0 paradigm and that some focused attention should be given to investigate how these can introduce Industry 4.0 initiatives. Therefore, this research will take a first step towards this goal by conducting a systematic literature review to uncover and consolidate the recommendations for implementing digitalisation and Industry 4.0 initiatives in SMEs. Hence, the following research question is proposed: *What are the current recommendations for adopting Industry 4.0 technology in SMEs based on contemporary research?*

This work is meant as a starting point for companies and researchers venturing into new digitalisation and Industry 4.0 research projects as it provides the basic enablers of the technological, organisational, and environmental aspects of Industry 4.0. The remaining sections are organised as follows: Section 2.2 will describe the methods used to gather data for the systematic literature review, and it will comment on the data. Section 2.3 will describe the findings of the review. Section 2.4 will discuss the results, and Section 2.6 will conclude the paper.

2.2. Methodology

This research followed a rigorous process that will be described in this section. The goal was to provide a completely transparent search and filtering process, which, at the same time, was as inclusive as possible. This was achieved using several Python scripts, which can rigorously process large amounts of metadata. First, query strings were generated using lists of keywords. Second, these query strings were copied into the search fields of the selected databases, and the metadata from the search results were downloaded. Third, after downloading the metadata from all queries and all included databases, the metadata was further processed by further scripts. These scripts provided information about the filtering process and a list of references to be manually screened. From this list, the title was read for each entry, and irrelevant papers were filtered out. Lastly, this was repeated for the abstracts, narrowing down the list of papers. Finally, the papers that remained in the dataset were acquired and read.

According to (Kitchenham et al., 2009), four databases is enough to conduct a reliable literature review, while (Yilma et al., 2021) use six. This research uses seven databases: ACM, IEEE, Sage, ScienceDirect, Scopus, Taylor & Francis, and Web of Science. These databases were searched based on the search strings generated by the scripts. The keywords for the query generation were divided into two categories: *technology* keywords and *implementation* keywords. Technology keywords are keywords that relate to specific digital technologies. Furthermore, these keywords were combined with their known aliases, as different authors use different terms. Each technology keyword was combined with its most common synonyms. The list of implementation keywords contains keywords that relate to the implementation and introduction of these digital technologies. This list contains not only synonyms per se but also words that are simply related to each other or are relevant to the context of implementing the technologies. For example, some authors use the words 'deploy' and/or 'implement' to describe putting an IoT device into an operational environment. Furthermore, the keywords were combined with the search terms 'SME' and 'small and medium', as this review focuses on SMEs. The keywords generated a total of 60 queries that were used to search the seven different databases. Examples of queries can be found in Figure 2.1.

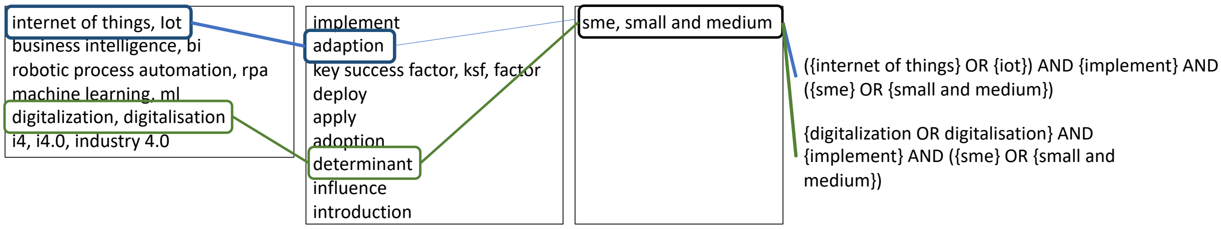

Figure 2.1: Queries generated from the listed keywords

To control the filtering of the metadata, the following inclusion criteria were set:

C1. Only recent studies, published in 2018 or later, should be included. This is to ensure relevance of the publications
C2. Only unique papers should be included; duplicates must be removed.
C3. Papers must include the keyword combinations (as presented in the query strings) in the title, abstract, and/or keywords.

From all the metadata acquired, a total of 15,347 unique papers were identified using the queries from all seven databases. After removing entries with duplicate DOIs, 6,931 papers remained. From there, entries with duplicate titles were removed. This operation was performed because not all entries had an available DOI. This led to the removal of an additional 85 entries. Lastly, all entries that did not meet the rigorous query requirements were filtered out. This was achieved by checking to see if the combination of keywords in each query string was present in the title, abstract, or keywords of each entry. Filtering out all entries that did not meet this requirement left 801 papers in the dataset; thus, a large proportion of the papers were filtered out. The remaining 801 papers underwent a manual process consisting of reading the titles and abstracts of each paper and filtering out the papers that seemed irrelevant. To steer this process, further criteria were set:

C4. Publications must be peer-reviewed conferences or journal publications. This means that books, patents, reports, and theses are not included.
C5. The language of the papers must be English.
C6. The studies must contain empirical work – this means that other literature review papers will be discarded. This is to avoid accumulated interpretation bias.

This left 201 papers in the final dataset. Each of the 201 papers was downloaded and read from start to finish to determine its relevance for this review. To control the filtering, the following inclusion criteria were set:

C7. The studies must make recommendations or propose drivers for introducing digitalisation/Industry 4.0 initiatives. Papers that focus only on barriers or only highlight issues will not be included, as converting these into recommendations may introduce interpretation bias.
C8. The studies must be technology focused. Some papers discuss business aspects of technology initiatives but do not discuss technology itself.
C9. The papers must also study the impact of technology initiatives on business.

As a result of this process, 148 papers were discarded, leaving 50 papers to be included in this literature review.

Looking at the year of publication for the included papers, there seems to be an increasing trend of such papers being published over the last four years. The data were obtained up until October 2021; more papers will likely be published throughout 2021, thus continuing the trend (Figure 2.2).

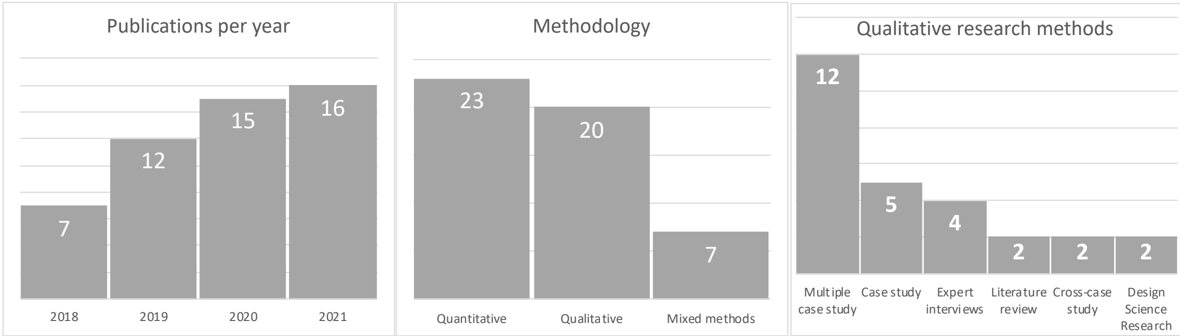

Figure 2.2: Descriptive statistics of the year of publication, type of research, and methodology

Scanning the methodology sections from the included papers revealed that 23 papers used quantitative research methods, 20 papers used qualitative methods, and seven papers used mixed methods. While all of the quantitative papers used questionnaires, the qualitative papers performed different types of studies. As shown in Figure 2.2, the majority of the qualitative papers mainly conducted case studies. Most of these papers performed multiple case studies, while three papers perform single case studies and two papers conducted cross-case studies. The remaining papers conducted expert interviews or design science research (Figure 2.2). Looking at the geographical distribution (Figure 2.3), most of the papers originated in Europe, specifically Western Europe. Most of the papers from Western Europe (10) were from Germany. Most papers from Eastern Europe were from the Czech Republic (4). Most papers from Southern Europe were from Italy (8).

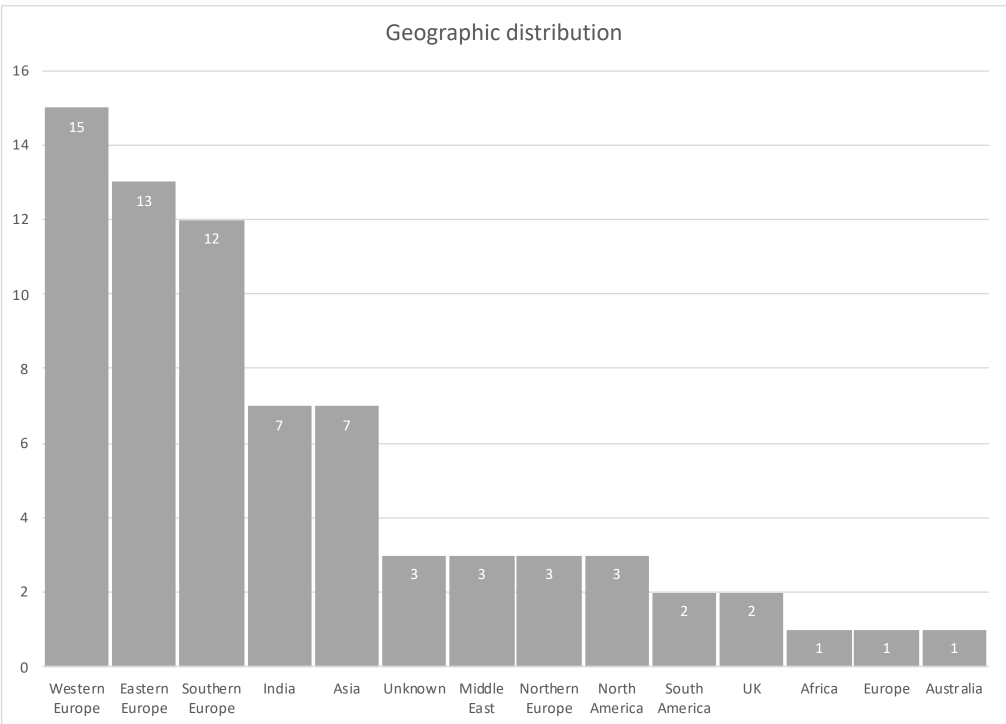

Figure 2.3: Geographical sources of the included papers

To gain a deeper understanding of the papers in the dataset, a cross-reference analysis was performed. This was done by determining which of the references in each paper existed in the dataset. This analysis provides an overview of the interlinkages between the papers in the dataset and thereby highlights defining papers in the field. This interrelationship between the papers can usually be illustrated using a network graph (Mariani & Borghi, 2019). However, due to the number of entries, this graph became rather large and quite unreadable. Instead, the centrality score for each node in the network was saved in the dataset. The centrality score indicates the importance of each node in the network; it represents the number of connections to the node.

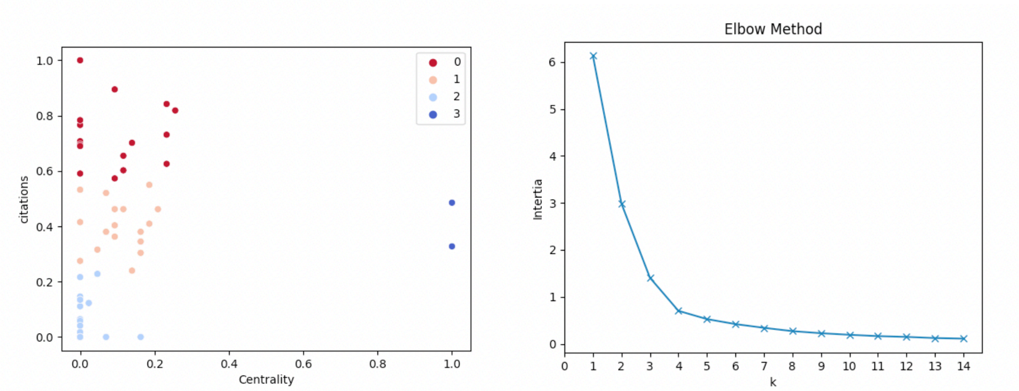

Figure 2.4: Results from k-means clustering

Finally, the papers were clustered based on each paper's number of citations and centrality score. This was achieved through k-means clustering; the Elbow method suggested four clusters. According to Figure 2.4, the clusters are mainly controlled by the number of citations, except for Cluster 3, which contains two papers with significantly higher centralities. This suggests that the Cluster 0 papers are the most prominent papers within the field and that the Cluster 3 papers are the most connected papers in the dataset. This sets the order of review, so that the most central work is prioritised.

2.3. Results

From the reviewed papers, focus areas were extrapolated and categorised using the high-level categories from the technology-organisation-environment (TOE) framework. The TOE framework is a theoretical framework describing the adoption of technology in socioenvironmental contexts (Oliveira & Martins, 2010). Subcategories were established under each TOE area to theme the recommendations further. As each author addresses multiple areas and categories, they will be referred to multiple times within the framework. Furthermore, it is important to emphasise that some authors' recommendations may be relevant to multiple categories. Hence, some of the boundaries between the sections should be considered fluid, as some of the recommendations touch on multiple aspects. However, the following sections describe the main points extrapolated from the papers. An overview of the categories that the authors address can be found in Table 2.1.

Table 2.1: References to developed categories in included papers

	Technology			Organisation					Environment		
Authors	SI & IF	DCA	LC PoC	SA	MS & L	HC	OC	FE	EKS	SC	SP
(Jayashree et al., 2021)	x				x					x	
(Agostini & Nosella, 2019)	x			x	x			x	x		
(Subramanian et al., 2021)	x										

(Müller et al., 2020)	x									x	
(Narwane et al., 2020)	x	x			x						
(Chang et al., 2021)	x										
(Nwaiwu et al., 2020)	x			x							
(Vrchota et al., 2019)	x				x	x	x	x	x		
(Ghobakhloo & Ching, 2019)	x	x	x	x		x		x		x	
(Siemen et al., 2018)	x		x	x						x	
(Türkeş et al., 2019)	x	x				x		x		x	
(Chen, 2019)	x	x								x	
(Bär et al., 2018)	x			x		x				x	
(Moeuf et al., 2020)	x	x	x	x	x	x			x		
(Trstenjak et al., 2020)	x					x	x				
(Welte et al., 2020)	x		x	x		x	x				
(Sivathanu, 2019)	x	x			x	x				x	
(Molero et al., 2019)	x										
(Dutta et al., 2020)	x	x				x		x			
(Gamache et al., 2020)	x	x			x	x					
(Kilimis et al., 2019)	x						x				
(Hamzeh et al., 2018)	x	x	x			x	x		x		
(Puklavec et al., 2018)	x				x						
(Moica et al., 2018)	x				x	x				x	
(Jiwangkura et al., 2020)		x	x		x						
(Bosman et al., 2019)		x		x			x				
(Ricci et al., 2021)		x							x	x	
(Haseeb et al., 2019)		x									
(Cimini et al., 2021)		x	x		x	x					
(Somohano-Rodríguez et al., 2020)		x		x						x	
(Amal Krishnan et al., 2021)		x				x					
(Sriram & Vinodh, 2021)			x			x		x	x		
(Maroufkhani et al., 2020)			x		x			x		x	
(Amaral & Peças, 2021)			x								
(Soluk & Kammerlander, 2021)			x	x			x	x			x
(Yu & Schweisfurth, 2020)			x			x					
(Julian M. Müller et al., 2021)				x			x			x	
(Spalinger et al., 2019)				x		x				x	x
(Eleftheriadis & Myklebust, 2018)				x	x	x					
(Canhoto et al., 2021)				x			x		x		
(Arcidiacono et al., 2019)				x	x				x		
(Vrchota et al., 2021)					x						
(Julian Marius Müller et al., 2018)					x	x					
(Chatterjee et al., 2021)					x	x					
(Annosi et al., 2019)					x						
(Roblek et al., 2021)						x	x				
(Tortora et al., 2021)						x	x		x		
(Ascúa, 2021)						x				x	
(Michna & Kmieciak, 2020)							x				
(Stentoft et al., 2021)								x			
(Sriboonlue & Puangpronpitag, 2019)									x	x	x

System Integration and Information Flow (SI & IF), Data Collection and Analysis (DCA), Low-cost Proof-of-Concept (LC PoC), Strategic Alignment (SA), Management Support and Leadership (MS & L), Human Capital (HC), Organisational Culture (OC), Financial Expectations (FE), External Knowledge Search (EKS), Stakeholder Collaboration (SC), Support Programmes (SP)

2.3.1. Technology

2.3.1.1. System integration and information flow

Several authors highlight the importance of system integration and intercompatibility, which can be described from both internal and external perspectives (Agostini & Nosella, 2019; Jayashree et al., 2021). Keywords in this field can be dynamic capabilities in SMEs, top management commitment, IT infrastructure and supply chain integration, and triple bottom line sustainability. From a technology perspective, system integration is the most influential factor. (Narwane et al., 2020), who identify issues with implementing the Cloud of Things (CoT) (IoT + cloud computing) in SMEs state that the requirements are stable systems and information structures to provide interoperable and secure solutions transparent to stakeholders in the supply chain with proper risk management, compliance, and the use of standards and protocols. (Chang et al., 2021; Nwaiwu et al., 2020) investigate how SMEs adopt Industry 4.0 technologies to establish the potential for performance progress underscoring technology readiness. (Vrchota et al., 2019) conclude that the renewal and optimal use of technologies and IT systems in SMEs is a major factor in the integration of Industry 4.0 initiatives. (Chen, 2019; Ghobakhloo & Ching, 2019; Siemen et al., 2018; Türkeş et al., 2019) find that compatibility and data integration is central for seeing how SMEs can employ technology to participate in global supply chains based on interoperable systems. (Bär et al., 2018) investigate which Industry 4.0 technologies influence the supply chains of SMEs and how SMEs can use Industry 4.0 initiatives in their supply chains. The authors find that it is vital to scope out and select digital technologies that assist in optimising information flows. These technologies must support the SME's organisational needs and make it possible to integrate stakeholders into supply chains. (Moeuf et al., 2020) emphasise that IT infrastructure should facilitate the flow of information. (Trstenjak et al., 2020; Welte et al., 2020) provide a detailed overview of possibilities of digital concept strategies and implementations and find that companies should increase their internet infrastructure and software flexibility, including databases. (Sivathanu, 2019) studied the adoption of Industrial Internet of Things (IIoT) in auto-component manufacturing SMEs finding that infrastructure, compatibility, and security influence whether or not companies choose to adopt IoT, as heterogeneity leads to difficulties in managing devices and data. This also reflects compatibility with other IT infrastructure, such as machines, programming logic controllers (PLCs), enterprise resource planning (ERP), manufacturing execution systems (MES), etc. Compatibility is also highlighted in (Molero et al., 2019), who identify key factors for implementing a new modular IT solution in a transportation SME.

2.3.1.2. (Digital) Data collection and analysis

Several papers highlight the importance of digitalising data collection and conducting data analytics. (Dutta et al., 2020) conclude that it is imperative to capture real-time machine data and analyse these data to establish improvement opportunities in both manufacturing and design decisions. The authors highlight the need to connect equipment and implement IoT devices to generate data that can be used to prioritise areas of improvement in both products and processes. Furthermore, SMEs should generate analytics and digital documentation that can be used to improve processes and maintain traceability. This will help track changes in costs, which will eventually ensure profitability (Ghobakhloo & Ching, 2019; Jiwangkura et al., 2020; Ricci et al., 2021; Sivathanu, 2019). The latter suggest focusing on cybersecurity, data analytics, ERP, PLCs, and actuators, i.e. technologies that enhance data collection and information processing. (Haseeb et al., 2019) investigate the relationships between big data, IoT, and smart factories, and their relationships with IT implementation. The study finds that they all have a positive relationship with IT implementation. (Haseeb et al., 2019) find that IoT initiatives increase IT implementation, which ultimately can have a positive effect on business performance (Chen, 2019; Cimini et al., 2021; Moeuf et al., 2020; Somohano-Rodríguez et al., 2020; Türkeş et al., 2019). (Moeuf et al., 2020) show that the first step for SMEs is to exploit existing data resources. By doing this, SMEs can develop their business models and skill sets with fewer risks (Narwane et al., 2020). (Amal Krishnan et al., 2021; Gamache et al., 2020) find that digital architecture, automation, and quality data can increase digital performance for SMEs, but SMEs seek data before they seek automation. (Hamzeh et al., 2018) highlight the need for SMEs to identify and collect relevant data alongside their business processes. To summarise, introducing data collection and analytics in SMEs offers low-risk, baseline technologies that SMEs will be able to use in most of their business areas, and they can function as incubators for future and more advanced technologies.

2.3.1.3. Low-cost proofs of concepts

In this last technology-related category, various authors highlight the benefits of simplifying Industry 4.0 initiatives to increase the chances of success (Moeuf et al., 2020; Sriram & Vinodh, 2021). (Maroufkhani et al., 2020) investigate how 11 different TOE factors influence the adoption of big data analytics in SMEs, concluding that the complexity of technologies, uncertainty about the results, and the possibility of trying out solutions all influence the adoption of big data analytics in SMEs. Similar findings can be observed in (Amaral & Peças, 2021), who conducted two SME case studies. The authors conclude that SMEs can benefit from digitalising processes gradually by exploiting existing resources to make small and inexpensive advancements. This advocates for an internal grassroots innovation strategy where innovation is primarily bottom-up and focuses on gradually developing technical solutions and growing competences. (Jiwangkura et al., 2020) add lightweight flexibility as influencing the adoption of IIoT implementation strategies. Specifically, the authors recommend implementing simple, inexpensive, pilot IoT, pain-point-driven solutions in a manufacturing setting. (Bosman et al., 2019; Soluk & Kammerlander, 2021; Welte et al., 2020) highlight that SMEs should look for third-party funding from innovation or DT grants from governmental initiatives. (Yu & Schweisfurth, 2020) investigate the reason for SMEs' lack of Industry 4.0 technologies, finding that companies are more likely to implement technologies with which they have experience and in which they can recognise opportunities. (Hamzeh, Zhong, and Xu 2018) also incite SMEs to develop prototypes and demonstrate technologies to learn from them. Likewise, (Cimini et al., 2021) state that companies should experiment with technology and use this experimentation to open themselves up to change. Lastly, this is repeated in (Siemen et al., 2018), who uncover that SMEs prefer low setup costs over low subscription costs. Overall, there is a consensus between the authors mentioned here that SMEs should work with low-cost solutions and engage in trial programmes, as this allows the testing of proof-of-concept solutions.

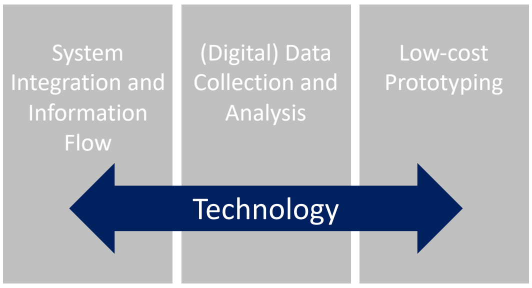

Figure 2.5: Relationship between technological themes

2.3.2. Organisation

2.3.2.1. Strategic alignment

Strategic alignment is key to adopting Industry 4.0 initiatives done, e.g., by developing digital strategies, ensuring compatibility with business goals, and ensuring alignment with innovation strategies. (Eleftheriadis & Myklebust, 2018; Nwaiwu et al., 2020; Siemen et al., 2018; Soluk & Kammerlander, 2021; Spalinger et al., 2019; Welte et al., 2020) discuss that a strategic plan for any Industry 4.0 transition should exist to ensure alignment with the organisational, operational, and technical characteristics of the organisation. (Agostini & Nosella, 2019; Canhoto et al., 2021; Somohano-Rodríguez et al., 2020) highlight that integration, beyond technology, is the foundation of Industry 4.0 and that social capacity is a determinant for this integration. (Arcidiacono et al., 2019) aim to highlight strategic decisions that support SMEs' adoption of Industry 4.0 technologies. The authors conclude that a strong strategic vision is a proactive approach to Industry 4.0 adoption. This will facilitate a gradual grasping of Industry 4.0 concepts and application scenarios, allowing SMEs to plan their next steps. This is also likely to contribute to building the capabilities that allow digital information exchange with customers, in addition to building confidence and trust in this exchange. Additionally, (Bär et al., 2018; Moeuf et al., 2020) find that Industry 4.0 initiatives should appear in long-term strategies, and they should be aligned across the organisation. (Ghobakhloo & Ching, 2019) specifically suggest that SMEs create strategic roadmaps, as this facilitates digital technology adoption. They find that this is one of the discriminators between non-adopters and adopters. Likewise, (Bosman et al., 2019) recommend that companies conduct strategic analyses regularly. (Julian M. Müller et al., 2021), who investigate how SMEs differ from larger companies in terms of relationships between their absorptive capacities, innovation strategies, and business model innovations, conclude that companies should focus on novelty-centred business models instead of just focusing on becoming more efficient in existing processes. This is supported by (Canhoto et al., 2021), who also uncover patterns that show how SMEs' behaviour changes with increasing technology use and technology adoption. Generally, the authors suggest that as the companies adopt more technology, they become less focused on reducing change and risks and more focused on embracing change and disrupting their industry. To summarise, the authors above mainly highlight the importance of developing long-term plans and strategies for digital initiatives to ensure coherence among different investments in technology. Furthermore, the authors also highlight the importance of aligning these digital strategies with business goals to ensure that these goals support and develop the core functions of the business.

2.3.2.2. Management support and leadership

(Gamache et al., 2020) find that developing a sophisticated digital strategy or engaging in many digital investments does not have a significant impact on a company's digital performance. According to the authors, highly committed management, the utilisation of quality data, and effective change management are far more important. Several authors address the importance of having strong support from top management. This is observed in the paper by (Chatterjee et al., 2021), who seek to identify the antecedents of AI adoption in manufacturing. The study finds that strong leadership support accelerates the adoption of AI.

The need for strong management and leadership support is furthermore elaborated in, e.g., (Jayashree et al., 2021; Maroufkhani et al., 2020; Sivathanu, 2019). Moreover, (Agostini & Nosella, 2019) conclude that with the presence of strong top management support and absorptive capacity, the relationship between external social capacity and Industry 4.0 adoption becomes positive and significant. (Puklavec et al., 2018) point to top management support being more important in the evaluation stage than in the adoption stage. However, management support is stronger when the manager is a part of the adoption team. According to (Cimini et al., 2021), managers should ensure that technology investments are co-designed with the organisation. (Annosi et al., 2019) find a positive correlation between managers' ability to collect evidence-based information about the technologies and technology adaptation. (Eleftheriadis & Myklebust, 2018) highlight that managers must teach themselves about relevant technologies. (Jiwangkura et al., 2020) also point out that top management's ability to make real-time decisions impacts IoT adoption strategies. Like (Annosi et al., 2019), (Agostini & Nosella, 2019) find that management support also controls the impact of investments in advanced manufacturing technologies and internal social capacity, and the intensiveness of Industry 4.0 technology adoption.(Julian Marius Müller et al., 2018) investigate how Industry 4.0 triggers changes in the business models of SMEs in Germany: SMEs need to sense the right timing for implementing Industry 4.0 technology, based on their human and financial capital. (Arcidiacono et al., 2019; Moeuf et al., 2020; Narwane et al., 2020; Subramanian et al., 2021) support the importance of top management, and state that managers must ensure the training of their workforce to ensure success and increase confidence in the workforce. (Moica et al., 2018; Vrchota et al., 2021) find success in establishing multidisciplinary project teams with associated key performance indicators (KPIs). (Puklavec et al., 2018; Subramanian et al., 2021) also highlight project management as an assisting factor.

2.3.2.3. Human capital

Human capital, knowledge, skills, and insight are critical in Industry 4.0 initiatives. (Naushad & Sulphey, 2020) investigate the potential ICT adoption dynamics of SMEs. The authors find that 'technological self-efficacy' is the most influential factor in ICT adoption, leading to perspectives of training. (Roblek et al., 2021) highlight investment in employee training as a key organisational factor. (Gamache et al., 2020; Welte et al., 2020) observe that the acquisition and development of skills is among the factors with the greatest potential for increasing digital performance. This is also supported by(Julian Marius Müller et al., 2018; Tortora et al., 2021; Trstenjak et al., 2020; Yu & Schweisfurth, 2020), who find that organisations need to develop knowledge, skills, and confidence. In conjunction with the previous section on management and leadership, several papers specifically treat education and competence development on management levels (Amal Krishnan et al., 2021; Ascúa, 2021; Bär et al., 2018; Hamzeh et al., 2018; Moica et al., 2018; Spalinger et al., 2019; Tortora et al., 2021). (Dutta et al., 2020) conclude that skilled talent in manufacturing is a critical success factor for implementing Industry 4.0 initiatives. This is further supported by (Eleftheriadis & Myklebust, 2018; Maroufkhani et al., 2020) who both state that employees' skill sets are important for digital initiatives. Additionally, (Chatterjee et al., 2021) highlight that competencies in the organisation positively influence the perceived usefulness of AI technology. (Vrchota et al., 2019) find that there is a constant need to develop skills and knowledge among staff. (Sriram & Vinodh, 2021) suggest that technology workshops can be used to improve employees' technical skills and awareness and to keep them up to date. (Ghobakhloo & Ching, 2019) emphasise the importance of having great information processing capabilities in the organisation with competencies that can facilitate and speed up the adoption of digital technologies. (Sriram & Vinodh, 2021; Trstenjak et al., 2020) also recommend that companies learn about big data and its possibilities.

2.3.2.4. Organisational culture

Organisational factors describe organisational structure, culture, formal and informal processes, and communication as determining factors for implementing Industry 4.0 initiatives. As a general term, 'digital culture' is understood as cultural characteristics that relate to the implementation of Industry 4.0 initiatives and digitalisation (Hamzeh et al., 2018; Tortora et al., 2021). (Soluk & Kammerlander, 2021) highlight employee resistance as a significant barrier for Industry 4.0 initiatives, namely resistance related to fear of obsolescence or deskilling. This can be mitigated by the early communication of success stories.

(Kilimis et al., 2019) suggest including blue-collar workers when introducing digital technologies in operational processes, as this will help them to utilise and develop in-house capabilities and ease change management. (Roblek et al., 2021) find the determinants of innovation culture to be a tolerance of failures and openness and willingness to change. (Welte et al., 2020) highlight that a machine-learning project is only successful if the employees think that it is successful and not imposing a situation of stress. (Trstenjak et al., 2020) recommend a communicative levelled approach. (Bosman et al., 2019) highlight that SMEs must identify their own industry-sanctioned credentials, and they must identify the incentives their employees should implement along with open-mindedness through sharing knowledge. (Michna & Kmieciak, 2020) find a positive relationship between open-mindedness and the willingness to implement Industry 4.0 initiatives in SMEs. The authors propose a bidirectional relationship, suggesting that increased financial performance can also increase knowledge sharing and open-mindedness. (Müller et al., 2021) conclude that an adequate corporate culture that encourages cross-functional thinking and innovation search is required. (Vrchota et al., 2019) assume a need for the optimal culture, which makes it possible to introduce innovations and changes and to continuously monitor these changes. (Roblek et al., 2021) highlight innovation culture as determining the introduction of disruptive innovations in SMEs. According to (Canhoto et al., 2021), companies that are less focused on reducing change and risks and more focused on embracing change and disrupting their business are also the companies that experience a culture that goes from resisting to embracing change. The authors describe the most transformational companies as having a culture that promotes discovery, vigilance, and the implementation of opportunities. The authors above, to some degree, all describe the need for strong cultural support, which can be obtained through strong communication and the inclusion of employees, open-mindedness, and idea sharing. Ultimately, SMEs need to develop a culture that embraces changes rather than perceiving them as disturbances.

2.3.2.5. Financial expectations

From the literature, it is evident that no Industry 4.0 initiative can take place without some sort of financial investment. This imposes serious restrictions to digitalisation in SMEs (Agostini & Nosella, 2019; Maroufkhani et al., 2020). (Sriram & Vinodh, 2021; Türkeş et al., 2019) conclude that the shift to Industry 4.0 requires determination, and high capital to implement new technologies. (Ghobakhloo & Ching, 2019) state that the future of an SME can be put in danger by unsuccessful investments; hence, companies must allocate carefully. (Soluk & Kammerlander, 2021) argue that a strong barrier in family-controlled SMEs is paternalistic decision-making unaware of opportunities related to digital technologies (Stentoft et al., 2021; Vrchota et al., 2019). According to the authors, it is important to develop effective processes for determining the effectiveness of investments, such as the recovery rate or return on investment, and risk analysis is a big part of this. (Dutta et al., 2020) conclude that it is critical to relate operational performance to KPIs, such as cost, efficiency, relatability, and maintainability. To summarise, SMEs must not expect Industry 4.0 initiatives to be free to engage in; however, they should rely heavily on developing business cases to objectively assess the different investments and thereby reduce risks.

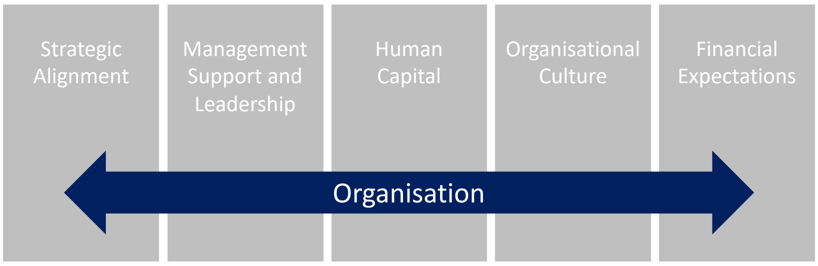

Figure 2.6: Relationship between organisational themes

2.3.3. Environment

2.3.3.1. External knowledge search

There is a need for SMEs to look for knowledge and expertise outside their organisations, (Canhoto et al., 2021; Hamzeh et al., 2018). The external environment goes from managing external pressure to seeking opportunities as the company adopts more technology, and the approach generally goes from being reactive to being more purposeful. (Vrchota et al., 2019) discuss factors such as the market, technological development, competition, government, and ecology. Several authors specifically recommend that SMEs engage in collaborations with universities and research institutions to transfer knowledge from academia to industry (Moeuf et al., 2020; Sriboonlue & Puangpronpitag, 2019). Leaders should get involved in business-to-business (B2B) networks to estimate the opportunities offered by Industry 4.0 initiatives. Generally, the problem of a lack of knowledge resources should be mitigated by having external experts make a preliminary audit of the state of machinery, workshops, and processes. After this, the SME will need to be supported in implementing its chosen technology. The authors recommend relying on academia, as knowledge transfer is not always guaranteed with consultants. The adapted competencies should then be generated by training employees (Section 2.3.2.3). Although this training is time-consuming, it does promote better integration. (Ricci et al., 2021) find that the breadth and depth of an external knowledge search do indeed affect the adoption of Industry 4.0 technologies, based on the sensing and seizing of different types of innovation opportunities. (Agostini & Nosella, 2019) find that a strong external social capacity, including a culture of openness and integration, can help with Industry 4.0 adoption and that external knowledge can accelerate this adoption but only with strong management support. (Sriram & Vinodh, 2021) also find that SMEs should establish connections with partners across the globe to increase awareness of new opportunities and share their own facilities. Finally, (Arcidiacono et al., 2019; Tortora et al., 2021) both highlight that close collaborations with universities, research institutions, consultants, and innovation managers can be a determining factor for implementing Industry 4.0 initiatives in SMEs. To summarise, this section highlights the importance of SMEs searching for knowledge outside themselves. This can be done through collaboration with universities, engagement in B2B networks, and/or the use of external experts.

2.3.3.2. Stakeholder collaboration and information sharing

External collaboration and information sharing are vital success factors for SMEs engaging in Industry 4.0 initiatives, (Ascúa, 2021; Soluk & Kammerlander, 2021; Sriboonlue & Puangpronpitag, 2019; Türkeş et al., 2019). (Ricci et al., 2021) suggest building collaborations with universities, technology vendors, or consultancies. The key is to develop trust and a shared vocabulary so that parties can share data confidently. (Julian M. Müller et al., 2021) conclude that SMEs that are successful in working with external knowledge are better prepared to engage in exploratory and exploitive innovation, which allows them to find new business models. Companies should learn to share information across the entire organisation and its value creation network, which includes more than just the closest suppliers and customers. (Chen, 2019; Somohano-Rodríguez et al., 2020) also report a relationship between innovation strategy and firm innovation regarding Industry 4.0. This is grounded in the fact that Industry 4.0 suggests collaboration and idea sharing between partners with complementary technologies, which allows SMEs to focus on the aspects that contribute the most to value creation. (Siemen et al., 2018) find that companies can benefit from intercompany data analysis; however, it is important that SMEs have the power to decide what information to share, as trust must be developed throughout the process. On the contrary, (Jayashree et al., 2021) do not find a positive relationship between supply chain integration and the effective implementation of Industry 4.0. They do, however, still recommend integrating the supply chain and explain that there is a lack of correlation because this process is still quite new to SMEs. (Moica et al., 2018) also recommend the implementation of logistics functions to respond to the market and extend processes towards customers. (Ghobakhloo & Ching, 2019) find that pressure from external stakeholders is a discriminator between non-adopters and adopters of digital technologies. Likewise, (Sivathanu, 2019) finds that competitive pressure is the most influential factor in the adoption of IIoT and that support from vendors is important. Additionally, (Maroufkhani et al., 2020) conclude that external support influences the adoption of big data analytics. Finally, (Amal Krishnan et al., 2021; Arcidiacono et al., 2019; Spalinger et al., 2019) all find that SMEs must collaborate with vendors and customers. Furthermore, it was noticed that the literature recommends collaboration with both customers and vendors and that no one recommends transactional endeavours where digital initiatives are blindly outsourced in one-time purchases. This suggests that in all external collaborations there should exist a learning element for the SME which seeks to develop digital competences in the business whenever new digital activities are initiated.

2.3.3.3. Support programmes

Lastly, some authors recommend that companies should look for external funding sources. This can be seen in the papers by (Soluk & Kammerlander, 2021; Spalinger et al., 2019). The authors emphasise that SMEs should look for subsidy programmes for ICT adoption, as these programmes can help reduce the costs for SMEs. Finally, (Sriboonlue & Puangpronpitag, 2019) also highlight that for SMEs with entrepreneurial capabilities, private funds are an option; in this case, well-developed business planning is a part of receiving funding.

Figure 2.7: Relationships between environmental themes

2.4. Recommendations for SMEs

This review covers many different aspects of Industry 4.0 implementation, which raises questions like the following: *Is it better to start building relationships or to start researching the optimal IT infrastructure? Is it better to first focus on competence development rather than changing the organisational culture?* Based on Section 2.3, a set of recommendations has been extrapolated. These take their origin in "technology" as this domain is the overall driver for Industry 4.0 and central to many of the themes described in this review. The recommendations are anchored in the most clearly linked themes across the domains described in this review (Section 2.3), visualised in Figure 2.8. These recommendations assume technology to be the basic enabler, and it should therefore be prioritised, as also suggested by (Sundberg et al., 2019). To the best of our knowledge, this paper is the first to present specific recommendations that take this approach while remaining true to the existing accumulated literature and remaining TOE factors.

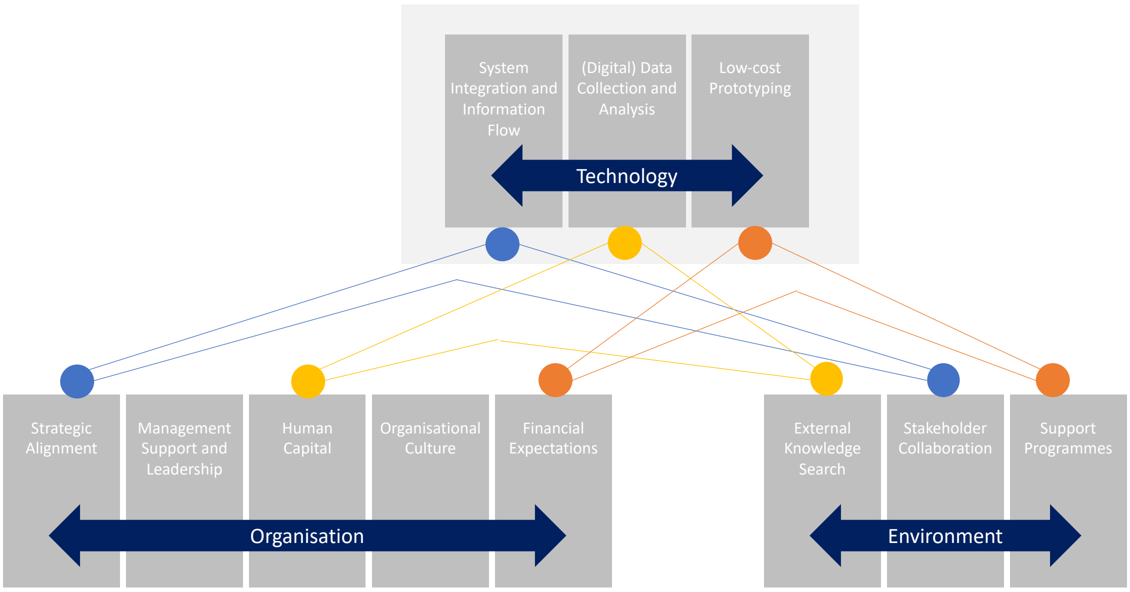

Figure 2.8: Anchoring of the recommendations

2.4.1. Recommendation 1: Prioritise the integration of IT systems across the value chain

This review describes the importance of purposeful IT infrastructure where coherent system integration and efficient information flow supports the business in its core activities (Section 2.3.1.1). From a technical perspective, this suggests data integration between IT systems that allows for the consolidation of data from various sources. This should not only take place inside the company but should also reach further into the external environment of the company where trust and relations should be built with stakeholders, with the purpose of integrating IT solutions and establishing data exchanges. Furthermore, from the sections, it is obvious that building a purposeful IT architecture for a company is something that must be done in close collaboration with customers and vendors. As highlighted in this review, these activities must originate at the strategic level of the business to ensure alignment with business goals (Section 2.3.1.1 and 2.3.1.3).

2.4.2. Recommendation 2: Develop human capital with competences in knowledge exploration and data analytics

This review describes the importance of collecting useful data that can be used to support business decisions (Section 2.3.1.2). Several of the organisational subsections describe the importance of data-driven decision-making and analytics skills. This requires human capital that can analyse and understand the potential in large amounts of data. This is important, as Industry 4.0 is highly data driven. This must take place at both the managerial and operational levels of the organisation (Sections 2.3.2.2 and 2.3.2.3). Furthermore, the review also highlights the importance of having internal human capital that can develop new competences on their own to stay educated about the possibilities of new technologies.

2.4.3. Recommendation 3: Explore the possibilities in existing resources

In the review, several authors discuss how SMEs can 'do more with less' when it comes to digitalisation initiatives (Sections 2.3.1.2 and 2.3.1.3). Various authors describe how companies can exploit the fact that many 'base' technologies, with the purpose of collecting data, can be used in low-risk experiments with other technologies to establish their usability for the company. Similarly, the authors describe how low-cost proofs of concepts can be used for the same purpose. This suggests that companies should make an effort to exploit their existing infrastructure and resources before engaging in new innovations, as this may satisfy their resource constraints more efficiently. This also makes for an interesting topic for further research; however, companies should allocate budgets to explore new technologies and opportunities (Section 2.3.2.5). Yet, exploring existing technologies in the company may result in stronger business cases, which can help mitigate low trust, which acts as a barrier to digitalisation.

2.5. Discussion and future research

The literature on Industry 4.0 and digitalisation initiatives in SMEs is undoubtedly rich, yet this review manifests some concerns for the typical SME. Generally, it seems that the current research and the applied research methods are not fundamentally contributing to the progression of Industry 4.0 implementation in SMEs. While this argument seems bold, there is a particular need for critical assessment of research from the perspective of practical and industrial applicability (Sundberg et al., 2019). For example, Sundberg et al. (2019) survey Swedish companies on digital maturity and conclude that the companies have not implemented anything that resembles Industry 4.0 concepts. In fact, the authors highlight that companies tend to score their organisational maturity higher than their technology maturity, which indicates that companies tend to believe they are more mature than they are. A chasm can thus be empirically established on the discrepancy between mainstream academia and industrial practices. Engaging in digital initiatives inevitably adds to the number of activities to which an SME has to attend and subsequently adds to the load within dynamic capabilities.

While digitalisation is a long-running process that requires both financial investment and competence development, this collides with the fact that SMEs are the fundamental key deficiencies of this type of company. SMEs are generally known to be focused on revenue and profit generation. This means that these organisations usually operate in a relatively lean fashion, in which employees fill multiple roles, with little room for non-direct value-adding activities. The longevity of digital projects therefore challenges the abilities of SMEs, as they must develop in numerous domains without compromising their core business performance. This puts the SMEs in an impossible situation where they must employ or develop competences and invest in digital technology that may not yield immediate benefits, and which may leave them in vulnerable situations. Yet, eventually, the SME is forced to develop if it wishes to remain competitive.

Returning to the initial premise of this paper, the risk aversion of the typical SME creates a vicious circle that must be broken. Hence there is a need for short routes from the identification of needs to the development and implementation of solutions. While these issues are continuously highlighted through the reviewed literature, very few papers actually attempt to solve this problem. Additionally, there seems to be a noticeable lack of interdisciplinary research. Most of the presented papers conduct qualitative or quantitative research using interviews and surveys to draw conclusions and propose recommendations. These papers take a snapshot of a specific moment in time and analyse the data post-capture. While this, in most cases, provides valuable insights from organisations, it fails to fully document the grounded "hows" of digitalisation and rarely helps the companies with respect to what to do. Building on this premise, it also obstructs the spread of knowledge from academia to industry, as the main, current research methods fail to deliver actionable insights to SMEs. To mitigate this, future research must make a targeted effort to reduce this gap between academia and industry by bridging knowledge through SME-targeted research.

A similar point can be found in (Estensoro et al., 2021), who recommend operational research on Industry 4.0 implementation in SMEs. The authors research SMEs' transition towards different stages of Industry 4.0 implementation from a resource-based view. Of 354 SMEs, the authors find that more than half have not effectively implemented Industry 4.0 initiatives. Furthermore, more than half of the SMEs that have, have done so without any formal process, which manifests the operational perspectives of SMEs. (Amaral & Peças, 2021), who demonstrate such methods, argue for more pragmatic research on Industry 4.0 in SMEs. Hence, we suggest that future research should study the practical implementation of digitalisation initiatives as they progress. Based on the results of this literature review and the findings of (Amaral & Peças, 2021) and (Sundberg et al., 2019), we specifically suggest prioritising practical research on the three recommendations from this paper through multiple case studies.

Therefore, this literature review finds its novel academic standpoint in recommending a shifting research focus to pragmatic research on how SMEs can initiate and fully implement digital initiatives from an applied technology perspective. This review has been especially dedicated to SMEs from which the contributions and future research agenda are derived. Future research should explore whether the same recommendations and research issues are common for larger organisations as well.

The broad set of definitions of Industry 4.0 and digitalisation results in extremely broad research topics. This makes it challenging to define exactly what qualifies as Industry 4.0/digitalisation initiatives and to decide which other topics to include. During this literature review, many different types of papers were encountered. Some papers conduct surveys and statistical analyses, while others take more qualitative approaches with semi-structured interviews. It is also challenging to balance business and technology aspects, as some papers focus more on one than the other, yet somewhere a line must be drawn. This review of recommendations for introducing Industry 4.0 initiatives in SMEs was structured using the three main themes of the TOE framework. These were further divided into subcategories to cluster the content of each of the three main themes. This creates a taxonomy that steers the direction of the research, as the subcategories are derived from the data identified for this review. Furthermore, we observed many internal relationships in the TOE sections. For example, multiple subcategories under the 'Organisation' category treat different aspects of education, which becomes imperative for both managers and employees and is a prerequisite for changing the organisational culture. Likewise, there are also significant overlaps between organisational culture and competence development. When studying these attributes, it becomes difficult to strictly agree to which category the company's ability to educate itself belongs.

2.6. Conclusion

This structured literature review sought to answer the following research question: *What are the current recommendations for adopting Industry 4.0 technology in SMEs based on contemporary research?* To choose the papers to review, a rigorous approach for processing metadata was developed. This led to a final dataset of 50 papers for review. From reviewing the papers, recommendations were extrapolated and grouped into three categories using the TOE framework. Within each category, subcategories were developed to cluster the content of these categories.

This led to a total of 11 focus areas, which are strongly interrelated for SMEs to use within their own contexts; however, as previous research has emphasised a lack of technology focus in SMEs, three recommendations have been extrapolated from the focus areas, which prioritise the technological focus areas while respecting the interdependency to the organisational and environmental domains. In short, SMEs should do the following: prioritise the integration of IT systems across the value chain, invest in human capital with competences in knowledge exploration and data analytics, and explore possibilities in existing resources.

These recommendations facilitate the SMEs' need to create an infrastructure through which information can flow, like roads and highways for data between information systems. With this infrastructure established, there would be a foundation for collecting and analysing data from different sources that would allow companies to gain insights from their data. The combination of ensuring efficient IT infrastructure and the collection and analysis of data allows companies to experiment with digital technologies and explore new opportunities while minimising risks. This points towards strong interrelationships between these three disciplines, suggesting that a single discipline cannot stand alone. Building on these recommendations, this literature reviews highlights some concerns regarding the implementation of Industry 4.0 in SMEs. As the overall implementation across SMEs is very low, this study questions the current research methods and points to a discrepancy between academia and industry. To correct this, this review suggests adopting technological and pragmatic research methods to ensure that future research encapsules the entireties of how SMEs can digitalise their businesses.

2.7. References

Agostini, L., & Nosella, A. (2019). The adoption of Industry 4.0 technologies in SMEs: results of an international study. Management Decision, 58(4), 625–643. https://doi.org/10.1108/MD-09-2018-0973

Amal Krishnan, U. C., Sasidharan, A. T., Prakash, T., & Vivek, C. P. (2021). Challenges in Adoption of Industry 4.0 in Apparel Supply Chain: A Cross Case Study. Lecture Notes in Electrical Engineering, 355, 267–275. https://doi.org/10.1007/978-981-16-1244-2_23

Amaral, A., & Peças, P. (2021). SMEs and Industry 4.0: Two case studies of digitalization for a smoother integration. Computers in Industry, 125, 103333. https://doi.org/10.1016/j.compind.2020.103333

Andulkar, M., Le, D. T., & Berger, U. (2018). A multi-case study on Industry 4.0 for SME's in Brandenburg, Germany. Proceedings of the 51st Hawaii International Conference on System Sciences, 4544–4553. https://doi.org/10.24251/HICSS.2018.574

Annosi, M. C., Brunetta, F., Monti, A., & Nat, F. (2019). Is the trend your friend? An analysis of technology 4.0 investment decisions in agricultural SMEs. Computers in Industry, 109, 59–71. https://doi.org/10.1016/j.compind.2019.04.003

Arcidiacono, F., Ancarani, A., Di Mauro, C., & Schupp, F. (2019). Where the Rubber Meets the Road. Industry 4.0 among SMEs in the Automotive Sector. IEEE Engineering Management Review, 47(4), 86–93. https://doi.org/10.1109/EMR.2019.2932965

Ascúa, R. A. (2021). Industry 4.0 in manufacturing SMEs of Argentina and Brazil. Journal of the International Council for Small Business, 2(3), 203–222. https://doi.org/10.1080/26437015.2021.1899773

Bakkari, M., & Khatory, A. (2017). Industry 4.0: Strategy for more sustainable industrial development in smes. Proceedings of the International Conference on Industrial Engineering and Operations Management, 1693–1701.

Bär, K., Herbert-Hansen, Z. N. L., & Khalid, W. (2018). Considering Industry 4.0 aspects in the supply chain for an SME. Production Engineering, 12(6), 747–758. https://doi.org/10.1007/s11740-018-0851-y

Bidan, M., Rowe, F., & Truex, D. (2012). An empirical study of IS architectures in French SMEs: integration approaches. European Journal of Information Systems, 21(3), 287–302. https://doi.org/10.1057/ejis.2012.12

Bosman, L., Hartman, N., & Sutherland, J. (2019). How manufacturing firm characteristics can influence decision making for investing in Industry 4.0 technologies. Journal of

Manufacturing Technology Management, 31(5), 1117–1141. https://doi.org/10.1108/JMTM-09-2018-0283

Bouwman, H., Nikou, S., & de Reuver, M. (2019). Digitalization, business models, and SMEs: How do business model innovation practices improve performance of digitalizing SMEs? Telecommunications Policy, 43(9), 101828. https://doi.org/10.1016/j.telpol.2019.101828

Canhoto, A. I., Quinton, S., Pera, R., Molinillo, S., & Simkin, L. (2021). Digital strategy align-ing in SMEs: A dynamic capabilities perspective. Journal of Strategic Information Sys-tems, 30(3). https://doi.org/10.1016/j.jsis.2021.101682

Chang, S. C., Chang, H. H., & Lu, M. T. (2021). Evaluating industry 4.0 technology application in smes: Using a hybrid mcdm approach. Mathematics, 9(4), 1–20. https://doi.org/10.3390/math9040414

Chatterjee, S., Rana, N. P., Dwivedi, Y. K., & Baabdullah, A. M. (2021). Understanding AI adoption in manufacturing and production firms using an integrated TAM-TOE model. Technological Forecasting and Social Change, 170(November 2020), 120880. https://doi.org/10.1016/j.techfore.2021.120880

Chen, C. L. (2019). Value Creation by SMEs Participating in Global Value Chains under Indus-try 4.0 Trend: Case Study of Textile Industry in Taiwan. Journal of Global Information Technology Management, 22(2), 120–145. https://doi.org/10.1080/1097198X.2019.1603512

Cimini, C., Boffelli, A., Lagorio, A., Kalchschmidt, M., & Pinto, R. (2021). How do industry 4.0 technologies influence organisational change? An empirical analysis of Italian SMEs. Journal of Manufacturing Technology Management, 32(3), 695–721. https://doi.org/10.1108/JMTM-04-2019-0135

Coleman, S., Göb, R., Manco, G., Pievatolo, A., Tort-Martorell, X., & Reis, M. S. (2016). How Can SMEs Benefit from Big Data? Challenges and a Path Forward. Quality and Reliabil-ity Engineering International, 32(6), 2151–2164. https://doi.org/10.1002/qre.2008

Crupi, A., Del Sarto, N., Di Minin, A., Gregori, G. L., Lepore, D., Marinelli, L., & Spigarelli, F. (2020). The digital transformation of SMEs – a new knowledge broker called the digital innovation hub. Journal of Knowledge Management, 24(6), 1263–1288. https://doi.org/10.1108/JKM-11-2019-0623

De Marco, C. E., Martelli, I., & Di Minin, A. (2020). European SMEs' engagement in open innovation When the important thing is to win and not just to participate, what should innovation policy do? Technological Forecasting and Social Change, 152(December 2019), 119843. https://doi.org/10.1016/j.techfore.2019.119843

Decker, A. (2017). Industry 4.0 and SMEs in the Northern Jutland Region. In Value Creation in International Business (pp. 309–335). Springer International Publishing. https://doi.org/10.1007/978-3-319-39369-8_13

Dutta, G., Kumar, R., Sindhwani, R., & Singh, R. K. (2020). Digital transformation priorities of India's discrete manufacturing SMEs – a conceptual study in perspective of Industry 4.0. Competitiveness Review: An International Business Journal, 30(3), 289–314. https://doi.org/10.1108/CR-03-2019-0031

Eleftheriadis, R. J., & Myklebust, O. (2018). Industry 4.0 and Cyber Physical Systems in a Norwegian Industrial Context. Lecture Notes in Electrical Engineering, 451, 491–499. https://doi.org/10.1007/978-981-10-5768-7_52

Gamache, S., Abdul-Nour, G., & Baril, C. (2020). Evaluation of the influence parameters of Industry 4.0 and their impact on the Quebec manufacturing SMEs: The first findings. Cogent Engineering, 7(1), 0–31. https://doi.org/10.1080/23311916.2020.1771818

Ganzarain, J., & Errasti, N. (2016). Three stage maturity model in SME's toward industry 4.0. Journal of Industrial Engineering and Management, 9(5), 1119. https://doi.org/10.3926/jiem.2073

Ghobakhloo, M., & Ching, N. T. (2019). Adoption of digital technologies of smart manufacturing in SMEs. Journal of Industrial Information Integration, 16, 100107. https://doi.org/https://doi.org/10.1016/j.jii.2019.100107

Hamzeh, R., Zhong, R., & Xu, X. W. (2018). A Survey Study on Industry 4.0 for New Zealand Manufacturing. Procedia Manufacturing, 26, 49–57. https://doi.org/10.1016/j.promfg.2018.07.007

Haseeb, M., Hussain, H. I., Ślusarczyk, B., & Jermsittiparsert, K. (2019). Industry 4.0: A Solution towards Technology Challenges of Sustainable Business Performance. Social Sciences, 8(5), 154. https://doi.org/10.3390/socsci8050154

Holopainen, M., Ukko, J., & Saunila, M. (2022). Managing the strategic readiness of industrial companies for digital operations. Digital Business, 2(2), 100039. https://doi.org/10.1016/j.digbus.2022.100039

Horváth, D., & Szabó, R. Z. (2019). Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities? Technologi-cal Forecasting and Social Change, 146(October 2018), 119–132. https://doi.org/10.1016/j.techfore.2019.05.021

Jayashree, S., Reza, M. N. H., Malarvizhi, C. A. N., & Mohiuddin, M. (2021). Industry 4.0 implementation and Triple Bottom Line sustainability: An empirical study on small and medium manufacturing firms. Heliyon, 7(8), e07753. https://doi.org/10.1016/j.heliyon.2021.e07753

Jiwangkura, S., Sophatsathit, P., & Chandrachai, A. (2020). Industrial internet of things implementation strategies with HCI for SME Adoption. International Journal of Automation and Smart Technology, 10(1), 153–168. https://doi.org/10.5875/ausmt.v10i1.2108

Karki, B. R., Basnet, S., Xiang, J., Montoya, J., & Porras, J. (2022). Digital maintenance and the functional blocks for sustainable asset maintenance service – A case study. Digital Business, 2(2), 100025. https://doi.org/10.1016/j.digbus.2022.100025

Kilimis, P., Zou, W., Lehmann, M., & Berger, U. (2019). A survey on digitalization for SMEs in Brandenburg, Germany. IFAC-PapersOnLine, 52(13), 2140–2145. https://doi.org/10.1016/j.ifacol.2019.11.522

Kitchenham, B., Pearl Brereton, O., Budgen, D., Turner, M., Bailey, J., & Linkman, S. (2009). Systematic literature reviews in software engineering – A systematic literature review. Information and Software Technology, 51(1), 7–15. https://doi.org/10.1016/j.infsof.2008.09.009

Mariani, M., & Borghi, M. (2019). Industry 4.0: A bibliometric review of its managerial intellectual structure and potential evolution in the service industries. Technological Forecasting and Social Change, 149(November), 119752. https://doi.org/10.1016/j.techfore.2019.119752

Maroufkhani, P., Tseng, M. L., Iranmanesh, M., Ismail, W. K. W., & Khalid, H. (2020). Big data analytics adoption: Determinants and performances among small to medium-sized enterprises. International Journal of Information Management, 54(June), 102190. https://doi.org/10.1016/j.ijinfomgt.2020.102190

Masood, T., & Sonntag, P. (2020). Industry 4.0: Adoption challenges and benefits for SMEs. Computers in Industry, 121, 103261. https://doi.org/10.1016/j.compind.2020.103261

Matt, D. T., Rauch, E., & Zsifkovits, H. (2020). SME 4.0: The Role of Small- and Medium-Sized Enterprises in the Digital Transformation. In Industry 4.0 for SMEs (pp. 3–36). Springer International Publishing. https://doi.org/10.1007/978-3-030-25425-4_1

Menon, S., & Shah, S. (2020). Are SMEs Ready for Industry 4.0 Technologies: An Exploratory Study of i 4.0 Technological Impacts. Proceedings of International Conference on Computation, Automation and Knowledge Management, ICCAKM 2020, 203–208. https://doi.org/10.1109/ICCAKM46823.2020.9051550

Michna, A., & Kmieciak, R. (2020). Open-mindedness culture, knowledge-sharing, financial performance, and industry 4.0 in smes. Sustainability (Switzerland), 12(21), 1–17. https://doi.org/10.3390/su12219041

Moeuf, A., Lamouri, S., Pellerin, R., Tamayo-Giraldo, S., Tobon-Valencia, E., & Eburdy, R. (2020). Identification of critical success factors, risks and opportunities of Industry 4.0 in SMEs. International Journal of Production Research, 58(5), 1384–1400. https://doi.org/10.1080/00207543.2019.1636323

Moica, S., Ganzarain, J., Ibarra, D., & Ferencz, P. (2018). Change made in shop floor management to transform a conventional production system into an "Industry 4.0": Case studies in SME automotive production manufacturing. 2018 7th International Conference on Industrial Technology and Management, ICITM 2018, 2018-Janua(March), 51–56. https://doi.org/10.1109/ICITM.2018.8333919

Molero, G. D., Santarremigia, F. E., Poveda-Reyes, S., Mayrhofer, M., Awad-Núñez, S., & Kassabji, A. (2019). Key factors for the implementation and integration of innovative ICT solutions in SMEs and large companies involved in the multimodal transport of dangerous goods. European Transport Research Review, 11(1). https://doi.org/10.1186/s12544-019-0362-8

Müller, J. M., Buliga, O., & Voigt, K. I. (2018). Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. Technological Forecasting and So-cial Change, 132(January), 2–17. https://doi.org/10.1016/j.techfore.2017.12.019

Müller, J. M., Buliga, O., & Voigt, K. I. (2021). The role of absorptive capacity and innovation strategy in the design of industry 4.0 business Models - A comparison between SMEs and large enterprises. European Management Journal, 39(3), 333–343. https://doi.org/10.1016/j.emj.2020.01.002

Müller, J. M., Veile, J. W., & Voigt, K.-I. (2020). Prerequisites and incentives for digital information sharing in Industry 4.0 – An international comparison across data types. Computers & Industrial Engineering, 148, 106733. https://doi.org/10.1016/j.cie.2020.106733

Narwane, V. S., Raut, R. D., Mangla, S. K., Gardas, B. B., Narkhede, B. E., Awasthi, A., & Priyadarshinee, P. (2020). Mediating role of cloud of things in improving performance of small and medium enterprises in the Indian context. Annals of Operations Research, 0123456789. https://doi.org/10.1007/s10479-019-03502-w

Naushad, M., & Sulphey, M. M. (2020). Prioritizing technology adoption dynamics among SMEs. TEM Journal, 9(3), 983–991. https://doi.org/10.18421/TEM93-21

Nwaiwu, F., Duduci, M., Chromjakova, F., & Otekhile, C. A. F. (2020). Industry 4.0 concepts within the czech sme manufacturing sector: An empirical assessment of critical suc-cess factors. Business: Theory and Practice, 21(1), 58–70. https://doi.org/10.3846/btp.2020.10712

Oliveira, T., & Martins, M. F. (2010). Information technology adoption models at Firm Level: Review of literature. 4th European Conference on Information Management and Evaluation, ECIME 2010, May, 312–322.

Ortt, R., Stolwijk, C., & Punter, M. (2020). Implementing Industry 4.0: assessing the current state. In Journal of Manufacturing Technology Management (Vol. 31, Issue 5, pp. 825–836). Emerald Group Holdings Ltd. https://doi.org/10.1108/JMTM-07-2020-0284

Puklavec, B., Oliveira, T., & Popovič, A. (2018). Understanding the determinants of business intelligence system adoption stages an empirical study of SMEs. Industrial Manage-ment and Data Systems, 118(1), 236–261. https://doi.org/10.1108/IMDS-05-2017-0170

Rassool, R., & Dissanayake, R. (2019). DIGITAL TRANSFORMATION FOR SMALL & MEDIUM ENTERPRISES (SMES): WITH SPECIAL FOCUS ON SRI LANKAN CONTEXT AS AN EMERGING ECONOMY. International Journal of Business and Management, Vol.7(No. 4), pp.55-76.

Ricci, R., Battaglia, D., & Neirotti, P. (2021). External knowledge search, opportunity recognition and industry 4.0 adoption in SMEs. International Journal of Production Economics, 240(September 2020), 108234. https://doi.org/10.1016/j.ijpe.2021.108234

Roblek, V., Meško, M., Pušavec, F., & Likar, B. (2021). The Role and Meaning of the Digital Transformation As a Disruptive Innovation on Small and Medium Manufacturing Enterprises. Frontiers in Psychology, 12(June), 1–18. https://doi.org/10.3389/fpsyg.2021.592528

Sevinç, A., Gür, Ş., & Eren, T. (2018). Analysis of the Difficulties of SMEs in Industry 4.0 Applications by Analytical Hierarchy Process and Analytical Network Process. Processes, 6(12), 264. https://doi.org/10.3390/pr6120264

Siemen, C., Clever, N., Barann, B., & Becker, J. (2018). Requirements elicitation for an inter-organizational business intelligence system for small and medium retail enterprises. Proceeding - 2018 20th IEEE International Conference on Business Informatics, CBI 2018, 1, 129–138. https://doi.org/10.1109/CBI.2018.00023

Sivathanu, B. (2019). Adoption of Industrial IoT (IIoT) in Auto-Component Manufacturing SMEs in India. Information Resources Management Journal, 32(2), 52–75. https://doi.org/10.4018/IRMJ.2019040103

Soluk, J., & Kammerlander, N. (2021). Digital transformation in family-owned Mittelstand firms: A dynamic capabilities perspective. European Journal of Information Systems, November. https://doi.org/10.1080/0960085X.2020.1857666

Sommer, L. (2015). Industrial revolution - industry 4.0: Are German manufacturing SMEs the first victims of this revolution? Journal of Industrial Engineering and Management, 8(5), 1512–1532. https://doi.org/10.3926/jiem.1470

Somohano-Rodríguez, F. M., Madrid-Guijarro, A., & López-Fernández, J. M. (2020). Does Industry 4.0 really matter for SME innovation? Journal of Small Business Management, 00(00), 1–28. https://doi.org/10.1080/00472778.2020.1780728

Spalinger, D., Grivas, S. G., & de la Harpe, A. (2019). TEA - A technology evaluation and adoption influence framework for small and medium sized enterprises. Lecture Notes in Business Information Processing, 339, 433–444. https://doi.org/10.1007/978-3-030-04849-5_38

Sriboonlue, P., & Puangpronpitag, S. (2019). Towards Innovative SMEs: An Empirical Study of Regional Small and Medium Enterprises in Thailand. Procedia Computer Science, 158, 819–825. https://doi.org/10.1016/j.procs.2019.09.119

Sriram, R. M., & Vinodh, S. (2021). Analysis of readiness factors for Industry 4.0 implementation in SMEs using COPRAS. International Journal of Quality and Reliability Management, 38(5), 1178–1192. https://doi.org/10.1108/IJQRM-04-2020-0121

Stentoft, J., Adsbøll Wickstrøm, K., Philipsen, K., & Haug, A. (2021). Drivers and barriers for Industry 4.0 readiness and practice: empirical evidence from small and medium-sized manufacturers. Production Planning and Control, 32(10), 811–828. https://doi.org/10.1080/09537287.2020.1768318

Subramanian, G., Patil, B. T., & Gardas, B. B. (2021). Evaluation of enablers of cloud technology to boost industry 4.0 adoption in the manufacturing micro, small and medium enterprises. Journal of Modelling in Management, 16(3), 944–962. https://doi.org/10.1108/JM2-08-2020-0207

Tortora, A. M. R., Maria, A., Valentina, D. P., Iannone, R., & Pianese, C. (2021). A survey study on Industry 4.0 readiness level of Italian small and medium enterprises. Procedia Computer Science, 180, 744–753. https://doi.org/10.1016/j.procs.2021.01.321

Trstenjak, M., Opetuk, T., Cajner, H., & Tosanovic, N. (2020). Process planning in industry 4.0-current state, potential and management of transformation. Sustainability (Switzerland), 12(15). https://doi.org/10.3390/SU12155878

Türkeş, M. C., Oncioiu, I., Aslam, H. D., Marin-Pantelescu, A., Topor, D. I., & Căpuşneanu, S. (2019). Drivers and barriers in using industry 4.0: A perspective of SMEs in Romania. Processes, 7(3), 1–20. https://doi.org/10.3390/pr7030153

Ulas, D. (2019). Digital Transformation Process and SMEs. Procedia Computer Science, 158, 662–671. https://doi.org/10.1016/j.procs.2019.09.101

Veile, J. W., Kiel, D., Müller, J. M., & Voigt, K. I. (2020). Lessons learned from Industry 4.0 implementation in the German manufacturing industry. Journal of Manufacturing Technology Management, 31(5), 977–997. https://doi.org/10.1108/JMTM-08-2018-0270

Vrchota, J., Řehoř, P., Maříková, M., & Pech, M. (2021). Critical success factors of the project management in relation to industry 4.0 for sustainability of projects. Sustainability (Switzerland), 13(1), 1–19. https://doi.org/10.3390/su13010281

Vrchota, J., Volek, T., & Novotná, M. (2019). Factors introducing Industry 4.0 to SMEs. Social Sciences, 8(5). https://doi.org/10.3390/socsci8050130

Welte, R., Estler, M., & Lucke, D. (2020). A method for implementation of machine learning solutions for predictive maintenance in small and medium sized enterprises. Procedia CIRP, 93, 909–914. https://doi.org/10.1016/j.procir.2020.04.052

Xu, M., David, J. M., & Kim, S. H. (2018). The Fourth Industrial Revolution: Opportunities and Challenges. International Journal of Financial Research, 9(2), 90. https://doi.org/10.5430/ijfr.v9n2p90

Yilma, B. A., Panetto, H., & Naudet, Y. (2021). Systemic formalisation of Cyber-Physical-Social System (CPSS): A systematic literature review. Computers in Industry, 129. https://doi.org/10.1016/j.compind.2021.103458

Yu, F., & Schweisfurth, T. (2020). Industry 4.0 technology implementation in SMEs – A sur-vey in the Danish-German border region. International Journal of Innovation Studies, 4(3), 76–84. https://doi.org/10.1016/j.ijis.2020.05.001

Chapter 3. Digitalization of maintenance activities in small and medium-sized enterprises: A conceptual framework

The following journal article answers RQ2:

Grooss, O. F. (2024). Digitalization of maintenance activities in small and medium-sized enterprises: A conceptual framework. Computers in Industry, 154, 104039. https://doi.org/10.1016/j.compind.2023.104039

The published version of this paper can be found at this link: https://www.sciencedirect.com/science/article/pii/S0166361523001896

The content of this chapter is directly copied from this paper.

Abstract: Asset management and digitalization are two timely research topics, especially for small and medium-sized enterprises (SMEs). SMEs continue to struggle with implementing digital technologies while retaining effective asset management processes within maintenance and after-sales service. Therefore, this paper develops a conceptual framework that integrates technological and organizational factors for digitalizing maintenance processes in SMEs. Furthermore, this paper steps away from the prevalent high-tech narrative, to explore how SMEs practically can implement digital technologies amidst common constraints. A focal point of this study is leveraging existing technologies and data for low-cost optimizations as a practical steppingstone for SMEs, bridging the gap between high-tech digital discussions and SMEs' real-world scenarios. The framework addresses three theoretical challenges in the existing literature, drawing on multiple case studies, and employing pragmatic research methods. It offers a conceptual tool for assessing the digital maturity of maintenance processes in SMEs and identifying areas for improvement. Based on the framework, low-performing domains across the case studies are pinpointed for future research. These domains encompass technical competencies within information systems, strategic efforts, and human capital within prototyping, and organizational culture within digital data collection and analysis.

Keywords: *SMEs, Industry 4.0, Maintenance, Digitalization, Digital Maturity*

3.1. Introduction

While digitalization has been widely researched and discussed for the last decade, there are still many unclear aspects for especially small and medium-sized enterprises (SMEs). These have been proven to generally fall behind in digital transformation (Sommer, 2015). While the causes for this are listed to be many, most of them leads back to a lack of human capital and financial resources (Matt & Rauch, 2020; Sommer, 2015).

The overarching definitions of "digitalization" and "Industry 4.0" inherently encompass a broad range of sub-research areas, spanning from rigorous technical development and implementation of digital technologies to comprehensive examination of socio-economic factors related to the worker experience, business value and impact of technological interventions (Horváth & Szabó, 2019; Masood & Sonntag, 2020). With this also follows the discussion of technology enabling people versus people enabling technology. This discussion has briefly been touched upon in previous work (Grooss et al., 2022), where both aspects are presented in regard to digital maturity models. In short, as digital maturity models struggle with consistency in methods and terminology, focus organizational over technological factors, and rely on subjective self-reporting, their validity may conflict with more objective measures of technological states (Minonne et al., 2018; Sundberg et al., 2019; Williams & Lang, 2019). It's challenging to determine the correct balance of technology and organizational factors, but these points suggest that digital guidance models and tools for industrial use should encompass both domains. This conveniently segues into addressing three aspects of digitalization research in SMEs.

The first aspect relates to the lack of research that focus on digitalization of maintenance processes in SMEs, including both internal and external asset management. Both carries immense importance for SMEs, which can be seen in the extensive research on the development of digital technology solutions for predictive and prescriptive maintenance (Khan et al., 2022; Rastogi et al., 2020; Sang et al., 2020; Welte et al., 2020). Here, high-tech concepts such as Internet of Things and Deep Learning are combined to collect digital data from production equipment to predict failures and prescribe maintenance actions. While much of this research present the technology solutions, very little research focus on their implementation in the daily operations of SMEs, failing to address the interaction of technological and organizational factors. Specifically, (Psarommatis et al., 2023), who conducts a literature review on Maintenance 5.0, suggest future research to enable SMEs to achieve advanced maintenance strategies.

The second aspect relates to the lack of pragmatic research. Especially for SMEs, pragmatic research has proven valuable within Industry 4.0, as this has proven to generate actionable insights for SMEs, thereby bridging the gap between academia and industry. Examples of this can be found in (Amaral & Peças, 2021), who conducted two case studies of digitalization in SMEs, where a pragmatic approach was used to immerse in the companies practices to best understand them. Also (Ghobakhloo & Ching, 2019) suggest further case-based research in adoption of digital technologies in SMEs.

The last aspect relates to how low-cost implementation of digital initiatives and exploitation of existing resources can be a significant driver for digitalization in SMEs (Moeuf et al., 2020). There are several examples of this in the literature. For example, (Xing et al., 2020) manages to develop a low-cost solution for machine tool precision monitoring using hobby-grade hardware. Also, (Alex et al., 2021) develops a cyber-physical system based on low-cost hardware for state monitoring of a CNC machine and a robot. Lastly, (Amaral & Peças, 2021) conclude that companies can exploit existing resources to make minor incremental digital advancements. (Su et al., 2023) also highlight that SMEs with limited resources can identify most important technologies and competences that responds to the market preasure to capture opportunities. From here, they can adopt technologies that adapt their capabitlies and create breakthoughs. These three aspects collectively represent a need for pragmatic research on how SMEs can introduce digital initiatives through low-cost prototypes and solutions, with respect to technological and organizational factors. Therefore, the following research question is proposed: **What are the main organizational and technology factors that describes the maturity stages of maintenance activities in Small and Medium-sized Enterprises (SMEs)?**

3.2. Related work

3.2.1. Industry 4.0 and digitalization in SMEs

The idea of "Industry 4.0" started at the 2011 Hannover Fair in Germany (Masood & Sonntag, 2020; Matt & Rauch, 2020). It introduced a new paradigm where the implementation of various digital technologies connects products and processes and enables total inter-connectivity (Matt & Rauch, 2020). Digital technologies such as Internet of Things (IoT), Artificial Intelligence (AI) and Cloud Computing would harvest and leverage data for improving business processes, developing new products and offer novel services (Masood & Sonntag, 2020; Matt & Rauch, 2020; Sang et al., 2020).

However, Small and Medium-sized Enterprises (SMEs) often struggle with this transition due to limited funds and lack of necessary skills to implement digital technologies (Masood & Sonntag, 2020; Sommer, 2015). The cost of digital transformation can be high, and the expertise needed is often not present within these smaller firms, making the implementation of digital technologies difficult. Previous research has suggested less complex technology solutions to battle this (Amaral & Peças, 2021; Hansen & Bøgh, 2021). These are less expensive and provide a chance for organizations to learn and build their digital skills gradually. By starting with simpler tech solutions, SMEs can slowly learn, adapt, and grow towards more advanced digital solutions as their financial situation improves and they gain more expertise over time (Amaral & Peças, 2021).

Additionally, guidelines and helpful insights are being developed to support SMEs in bridging the digital gap, which will be presented in the following sub-sections.

3.2.1.1. Strategic Alignment

Previous literature has highlighted the importance of aligning technology initiatives with strategic initiatives to ensure a common understanding of these (Soluk & Kammerlander, 2021). This alignment can be achieved through a number of ways, but the main purpose is to develop a common vocabulary that can be used to communicate initiatives across the organization (Siemen et al., 2018). Much of the literature discuss this in terms of strategy formulation, either as part of business strategies or as standalone digital and/or innovation strategies, that aligns with the organization (Bär et al., 2018; Moeuf et al., 2020; Nwaiwu et al., 2020). (Bendig et al., 2023) investigates how digital strategy can impact the company's digital orientation on its evnironmental performance. The paper uses Environmental, social and corporate governance (ESG), employee review, and technological turbulance data derived from company datasets to establish measurements that describes relationships between digital orientation and enviromental performance and finds that strategic digital orientation has a positive impact on environmental performance.

Expanding upon this, although from a different perspective, some similarities can be found in the technological factors. Here, the preparation and optimization of information system infrastructure is repeatedly highlighted as a clear priority of action for SMEs (Agostini & Nosella, 2019; Jayashree et al., 2021; Subramanian et al., 2021). This insinuates a clear link to strategic factors, as technology infrastructure decisions often take place on higher levels of the organization. These ties can also be identified within data collection and analysis. Here, several authors highlight the importance of company-wide data-driven decision-making and the leverage of data and data technologies (Dutta et al., 2020; Ghobakhloo & Ching, 2019; Sivathanu, 2019), which likewise implies the need for a coordinated effort. Similarities from strategic alignment can also be observed within the literature that discuss the use of experimentation and prototypes in digital technologies. Specifically, attention is brought to risk mitigation and reduction of uncertainties through trials and pilot projects (Hamzeh et al., 2018; Maroufkhani et al., 2020; Welte et al., 2020).

3.2.1.2. Human Capital

Human capital has been credited as one of the most important factors for introducing digital initiatives (Gonzalez-Tamayo et al., 2023; Psarommatis et al., 2023). Especially, "technological self-efficacy" is highlighted, as the self-capability of acquiring and managing knowledge within digital technologies are within the most influential factors (Gamache et al., 2020; Naushad & Sulphey, 2020; Roblek et al., 2021). However, from a technology perspective, this may require some higher granulation. Here, the literature that discuss system integration also considers technology in an organizational context, which implies that human capital should exceed technical development capabilities, but also represent conceptual understanding of the technology in use (Agostini & Nosella, 2019; Narwane et al., 2020; Nwaiwu et al., 2020). This same distinction between conceptual and technical capabilities can also be observed within data collection and analysis, where some authors discuss development and deployment of technologies (Dutta et al., 2020; Ghobakhloo & Ching, 2019; Ricci et al., 2021), where others discuss leverage of data for business purposes (Jiwangkura et al., 2020; Sivathanu, 2019).

3.2.1.3. Organizational Culture

Several authors have highlight, organizational culture that embraces innovation, change and learning as a prerequisite for enduring digital initiatives. This has in some instances been translated to having a "digital culture" (Hamzeh et al., 2018; Roblek et al., 2021; Tortora et al., 2021). (Leal-Rodríguez et al., 2023) investigates the relationship between people, innovation, goals, and norms culture and digital culture, through surveying 285 respondents from 50 companies. The paper finds that people-oriented culture is the most facilitating factor for digital culture, while norms and goals culture obstructs it. This also means that employee resistance or misbehavior can act as significant barriers to digital initiatives (Soluk & Kammerlander, 2021; Welte et al., 2020). From a technology perspective, this would relate to the willingness to adapt and adhere to structures and compliance (Agostini & Nosella, 2019; Narwane et al., 2020). Data collection and analysis likewise ties to organizational culture. Here, authors discuss the collecting and leveraging data to advance into data-driven decision-making as a prerequisite to achieve agility and market responsiveness (Ghobakhloo & Ching, 2019; Jiwangkura et al., 2020).

3.2.1.4. Management Support and Leadership

Support from management and strong leadership has been highlighted by several authors as imperative for success with digital initiatives (Agostini & Nosella, 2019; Gamache et al., 2020; Maroufkhani et al., 2020). In general, the literature highlights two aspects of this. The first relates to the managers ability to educate themselves on how to manage digital technologies (Annosi et al., 2019; Cimini et al., 2021; Eleftheriadis & Myklebust, 2018). The second relates to the presence and manifestation of commitment to projects from management. (Agostini & Nosella, 2019; Moeuf et al., 2020). Within data collection and analysis, the connection to management support and leadership can also be recognized through the need for understanding leveraging data for decision making (Dutta et al., 2020; Sivathanu, 2019).

3.2.1.5. Financial Expectations

The literature consensus on the fact that all digital initiatives require some level of financial resource allocation. While this is one of the main issues of digitalization in SMEs, any initiative is associated with a cost, which must be recognized. Within system integration, this is mainly associated with allocating financial resources for optimizing information flows and IT infrastructure (Ghobakhloo & Ching, 2019; Jayashree et al., 2021). Within data collection and analysis, financial expectations relate to the costs associated with deployment of data collection mechanisms and analysis platforms, which are imperative for digital initiatives (Dutta et al., 2020).

3.2.2. Asset Management in SMEs

Asset management is a crucial practice for Small and Medium-sized Enterprises (SMEs) in the traditional manufacturing sector, encompassing a range of activities aimed at maximizing the value of physical assets throughout their lifecycle (Maletič et al., 2020; Tortorella et al., 2022). This is particularly vital in the realms of internal maintenance and after-sales service, which are essential for ensuring operational efficiency and customer satisfaction (Pagalday et al., 2018).

Effective asset management enables manufacturing SMEs to maintain their equipment in optimal working condition, which is fundamental for ensuring operational efficiency (Maletič et al., 2020). By scheduling regular maintenance activities, SMEs can prevent unexpected breakdowns and minimize downtime, thereby maintaining a steady production flow (Tortorella et al., 2022). Moreover, by investing in preventative maintenance as part of asset management, SMEs can extend the life of their machinery, reducing the costs associated with repairs and replacements (Maletič et al., 2020). On the other hand, providing prompt and effective after-sales service is a cornerstone for building strong customer relationships and represents an opportunity for revenue generation (de la Fuente et al., 2018; Pagalday et al., 2018). By offering maintenance contracts, spare parts, or upgrades, SMEs can create a steady stream of income post-sale. Effective asset management ensures that resources are available to support these services, contributing directly to profit (Pagalday et al., 2018; Tortorella et al., 2022). Moreover, after-sales service interactions provide valuable feedback which, when fed into an asset management system, can inform continuous improvement efforts (de la Fuente et al., 2018). Through a structured approach to asset management, traditional manufacturing SMEs can significantly benefit by ensuring smooth internal operations and offering superior after-sales service, thereby achieving a sustainable competitive advantage in the market (Maletič et al., 2020; Pagalday et al., 2018).

At the same time Asset Management be a costly, as it is extremely information intensive, why developing information system architectures for this is a difficult process (de la Fuente et al., 2018; Maletič et al., 2020; Pagalday et al., 2018). Especially for manufacturing companies, the contemporary focus on digital transformation within the industrial paradigm has introduced a wide array of digital technologies with the promise of revolutionizing what are critical and costly business processes (Bona et al., 2021; Rastogi et al., 2020). As part of the "4.0" wave, this has been described as "Maintenance 4.0" and "Service 4.0" (Pagalday et al., 2018; Tortorella et al., 2022).

This paper positions itself in the area of digitalizing maintenance activities, moving away from the common high-tech focus that mainly discusses the performance of advanced solutions. Instead, it dives into the practical aspect of how SMEs implement digital technologies, considering the usual constraints they encounter. A key perspective of this study is on using existing technologies and data for low-cost optimizations, providing a starting point for SMEs. This approach not only fits the resource limits of SMEs but also sets a practical foundation for further digital advancement. By doing so, this study provides novel insight into how SMEs can better approach the implementation of new digital technologies in maintenance activities—an area crucial for their business operations. Through this practical approach, the study aims to connect the high-tech digital discussions with the real-world situations of SMEs, fostering a dialogue that aligns with the practical goals and abilities of these enterprises.

3.3. Methodology

This paper employs cross-case analysis methodology across four individual case studies in Danish SMEs. The primary objective of these case studies is to determine how companies can harness their information systems and data for the digitalization of maintenance processes through prototyping. The cases were chosen because they manufacture and sell physical products and maintain equipment, either internally or as post-sale service. Two case studies were selected for each model. Furthermore, the case companies must be SMEs, by definition of the European Commission measured in number of employees (Commission, 2015).

The case studies were conducted using an action research approach, wherein each case was analyzed by addressing a specific issue relevant to the context of the individual case company. This approach was based on a three-step process derived from (Azhar et al., 2010), which includes: problem diagnosis, planning and taking action, and evaluation and learning. Similar approaches have previously been used within the field (Mantravadi et al., 2023; Ordieres-Meré et al., 2023; Yilmaz et al., 2023).

The initial step involved comprehending the business context of the case company and pinpointing a problem that needed resolution. This entailed conducting interviews and workshops where various stakeholders involved in maintenance processes would outline their business operations and any challenges encountered therein. Subsequently, discussions were held on how data and digital technologies could mitigate these challenges, and a consensus was reached on the scope of the problem-solving effort. The subsequent step entailed examining the company's data foundation and information system infrastructure to pinpoint areas for improvement. Following this, an artefact was created to resolve the scoped problem, primarily utilizing the case company's existing resources. In the final step, the case company assessed the artefact's outcome, which would either lead to a revision of the artefact through the cycle or cessation of the process based on the artefact performance. It is important to emphasize that this paper focus on the outcome of the process and not the performance of the artefacts. Each case study was conducted over approximately 3 months.

The empirical data collection itself was multi-faceted. Formal interviews were conducted, recorded, and transcribed. However, given the dynamic nature of SME operations, a significant portion of the data was also gleaned from informal interactions, such as spontaneous calls and on-site discussions. These were documented in note form. Additionally, observational data from information systems, databases and business documents enriched the research, providing nuanced insights into the practical aspects of digitalization in these enterprises.

While the profiles of the stakeholders varied across cases, care was taken to ensure representation from both the operational (operators/technicians) and managerial levels. The primary criterion for selecting these individuals was their profound understanding of the business context. Therefore, it was ensured that the participants were experienced individuals within their respective companies, possessing a deep understanding of the business dynamics and challenges. See Table 3.1 for more details on the case companies.

All collected data underwent thematic coding and was systematically categorized based on the five organizational categories identified from the related work and three technological factors: System Integration and Information Flow (SI&IF), Digital Data Collection and Analysis (DDCA) and Low-cost Proof-of-Concept (LC-PoC). This structured approach not only facilitates a comparative analysis across the case studies but also highlights patterns and themes. From here, maturity levels within each thematic code are developed by contrasting the findings from across the four case studies.

Table 3.1: Overview of case companies and interviewees

Case	**Category**	**Industry**	**No. of employees**	**No. of structured interviews**	**Main Stakeholder Interviewees**	**Artefact**
CASE1	Internal maintenance	Injection Molding	80	4	Maintenance manager, Production planner, Maintenance operator	Digital maintenance planning board using existing production data to estimate next maintenance dates.
CASE2	After-sales service	Container Cranes	114	5	Department Manager, Maintenance Manager, Maintenance operator (electrical), Maintenance operator (Mechanical)	Smartphone application using PLC data to warn operators about upcoming failures.
CASE3	After-sales service	Perimeter Fencing Systems	150	5	Technical Manager, Technical support, IT Specialist, Technician	Improvement of data quality across information systems
CASE4	Internal maintenance	Furniture	100	4	Factory Manager, Maintenance Manager, Maintenance operator, Production planner	Digital maintenance planning board using existing production data to estimate next maintenance dates.

3.4. Results

3.4.1. Strategic Alignment

Across the case companies, little attention was brought to strategic alignment. From a SI&IF perspective, all companies had established information systems based on business process requirements. For some processes spreadsheets or other feral information systems were used to fulfil otherwise not met needs. This was generally accepted by managements, and despite acknowledging the need for streamlining, this was not given significant strategic attention. However, in Case1 and Case3, management both expressed interest in keeping Enterprise Resource Planning (ERP) systems as close to the standardized solutions as possible and avoid customizations to mitigate upgrading difficulties or vendor lock-ins.

> *"We aim to keep our ERP as close to standard as possible, maybe 95%, so we are not suddenly locked to one vendor, because they did a lot of special customizations" - Production planner, Case1*

This was strongly expressed in Case3, where management were working on scaling an IoT solution to their products to be able to offer new service contracts and value proposition to existing customers.

From a DDCA perspective, Case2 and Case3 were actively pursuing strategic efforts within data collection and analysis. Case2 through an innovation project on data collection from container cranes to explore future gains from these, and Case3 through their IoT project and an upgrade of the Field Service Management system. In Case1, there was some attention to digital data collection from injection molds, but this was only at a planning stage with no on-going activities. Case4 also had plans for improving data collection from the production lines, but no initiatives were started.

Across the case companies, very little targeted attention was given towards LC-PoC. For Case1 and Case3 there was a generally strategy of making do with what was available, but this was on a very sporadic level and was not formulated in any strategic documentation.

3.4.2. Human Capital

Generally, the case companies showed low degrees of technical competences. From a SI&IF perspective, all case companies would completely outsource all information system development to external partners. This was mainly related to all the companies using commercially available information systems and technologies for all business-critical processes, where adaptions would be developed and implemented by the information system vendor or external service partners. Instead, conceptual competences were more dominant. In Case3, an administrative quality manager was allocated to optimizing administrative processes and the use of information systems. The quality manager would not develop new functionalities but would manage external developers. The quality manager would collaborate with system vendors to ensure that system functionalities would support the organization well. Similar showed across the other case companies, where understanding of business processes was more relevant than technical competences. Similar conceptual competences were recognized in Case1 and Case2, where the there was a high degree of conceptual understanding of how information systems could generally be improved to better support the business. Contrarily, in Case4, where the users were much less focused on how the systems could be improved.

This differed some from the DDCA perspective. Here, technical competences for data collection were observed in Case2 and Case3. In Case 2, a few electricians were very well versed in configuring PLC controllers for data collection, which was often used for identifying errors on the systems. Case3 also had a small department for developing new alarm solutions, where a few technicians would develop new product offering using different off-the-shelf solutions. Conceptual competences were observed in Case1 and Case2 where different employees and managers would have numerous specific ideas for data that could be interesting to collect and how these could benefit maintenance processes.

> *"I do have a lot of ideas for how we can use the different systems better in the business" - Maintenance Manager, Case2*

This was less specific in Case3, where managers were aware that more data could be collected, but they were considerably less specific when discussing potential use cases. Generally, the value of data was known, but the topic was discussed on a far more abstract level. Case4 reflected both of these scenarios. Here, the factory manager was highly aware about how collecting more data from production equipment, would allow for more accurate calculations of Overall Equipment Efficiency (OEE), which was a strategic focus point for the factory. However, outside these strategic KPIs, the manager expressed much less interest or knowledge development of data exploitation.

Within LC-PoC, conceptual competences and knowledge development were specifically noticeable in Case2, where the external innovation partner was assisting the company in developing new digital initiatives, with the aim of transferring knowledge into the company. Vice versa, this was much less present in Case4, who was much more operationally focused, which left very little time for exploration and development of digital initiatives. Case4 did have an employee working specifically with continuous improvement, but this was much more focused on traditional LEAN optimization than implementation of digital initiatives. Of all the case companies, only Case3 possessed some internal technical competences within low-code platforms, where Case2 would have them externally. For Case3, this was mainly rooted in two student workers, working to educate themselves on the use of a low-code business intelligence platform, which was previously fully managed by external consultants.

3.4.3. Organizational Culture

The observations from the case companies within organizational culture showed some granularity in form of change and behavior. From a SI&IF perspective, the case companies showed different examples of adherence to established processes. In Case3, a business unit would use a spreadsheet to record business critical information, rather than using the supported ERP system. This meant that some important data would not be transferred to the ERP system. In this case, the users of the spreadsheet were happy to convert using the ERP system, but this was blocked by the order of operations between the information flow and the system capabilities. In Case1, two different operators would register the same errors in two different systems. One operator had developed a spreadsheet due to lack of knowledge on how to use the ERP system, which caused the double work. However, both operators were open for improving this workflow, to make it more efficient. Contrarily, in Case2, a maintenance management system intended for managing and describing work orders, was only used to register work time for paycheck purposes. Being aware that this was not ideal, the technicians reported that they often would request a better system for this, indicating some leniency to change. However, the system was able to register this information, but the technicians found that the system was too unintuitive and that it took too long to input the information, causing this to be disregarded.

From a DDCA perspective, the misuse of the system meant that important root cause and repair descriptions for the equipment were not registered. This meant that there was no data describing when and why systems would malfunction. In this case, there was a very strong resistance towards change, as the technicians were uncomfortable spending more time reporting data. This was mainly related to the technicians wanting to use their time efficiently for optimizing equipment utilization. In Case3, technicians would wrongly assign consumed resources to work orders, causing incorrect service history on customer assets. Also, here some resistance was present, as doing it incorrectly was faster and would leave more time for doing the actual services. Contrary, in the administrative business units of Case3, change was requested and embraced, as the quality of the data would influence the quality of their work. Here, the IT manager also recognized that inefficient information systems caused poor data management behavior among technicians.

> *"It's faster to just assign the consumables to whatever facility is on the top of the service list, instead of finding the correct one, so I can get on with my day." - Service Technicians, Case3*

Case4 was also influenced by resistance to changing behavior on the shop floor. In this case, production equipment was intentionally configured to allow for higher variation in cycle and stop times, to prevent equipment raising error messages for the operators to report. This was the result of operators' complaints of reporting too much information too frequently. Yet also in this case, the administrative business units were more receptive to improving data quality, as it would directly influence the quality of their work.

These adaption and adherence themes were also recognized from a LC-PoC perspective. From the cases, very little prototyping was done across the board. Instead, the companies would engage with external providers to adapt commercially available information systems to meet organizational needs. As a small exception, Case2 used external innovation partners to innovate on processes through digitalization. The continuous presence and efforts by these partners resulted in increasing requests from operators and technicians based on previous results. However, across the case studies, well-functioning, operational prototypes were generally well-received and raised new suggestions and requests for additional solutions.

3.4.4. Management Support and Leadership

Within Management Support and Leadership, there was some granularity found within managing technologies and communication. From a SI&IF perspective, this was evident in Case2 where the manager was highly motivated working with digital initiatives and was capable of independently acquiring knowledge on specific technologies. This allowed the manager to participate in workshops with external consultants and ensure that business requirements were correctly translated for developers. Specifically, the manager was explicit on how the unintended use of the maintenance management system was significantly hindering the daily operations and the quality of the accumulated data pool. The manager generally showed understanding of the consequences of the use of information systems and how these could be improved. However, this knowledge was rather limited to existing information systems in use and not towards alternatives. The manager was also very communicative about digital initiatives and was constantly manifesting the need for digitalization by expressing confidence in their success. On the contrary, the manager in Case4 was far less invested in acquisition of knowledge about information systems. It was unclear if this was due to the capabilities of the manager or simply a matter of allocation of time, but the manager was very explicit about not being able to make decisions about which digital technologies to engage in. Specifically, the manager was interested in implementing a maintenance management system but felt insecure in deciding on a platform.

> *"I can easily see that we need a maintenance management system and a new packaging line, but I can just not tell what would be right for us" - Factory Manager, Case4*

A similar distinction was clear from a DDCA perspective. In Case3, the management would often present ideas of new initiatives based on yet uncollected data. While most ideas would require significant technical effort, they expressed understanding how the data could benefit the business. Similarities could be observed in Case1, where the manager had a high interest in using company data for process optimization, which allowed for idea generation of future use cases. Contrarily, the manager at Case4 was less invested in data outside the corporate KPIs and was mainly focused on how to improve them, while new data collection initiatives were not encouraged.

Finally, management and support of technologies could also be recognized from a LC-PoC perspective. In Case1, Cas2, and Case3 management were very supportive of developing low-cost prototypes of ideas, to test their potential. In all cases, the prospect of potentially developing operational tools using low-code platforms and existing data, was enough for the managers to support the ideas.

3.4.5. Financial Expectations

From a SI&IF perspective, there was a general consensus among the case companies that developing system integrations or changes to system functionalities comes with costs of development and implementation. Here, the companies were very aware of these costs, which is likely to be related to this being managed by external consultants, which eventually invoice their work. Allocation of financial resources was most often done based on cost-benefit analyses of individual initiatives, meaning that a new functionality would only be developed for a system, if it were to provide a return on investment. Case2 stood out from this as their strategic partnership with the external consultants, were based more on an arbitrary expectation of eventually achieving some return on investment, rather than a clear-cut business case. Oppositely, Case4 had a much more cost focused view on this. Here, there was a clear need for a system integration which required a larger investment to allow for calculating OEE correctly in the factory. This was in high demand from management and also had a healthy business case. Despite this, it was not possible to get the investment approved by management, yet they would still unrealistically request the KPIs.

> *"I know that I need this integration [between two information systems] to get this data, but I cannot get the money to make it. I have told management this, but they still just want the numbers". Factory Manager, Case4*

The same was recognized from a DDCA perspective. Here, Case3 stood out with having a strategic initiative of collecting and analyzing data through their newly acquired IoT platform, for which a substantial financial investment had to be made, without assurance of results. Lastly, the need for financial resource allocation could likewise be recognized from a LC-PoC perspective. This was primarily observed in Case2, with the biggest allocation for such activities. Yet, Case1 and Case3 also provided access to remote desktop environments and necessary software licenses for prototyping development, being relatively low-cost.

3.5. Framework development

Based on the acquired knowledge from the case studies and the established literature, a conceptual framework can be developed (Figure 3.1). The framework describes how technological and organizational factors facilitate the digitalization of maintenance processes in SMEs. The framework proposes an alternative view to digital maturity and consider organizational factors as integrated parts of the individual technological domains. By doing so, the state of technological factors can be evaluated through organizational topics, which can help SMEs identify improvement areas within digitalization of maintenance activities. The following sections will granulate these domains and maturity stages based on the results.

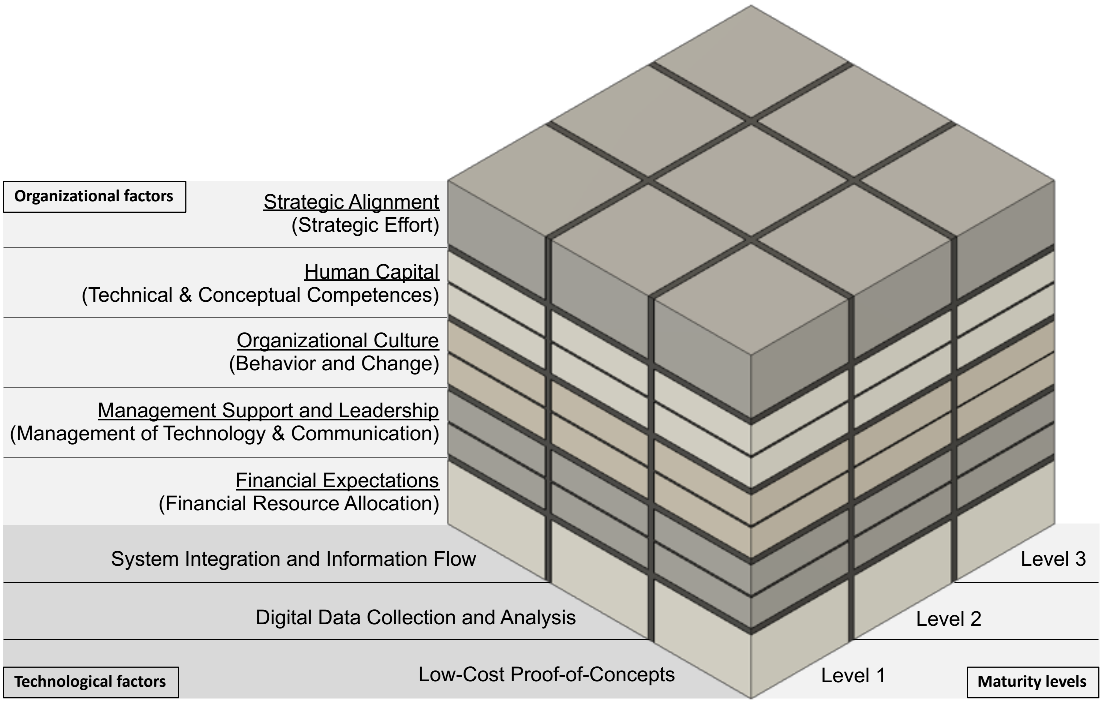

Figure 3.1: Visualization of how the literature and the empirical data contributes to the framework

Based on the empirical work and the literature, the following levels within a single sub-category, "Strategic Effort", can been developed (Table 3.2). In the SI&IF technology domain, Strategic Effort represent the degree of strategic attention towards improving system integrations and information flows. In the DDCA technology domain, Strategic Effort represent attention to strategically utilizing digital data collection and analysis to improve key value propositions and optimize business processes. Lastly, in the LC-PoC technology domain, Strategic Effort represent the attention to exploiting and utilizing existing resources and digital technologies to generate knowledge about digitalization in the organization.

Table 3.2: Overview of Strategic Alignment sub-domains and their granularities.

Strategic Alignment		Level 1 - Low	Level 2 - Medium	Level 3 - High
System Integration and Information Flow	Strategic Effort	There are no planned strategic initiatives for improving system integration and information flows	There are planned strategic initiatives for improving system integration and information flows but there are no on-going activities	There are planned strategic initiatives for improving system integration and information flows and there are on-going activities
Digital Data Collection and Analysis	Strategic Effort	There are no planned strategic initiatives for improving for digital data collection and analysis	There are planned strategic initiatives for improving digital data collection and analysis but there are no on-going activities	There are planned strategic initiatives for improving digital data collection and analysis and there are on-going activities
Low-Cost Proof-of-Concepts	Strategic Effort	There are no planned strategic initiatives for engaging in experimentation and prototyping using already existing digital technologies.	There are planned strategic initiatives for engaging in experimentation and prototyping using already existing digital technologies but there are no ongoing activities	There are planned strategic initiatives for engaging in experimentation and prototyping using already existing digital technologies and there are ongoing activities

The Human Capital domain has been divided into three sub-categories: "Conceptual Competences" and "Technical Competences" (Table 3.3). In the SI&IF technology domain, conceptual competences represent knowledge of the use of information systems and how they should function to operate most effectively for the organization. Technical competences represent the degree of development competences within information systems. In the DDCA technology domain, conceptual competences represent how data can be collected and used to benefit the organization. Technical competences represent development of digital data collection mechanisms, such as deployment of IoT devices, and data analytics skills. Lastly, in the LC-PoC technology domain, conceptual capabilities represent the creative innovation capabilities in the organization. Here, technical capabilities specifically represent capabilities within low-code platform development. This was found as operational prototypes across the cases could be developed using low-code platforms already integrated in the companies IT infrastructure.

Table 3.3: Overview of Human Capital sub-domains and their granularities.

Human Capital		Level 1 - Low	Level 2 - Medium	Level 3 - High
System Integration and Information Flow	Conceptual Competences	Little or no conceptual understanding of information systems use	Some conceptual knowledge within main information systems in use	Strong conceptual understanding of all information systems in use
	Technical Competences	Little or no technical competences within information system development	Some technical development competences within main information systems	Strong technical development competences within most information systems in use
Digital Data Collection and Analysis	Conceptual Competences	No conceptual understanding of how data can be digitally collected and utilized in the organization	Some conceptual understanding of how data can be digitally collected and utilized in the organization	Strong conceptual understanding of how data can be digitally collected and utilized in the organization
	Technical Competences	No technical competences in systematically developing digital data collection mechanisms nor analysing data	Some technical competences in systematically developing digital data collection mechanisms and analysing data	Strong technical competences in systematically developing digital data collection mechanisms and analysing data
Low-Cost Proof-of-Concepts	Conceptual Competences	No innovation competences across the organization	Sporadic innovation competences across the organization	Widespread innovation competences in the organization
	Technical Competences	No low-code competences in the organization	Limited low-code competences in the organization	Experienced low-code competences in the organization

Through the case studies two areas stood out, "Behavior" and "Change" (Table 3.4). Where Behavior represents the level adherence to guidelines and best-practices in the use of technologies and processes. Change represents the inclination to change behavior in the interaction with these. This distinction is important, as some employees may not adhere to a certain process, but as a result of lack of knowledge, rather than simply out of principle. In the SI&IF technology domain "Behavior" represents the intendedness of the use of information systems, where "Change" represents the willingness to change this use. This was especially noticeable in Case1, Case2, and Case3, which all had cases where information systems were used unintentionally. In the DDCA technology domain, Behavior represents the degree to which employees gather reliable data from processes, where Change represents the willingness to collect more and/or better data. In the LC-PoC technology domain, Behavior represents the degree to which employees engage in experimentation and prototyping using digital technologies, where Change represents the willingness to engage more.

Table 3.4: Overview of Organizational Culture sub-domains and their granularities.

Organizational Culture		Level 1 - Low	Level 2 - Medium	Level 3 - High
System Integration and Information Flow	Behaviour	Information systems are not used as intended	Information systems are mostly used as intended, but with some deviation	Information systems are used as intended
	Change	Employees are resistant to change within information flows and information systems	Employees tolerate change within information flows and information systems	Employees embrace change within in information flows and information systems
Digital Data Collection and Analysis	Behaviour	Necessary data are unreliably measured and/or reported with low accuracy	Necessary data are reliably measured and/or reported with high accuracy	Necessary data and additional data are reliably measure and/or reported with high accuracy
	Change	Employees are resistant to change within data collection and analysis	Employees tolerate data collection and analysis	Employees embrace data collection and analysis
Low-Cost Proof-of-Concepts	Behaviour	Employees do not request and encourage experimentation and prototyping using digital technologies	Employees occasionally request and encourage experimentation and prototyping using digital technologies	Employees continuously request and encourage experimentation and prototyping using digital technologies
	Change	Employees are resistant to experimentation and prototyping	Employees tolerate experimentation and prototyping	Employees embrace experimentation and prototyping

From the case studies it was clear that there was a difference between how managers would discuss digital technologies and how they would manage the implementation of these. Therefore, the Management Support and Leadership domain has been divided into two sub-categories: "Management of Technology" and "Communication" (Table 3.5). The Management of Technology category represents the managers knowledge of digital technologies and their abilities to educate themselves on how to manage their implementation, where Communication represent how management communicates digital initiatives to the rest of the organization. In the SI&IF technology domain, Management of Technology represents the ability to manage and educate themselves on the use of information system for their organization. In the DDCA technology domain, Management of Technology represents the knowledge of how data and data analytics can benefit the organization, where Communication represents the encouragement to utilize data and data analytics in the organization. In the LC-PoC technology domain, Management of Technology represents the understanding of how experimentation and prototyping using digital technologies can benefit the organization.

Table 3.5: Overview of Management Support and Leadership sub-domains and their granularities.

Management Support and Leadership		Level 1 - Low	Level 2 - Medium	Level 3 - High
System Integration and Information Flow	Management of Technology	Management is unaware of how information system development can benefit the organization	Management only have understanding of managing a specific array of information systems	Management continuously educate themselves in the use and implementation of information systems
	Communication	No encouragement of information system improvements	Sporadic encouragement of information system improvements within specific domains	Strong encouragement of information system improvements across all domains

Digital Data Collection and Analysis	Management of Technology	Management is unaware of how digital data collection and analysis technologies can benefit the organization	Management have limited understanding of how digital data collection and analysis technologies can benefit the organization	Management continuously educate themselves in how the use of digital data collection and analysis technologies can benefit the organization
	Communication	No encouragement of digital data collection and analysis technologies	Sporadic encouragement of digital data collection and analysis technologies within specific domains	Continuous encouragement of digital data collection and analysis technologies across all domains
Low-Cost Proof-of-Concepts	Management of Technology	Management is unaware of how experimentation and prototyping using digital technologies can benefit the organization	Management only have understanding of how experimentation and prototyping using digital technologies can benefit the organization	Management continuously educate themselves in how experimentation and prototyping using digital technologies can benefit the organization
	Communication	No encouragement experimentation and prototyping using digital technologies	Sporadic encouragement experimentation and prototyping using digital technologies	Continuous encouragement experimentation and prototyping using digital technologies

In short, Financial Expectations represents the availability of financial resources to digital initiatives provided by the organization (Table 3.6). In the SI&IF technology domain, this represents the financial resource allocation for improving system integration and information flow. In the DDCA technology domain, Financial Expectations represents the allocation of financial resources for improving digital data collection and analytics. In the LC-PoC technology domain, Financial Expectations represent the allocation of financial resources for experimentation and prototyping using digital technologies.

Table 3.6: Overview of Financial Expectations sub-domains and their granularities.

Financial Expectations		Level 1 - Low	Level 2 - Medium	Level 3 - High
System Integration and Information Flow	Financial resource allocation	Minimal financial resource allocation for improving system integration and information flow	Financial resource allocation for improving system integration and information flow on single business case level	Continuous financial resource allocation for improving system integration and information flow
Digital Data Collection and Analysis	Financial resource allocation	Minimal financial resource allocation for improving digital data collection and analysis	Financial resource allocation for improving digital data collection and analysis on single business case level	Continuous financial resource allocation for improving digital data collection and analysis
Low-Cost Proof-of-Concepts	Financial resource allocation	Minimal financial resource allocation for experimentation and prototyping using digital technologies	Financial resource allocation for experimentation and prototyping using digital technologies on single business case level	Continuous financial resource allocation for experimentation and prototyping using digital technologies

By comparing the scorings of the case companies according to the model, it is clear that Case4 is the least mature and that Case2 is the most mature, followed by Case3 and Case1 (**Error! Reference source not found.**). From these results, the sum of the scores of each category have been compared to average of the sum of scores, to identify low-performing domains. From here, five observations have been made.

Table 3.7: Overview of scorings

Tech. domain	Org. domain	Category	Case 1	2	3	4	Sum	if sum<8
SI&IF	Human Capital	Technical competences	1	1	1	1	4	1
DDCA	Organizational Culture	Behaviour	2	1	1	1	5	1
DDCA	Organizational Culture	Change	2	1	1	1	5	1
LC-PoC	Organizational Culture	Behaviour	1	3	1	1	6	1
LC-PoC	Strategic Allignment	Strategic Effort	1	3	1	1	6	1
DDCA	Human Capital	Technical competences	1	2	3	1	7	1
LC-PoC	Human Capital	Conceptual competences	1	3	2	1	7	1
LC-PoC	Human Capital	Technical competences	1	3	2	1	7	1
SI&IF	Financial Expections	Financial Resource Allocation	2	3	2	1	8	0
DDCA	Financial Expections	Financial resource allocation	2	2	3	1	8	0
LC-PoC	Financial Expections	Financial resource allocation	2	3	2	1	8	0
SI&IF	Management Support and Leadership	Communication	2	3	2	1	8	0
LC-PoC	Management Support and Leadership	Management of Technology	2	2	2	2	8	0
SI&IF	Organizational Culture	Behaviour	2	1	2	3	8	0
DDCA	Human Capital	Conceptual competences	3	3	2	1	9	0
SI&IF	Management Support and Leadership	Management of Technology	3	3	2	1	9	0
DDCA	Management Support and Leadership	Communication	2	3	3	1	9	0
SI&IF	Organizational Culture	Change	3	1	3	2	9	0
SI&IF	Strategic Allignment	Strategic Effort	1	3	3	2	9	0
DDCA	Financial Expections	Strategic Effort	2	3	3	2	10	0
SI&IF	Human Capital	Conceptual competences	3	3	3	1	10	0
DDCA	Management Support and Leadership	Management of Technology	3	3	3	2	11	0
LC-PoC	Management Support and Leadership	Communication	3	3	3	3	12	0
LC-PoC	Organizational Culture	Change	3	3	3	3	12	0
Total			**48**	**59**	**53**	**35**	**Sum avg = 8**	

First, the lowest overall score relates to technical competences within SI&IF. This low score is related to the fact that the companies simply don't prioritize these skills, as they are more focused on the business operations. This raises the question of how relevant these technical skills are for SMEs to internalize compared to outsourcing them.

Second, in the sub-domain "Organizational Culture" within DDCA, both categories are represented with low scores. Here, Case2, Case3, and Case4 all scored the lowest on both Behavior and Change. In these cases, technicians and operators would provide little or inaccurate data to the information systems, as in most cases they did not feel like providing this properly. Generally, this was explained as a result of not wanting to prioritize this over what they felt were their actual jobs, which also provided a low score in "Change". As these data inputs are important to the overall data quality, it would be interesting to understand what should be improved to increase the quality and volume of human input data.

Next, a low score is found in Strategic Effort within LC-PoC. This score can be explained by most companies not providing strategic efforts to this area. This is only done by Case2, which also contributes to their high overall score. This is also reflected in Behavior within LC-PoC, where Case2 is the only company with recurring requests for prototypes and experiments, which could very well link back to this being a strategic initiative. This makes it interesting to investigate how strategic effort to this could improve digital maturity of maintenance processes in SMEs over time.

In relation to this, Human Capital within LC-PoC also scored below average on both categories. Again, these are highest in Case2, where these competences are external. By their strategic initiatives, Case2 have invested in both conceptual and technical competences which contributes to their high score. The same can be observed in Case3, who are less financially committed to their human capital on the area, where these skills are less developed. In the future, it would be interesting to investigate how the presence of these skills can help companies increase digital maturity of maintenance processes in SMEs.

Lastly, the technical competence category within DDCA has score below average. Where the medium and high score to Case2 and Case3 origins from having technicians that can develop data collection mechanisms, none of the case companies expressed that they have data analytics competences. This makes it interesting to investigate how data analytics competences can drive digital maturity within maintenance processes in SMEs.

3.6. Discussion and future work

This paper delves into asset management, identified as a critical business process for manufacturing SMEs. Through the examined case studies, the importance of asset management, particularly in the after-sales service sector, has been underscored, as reflected by the allocation of resources between the two areas. Across the case studies, it was evident how more resources were allocated to information system development and data collection in the after-sales service cases. From a practical perspective, after-sales service is built on a revenue-generating business model, thus the focus. In the internal maintenance cases, far less resources were invested in information systems and data collection. This raises the question: Can digital maturity be measured uniformly across maintenance activities? While this paper has developed a framework from all four cases collectively, thereby providing a general model for digitalization of maintenance activities, future research should adapt the framework to address individual maintenance activities more specifically.

From a methodological perspective, this paper contributes with findings from pragmatic research methods to the collective body of literature on digitalization in SMEs. While a copious amount of high-quality research has already well-established digital maturity and digitalization in SMEs, much of this literature is built on self-reporting survey data or single case studies. Where this literature unquestionably captures the essence effectively, this framework is built on deep insights from the daily operations of SMEs, which complements with another layer of pragmatism and real-world insights. Contrastingly, this study is challenged on generalizability. The four case studies represent a very small sample size, but as many of the results can be recognized in the literature, this paper considers these findings as effective representatives of similar companies. This also invites future research to contribute with more similar case studies.

Lastly, from a technology perspective, this paper has been built on the premise that low-tech and low-cost digital solutions are effective for the general digitalization of SMEs. While the specific outcomes of the developed artefacts are not the theme of this paper, this paper practically finds the premise to sustain. Despite the artefacts were developed on prototyping basis using existing data and platforms, they were still radically changing initiatives to existing processes and solutions. However, it should be questioned how digitally sustainable this is for SMEs. Eventually, more advanced technologies will be required to transition fully to the Industry 4.0 paradigm. This poses a future research direction which should investigate how SMEs can transition from developing low-cost digitalization projects, to implementing more sophisticated technology solutions.

3.7. Conclusion

This paper presented a framework that integrates technological and organizational factors as interconnected components of digitalization in SMEs. By addressing the theoretical challenges in the existing literature, this framework offers an alternative perspective that facilitates a more accurate assessment of digital maturity within SMEs. The framework emphasizes three main technological factors: System Integration and Information Flow, (Digital) Data Collection and Analysis, and Low-Cost Proof-of-Concepts. Additionally, it recognizes the significance of organizational factors by evaluating them in conjunction with these technological aspects, thereby establishing the interrelationship between these two domains. By adopting this integrated approach, the framework mitigates the issue of asymmetric evaluations, as highlighted by previous studies. It encourages SMEs to assess their organizational capabilities within the context of specific technological areas, challenging a holistic viewpoint and promoting a more realistic evaluation of their digital readiness. Drawing upon multiple case studies, this framework transcends the limitations of single-case digital maturity models. The discussion has illuminated several critical areas for future research.

The notably low score in technical competences within SI&IF, juxtaposed with SMEs' operational focus, raises questions about the actual relevance of these technical skills for SMEs. The observed deficiencies in "Organizational Culture" within DDCA, particularly in the realms of Behavior and Change, necessitate a deeper dive into strategies that can elevate the quality and volume of human data input. The diminished emphasis on Strategic Effort within LC-PoC across most companies, suggests a potential research trajectory into the impact of strategic initiatives and human capital focusing on prototyping on the digital maturity of maintenance processes in SMEs. The below-average performance in the technical competence category within DDCA, especially in the context of data analytics competences, offers another promising avenue for research. This could determine how these competences can be leveraged to drive digital maturity in maintenance processes in SMEs. The identified overlap between individual technology domains, suggests an opportunity to refine and expand the current framework. This would ensure a more holistic understanding of the interplay between technological and organizational factors, potentially leading to a more actionable model for SMEs.

Generally, future research should continue to bridge the gap between academia and industry remains crucial, as continued knowledge transfer can foster mutually beneficial collaborations and facilitate the advancement of digitalization in SMEs.

3.8. References

Agostini, L., & Nosella, A. (2019). The adoption of Industry 4.0 technologies in SMEs: results of an international study. *Management Decision*, *58*(4), 625–643. https://doi.org/10.1108/MD-09-2018-0973

Alex, T., Danny, Z., Cristian, T., María, V., & Carlos, P. (2021). *Machine Monitoring Based on Cyberphysical Systems for Industry 4.0* (pp. 117–127). https://doi.org/10.1007/978-3-030-60467-7_10

Amaral, A., & Peças, P. (2021). SMEs and Industry 4.0: Two case studies of digitalization for a smoother integration. *Computers in Industry*, *125*, 103333. https://doi.org/10.1016/j.compind.2020.103333

Annosi, M. C., Brunetta, F., Monti, A., & Nat, F. (2019). Is the trend your friend? An analysis of technology 4.0 investment decisions in agricultural SMEs. *Computers in Industry*, *109*, 59–71. https://doi.org/10.1016/j.compind.2019.04.003

Azhar, S., Ahmad, I., & Sein, M. K. (2010). Action Research as a Proactive Research Method for Construction Engineering and Management. *Journal of Construction Engineering and Management*, *136*(1), 87–98. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000081

Bär, K., Herbert-Hansen, Z. N. L., & Khalid, W. (2018). Considering Industry 4.0 aspects in the supply chain for an SME. *Production Engineering*, *12*(6), 747–758. https://doi.org/10.1007/s11740-018-0851-y

Bendig, D., Schulz, C., Theis, L., & Raff, S. (2023). Digital orientation and environmental performance in times of technological change. *Technological Forecasting and Social Change*, *188*. https://doi.org/10.1016/j.techfore.2022.122272

Bona, G. Di, Cesarotti, V., Arcese, G., & Gallo, T. (2021). Implementation of Industry 4.0 technology: New opportunities and challenges for maintenance strategy. *Procedia Computer Science*, *180*(2019), 424–429. https://doi.org/10.1016/j.procs.2021.01.258

Cimini, C., Boffelli, A., Lagorio, A., Kalchschmidt, M., & Pinto, R. (2021). How do industry 4.0 technologies influence organisational change? An empirical analysis of Italian SMEs. *Journal of Manufacturing Technology Management*, *32*(3), 695–721. https://doi.org/10.1108/JMTM-04-2019-0135

Commision, E. (2015). User guide to the SME Definition. In *Publications Office of the European Union*. http://ec.europa.eu/growth/index_en.htm%5Cnhttp://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:BOOKLET+OF+STANDARDIZED+SMALL+AND+MEDIUM+ENTERPRISES+BOOKLET+OF+DEFINITION-2007#0

de la Fuente, A., González-Prida, V., Crespo, A., Gómez, J. F., & Guillén, A. (2018). *Advanced Techniques for Assets Maintenance Management*. *51*(11), 205–210. https://doi.org/10.1016/j.ifacol.2018.08.260

Dutta, G., Kumar, R., Sindhwani, R., & Singh, R. K. (2020). Digital transformation priorities of India's discrete manufacturing SMEs – a conceptual study in perspective of Industry 4.0. *Competitiveness Review: An International Business Journal*, *30*(3), 289–314. https://doi.org/10.1108/CR-03-2019-0031

Eleftheriadis, R. J., & Myklebust, O. (2018). Industry 4.0 and Cyber Physical Systems in a Norwegian Industrial Context. *Lecture Notes in Electrical Engineering*, *451*, 491–499. https://doi.org/10.1007/978-981-10-5768-7_52

Gamache, S., Abdul-Nour, G., & Baril, C. (2020). Evaluation of the influence parameters of Industry 4.0 and their impact on the Quebec manufacturing SMEs: The first findings. *Cogent Engineering*, *7*(1), 0–31. https://doi.org/10.1080/23311916.2020.1771818

Ghobakhloo, M., & Ching, N. T. (2019). Adoption of digital technologies of smart manufacturing in SMEs. *Journal of Industrial Information Integration*, *16*(October), 100107. https://doi.org/10.1016/j.jii.2019.100107

Gonzalez-Tamayo, L. A., Maheshwari, G., Bonomo-Odizzio, A., Herrera-Avilés, M., & Krauss-Delorme, C. (2023). Factors influencing small and medium size enterprises development and digital maturity in Latin America. *Journal of Open Innovation: Technology, Market, and Complexity*, *9*(2). https://doi.org/10.1016/j.joitmc.2023.100069

Grooss, O. F., Presser, M., & Tambo, T. (2022). Balancing Digital Maturity and Operational Performance - Progressing in a Low-digital SME Manufacturing Setting. *Procedia Computer Science*, *200*, 495–504. https://doi.org/10.1016/j.procs.2022.01.247

Hamzeh, R., Zhong, R., & Xu, X. W. (2018). A Survey Study on Industry 4.0 for New Zealand Manufacturing. *Procedia Manufacturing*, *26*, 49–57. https://doi.org/10.1016/j.promfg.2018.07.007

Hansen, E. B., & Bøgh, S. (2021). Artificial intelligence and internet of things in small and medium-sized enterprises: A survey. *Journal of Manufacturing Systems*, *58*, 362–372. https://doi.org/10.1016/j.jmsy.2020.08.009

Horváth, D., & Szabó, R. Z. (2019). Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities? *Technological Forecasting and Social Change*, *146*(October 2018), 119–132. https://doi.org/10.1016/j.techfore.2019.05.021

Jayashree, S., Reza, M. N. H., Malarvizhi, C. A. N., & Mohiuddin, M. (2021). Industry 4.0 implementation and Triple Bottom Line sustainability: An empirical study on small and medium manufacturing firms. *Heliyon*, *7*(8), e07753. https://doi.org/10.1016/j.heliyon.2021.e07753

Jiwangkura, S., Sophatsathit, P., & Chandrachai, A. (2020). Industrial internet of things implementation strategies with HCI for SME Adoption. *International Journal of Automation and Smart Technology*, *10*(1), 153–168. https://doi.org/10.5875/ausmt.v10i1.2108

Khan, M., Ahmad, A., Sobieczky, F., Pichler, M., Moser, B. A., & Bukovsky, I. (2022). A Systematic Mapping Study of Predictive Maintenance in SMEs. *IEEE Access*, *10*, 88738–88749. https://doi.org/10.1109/ACCESS.2022.3200694

Leal-Rodríguez, A. L., Sanchís-Pedregosa, C., Moreno-Moreno, A. M., & Leal-Millán, A. G. (2023). Digitalization beyond technology: Proposing an explanatory and predictive model for digital culture in organizations. *Journal of Innovation and Knowledge*, *8*(3). https://doi.org/10.1016/j.jik.2023.100409

Maletič, D., Pačaiová, H., Nagyová, A., & Maletič, M. (2020). The link between asset risk management and maintenance performance: a study of industrial manufacturing companies. *Quality Innovation Prosperity*, *24*(3), 50–69. https://doi.org/10.12776/QIP.V24I3.1477

Mantravadi, S., Srai, J. S., & Møller, C. (2023). Application of MES/MOM for Industry 4.0 supply chains: A cross-case analysis. *Computers in Industry*, *148*. https://doi.org/10.1016/j.compind.2023.103907

Maroufkhani, P., Tseng, M. L., Iranmanesh, M., Ismail, W. K. W., & Khalid, H. (2020). Big data analytics adoption: Determinants and performances among small to medium-sized enterprises. *International Journal of Information Management*, *54*(February), 102190. https://doi.org/10.1016/j.ijinfomgt.2020.102190

Masood, T., & Sonntag, P. (2020). Industry 4.0: Adoption challenges and benefits for SMEs. *Computers in Industry*, *121*, 103261. https://doi.org/10.1016/j.compind.2020.103261

Matt, D. T., & Rauch, E. (2020). SME 4.0: The Role of Small- and Medium-Sized Enterprises in the Digital Transformation. In *Industry 4.0 for SMEs* (pp. 3–36). Springer International Publishing. https://doi.org/10.1007/978-3-030-25425-4_1

Minonne, C., Wyss, R., Schwer, K., Wirz, D., & Hitz, C. (2018). Digital maturity variables and their impact on the enterprise architecture layers. *Problems and Perspectives in Management*, *16*(4), 141–154. https://doi.org/10.21511/ppm.16(4).2018.13

Moeuf, A., Lamouri, S., Pellerin, R., Tamayo-Giraldo, S., Tobon-Valencia, E., & Eburdy, R. (2020). Identification of critical success factors, risks and opportunities of Industry 4.0 in SMEs. *International Journal of Production Research*, *58*(5), 1384–1400. https://doi.org/10.1080/00207543.2019.1636323

Narwane, V. S., Raut, R. D., Mangla, S. K., Gardas, B. B., Narkhede, B. E., Awasthi, A., & Priyadarshinee, P. (2020). Mediating role of cloud of things in improving performance of small and medium enterprises in the Indian context. *Annals of Operations Research*, *0123456789*. https://doi.org/10.1007/s10479-019-03502-w

Naushad, M., & Sulphey, M. M. (2020). Prioritizing technology adoption dynamics among SMEs. *TEM Journal*, *9*(3), 983–991. https://doi.org/10.18421/TEM93-21

Nwaiwu, F., Duduci, M., Chromjakova, F., & Otekhile, C. A. F. (2020). Industry 4.0 concepts within the czech sme manufacturing sector: An empirical assessment of critical success factors. *Business: Theory and Practice*, *21*(1), 58–70. https://doi.org/10.3846/btp.2020.10712

Ordieres-Meré, J., Gutierrez, M., & Villalba-Díez, J. (2023). Toward the industry 5.0 paradigm: Increasing value creation through the robust integration of humans and machines. *Computers in Industry*, *150*, 103947. https://doi.org/10.1016/j.compind.2023.103947

Pagalday, G., Zubizarreta, P., Uribetxebarria, J., Erguido, A., & Castellano, E. (2018). Efficient development and management of after sale services. *Procedia Manufacturing*, *19*, 18–25. https://doi.org/10.1016/j.promfg.2018.01.004

Psarommatis, F., May, G., & Azamfirei, V. (2023). Envisioning maintenance 5.0: Insights from a systematic literature review of Industry 4.0 and a proposed framework. In *Journal of Manufacturing Systems* (Vol. 68, pp. 376–399). Elsevier B.V. https://doi.org/10.1016/j.jmsy.2023.04.009

Rastogi, V., Srivastava, S., Mishra, M., & Thukral, R. (2020). Predictive Maintenance for SME in Industry 4.0. *2020 Global Smart Industry Conference (GloSIC)*, 382–390. https://doi.org/10.1109/GloSIC50886.2020.9267844

Ricci, R., Battaglia, D., & Neirotti, P. (2021). External knowledge search, opportunity recognition and industry 4.0 adoption in SMEs. *International Journal of Production Economics*, *240*(September 2020), 108234. https://doi.org/10.1016/j.ijpe.2021.108234

Roblek, V., Meško, M., Pušavec, F., & Likar, B. (2021). The Role and Meaning of the Digital Transformation As a Disruptive Innovation on Small and Medium Manufacturing Enterprises. *Frontiers in Psychology*, *12*(June), 1–18. https://doi.org/10.3389/fpsyg.2021.592528

Sang, G. M., Xu, L., De Vrieze, P., Bai, Y., & Pan, F. (2020, June 4). Predictive Maintenance in Industry 4.0. *ACM International Conference Proceeding Series*. https://doi.org/10.1145/3447568.3448537

Siemen, C., Clever, N., Barann, B., & Becker, J. (2018). Requirements elicitation for an inter-organizational business intelligence system for small and medium retail enterprises. *Proceeding - 2018 20th IEEE International Conference on Business Informatics, CBI 2018*, *1*, 129–138. https://doi.org/10.1109/CBI.2018.00023

Sivathanu, B. (2019). Adoption of Industrial IoT (IIoT) in Auto-Component Manufacturing SMEs in India. *Information Resources Management Journal*, *32*(2), 52–75. https://doi.org/10.4018/IRMJ.2019040103

Soluk, J., & Kammerlander, N. (2021). Digital transformation in family-owned Mittelstand firms: A dynamic capabilities perspective. *European Journal of Information Systems*, *November*. https://doi.org/10.1080/0960085X.2020.1857666

Sommer, L. (2015). Industrial revolution - industry 4.0: Are German manufacturing SMEs the first victims of this revolution? *Journal of Industrial Engineering and Management*, *8*(5), 1512–1532. https://doi.org/10.3926/jiem.1470

Su, J., Zhang, Y., & Wu, X. (2023). How market pressures and organizational readiness drive digital marketing adoption strategies' evolution in small and medium enterprises. *Technological Forecasting and Social Change*, *193*. https://doi.org/10.1016/j.techfore.2023.122655

Subramanian, G., Patil, B. T., & Gardas, B. B. (2021). Evaluation of enablers of cloud technology to boost industry 4.0 adoption in the manufacturing micro, small and medium enterprises. *Journal of Modelling in Management*, *16*(3), 944–962. https://doi.org/10.1108/JM2-08-2020-0207

Sundberg, L., Gidlund, K. L., & Olsson, L. (2019). Towards Industry 4.0? Digital Maturity of the Manufacturing Industry in a Swedish Region. *2019 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 731–735. https://doi.org/10.1109/IEEM44572.2019.8978681

Tortora, A. M. R., Maria, A., Valentina, D. P., Iannone, R., & Pianese, C. (2021). A survey study on Industry 4.0 readiness level of Italian small and medium enterprises. *Procedia Computer Science*, *180*, 744–753. https://doi.org/10.1016/j.procs.2021.01.321

Tortorella, G. L., Saurin, T. A., Fogliatto, F. S., Tlapa Mendoza, D., Moyano-Fuentes, J., Gaiardelli, P., Seyedghorban, Z., Vassolo, R., Cawley Vergara, A. F. M., Sunder M, V., Sreedharan, V. R., Sena, S. A., Forstner, F. F., & Macias de Anda, E. (2022). Digitalization of maintenance: exploratory study on the adoption of Industry 4.0 technologies and total productive maintenance practices. *Production Planning and Control*. https://doi.org/10.1080/09537287.2022.2083996

Welte, R., Estler, M., & Lucke, D. (2020). A method for implementation of machine learning solutions for predictive maintenance in small and medium sized enterprises. *Procedia CIRP*, *93*, 909–914. https://doi.org/10.1016/j.procir.2020.04.052

Williams, C., & Lang, K. (2019). Digital Maturity Models for Small and Medium-sized Enterprises : A Systematic Literature Review Daniel Schallmo Luke Boardman. *ISPIM Innovation Conference –*, *June*.

Xing, K., Liu, X., Liu, Z., Mayer, J. R. R., & Achiche, S. (2020). Low-Cost Precision Monitoring System of Machine Tools for SMEs. *Procedia CIRP*, *96*, 347–352. https://doi.org/10.1016/j.procir.2021.01.098

Yilmaz, G., Salter, L., McFarlane, D., & Schönfuß, B. (2023). Low-cost (Shoestring) digital solution areas for enabling digitalisation in construction SMEs. *Computers in Industry*, *150*. https://doi.org/10.1016/j.compind.2023.103941

Chapter 4. Digitalization of after-sales service processes

The following journal article answers RQ3.

The paper was submitted to Computers in Industry (Elsevier).

The content of this chapter is directly copied from this paper.

Abstract

This study addresses the underexplored domain of digitalizing after-sales service processes in small and medium-sized enterprises (SMEs). Focusing on Danish SMEs, it investigates three key areas: the necessity of technical development competences within information systems, effective data management from a human-centric perspective, and the application of low-code tools in digitalizing business processes. The research employs semi-structured interviews and thematic analysis with six different Danish SMEs. The research finds that instead of focusing on technical development skills, SMEs benefit more from cultivating conceptual skills. This finding challenges the conventional emphasis on in-house technical expertise. Additionally, it is discovered that SMEs enhance their data maturity by demonstrating the practical implications of poor data quality, thus fostering a better understanding of data's role in business processes. Surprisingly, the adoption of low-code tools is less common than anticipated. Based on these insights, this paper synthesizes an analysis that uncover how SMEs position themselves in terms of data maturity, skill location, and solution phase.

Keywords: SME, Digitalization, After-sales service, Maintenance, Industry 4.0

4.1. Introduction

The advent of digitalization, digital transformation, and Industry 4.0 has been a cornerstone in the evolution of small and medium-sized enterprises (SMEs) over the past decade (Ghobakhloo et al., 2021; Kagermann & Wahlster, 2022; Masood & Sonntag, 2020). These technological paradigms have opened doors to innovative business models, enabling SMEs to adapt to changing customer demands and improve operational efficiencies. This transformation is well-documented in the literature, which has explored the influence of digital technologies and cultures across various business domains (Ghobakhloo et al., 2021; Masood & Sonntag, 2020; Moeuf et al., 2018). Despite the extent of Industry 4.0 and digitalization research, there are limited research that focus specifically on digitalization of asset management and maintenance processes in SMEs, and more specifically on after-sales service.

In relation to Industry 4.0 and digital transformation, after-sales service may bring forward associations to the term "servitization", which describes the integration of services as value propositions for manufacturing companies (Peillon & Dubruc, 2019; Pirola et al., 2020; Weking et al., 2020). Servitization has been widely discussed as part of digitalization and Industry 4.0 research, as the advancement of digital technologies, such as Internet of Things (IoT), cloud computing (CC) and artificial intelligence (AI), unlocking new service-based offerings through digital data collection and analysis (Kim et al., 2023; Peillon & Dubruc, 2019; Pirola et al., 2020).

Despite gaining significant attention in the context of Industry 4.0 and digital transformation, servitization is not a new concept in the manufacturing SME sector (Pirola et al., 2020). For many manufacturing SMEs after-sales and has been a core component of their business strategy for a long time (de la Fuente et al., 2018; Pagalday et al., 2018). These services enhance customer satisfaction, foster customer loyalty, and generate ongoing revenue streams (Pagalday et al., 2018; Weking et al., 2020). This is typically achieved through service contracts offering diverse levels of support, incentivized by discounts based on loyalty and service type. The attention to servitization in other industries and the increasing accessibility of digital technologies only underscores the importance of efficient and effective after-sales service business processes in SMEs, as these becomes progressively important to deliver on customer expectations, competitive parameters, and operational performance (Somohano-Rodríguez et al., 2022).

However, the integration of digital technologies into after-sales processes is a complex endeavor, often requiring significant investment and strategic planning (Somohano-Rodríguez et al., 2022). This is particularly challenging for SMEs, which are confronted with the difficulties of balancing the costs of digitalization with the expected return on investment, especially in the short term (Masood & Sonntag, 2020). Studies such as Dolatabadi and Budinska (2021) and Pinciroli et al. (2023) have highlighted this financial predicament, underscoring the need for SMEs to navigate their digitalization journey carefully. Grooss (2024) presents a conceptual framework that integrates technological and organizational factors for digitalizing maintenance processes in SMEs. This framework focuses on leveraging existing technologies and data for low-cost optimizations, bridging the gap between high-tech discussions and real-world SME scenarios. In this paper, Grooss (2024) identifies a series of underperforming aspects of digitalization of maintenance activities in SMEs.

First, the paper finds that technical development competences within system integration and information flow scores extremely low. As these does not seem to be prioritized, the paper questions the relevance of these competences. Browsing the existing literature enforces this question. Generally, the current literature is highlighting the need for digital capabilities to succeed with Industry 4.0 and digital transformation initiatives (Castelo-Branco et al., 2022; Naushad & Sulphey, 2020; Tortora et al., 2021). However, this literature is not explicitly discussing whether conceptual skills or technical skills are most relevant for SMEs. The second aspect relates to the human aspects of digital data collection and analysis. Grooss (2024) finds that the quality and volume of data inputs often suffers due to mis-prioritization by technicians and operators. Building on this, (Kim et al., 2023) conducts an extensive literature review using text mining to future research agendas on digital servitization. The authors specifically suggest future studies that investigates the use of digital technologies for managing data-related activities. This makes it interesting to understand how this can be improved to increase the volume and quality of data inputted from a human perspective. Lastly, (Grooss, 2024) reveals that both strategic initiatives and human competencies within low-cost proof-of-concepts are low prioritized by SMEs. The authors suggests that future research investigates how the cultivation of skills related to low-code tools can contribute to the advancement of digital maturity in SMEs' maintenance processes. A similar research gap is highlighted by (Amaral & Peças, 2021; Hawkridge et al., 2021; Jiwangkura et al., 2020) who all suggests SMEs to engage in low-costs development of prototype to increase digitalization.

The existing literature and prior research, such as the work of Grooss (2024) and (Kim et al., 2023), highlights significant gaps in the current understanding of the digitalization of maintenance and after-sales service processes in SMEs. This gap is particularly evident in the areas of technical competencies, human aspects of data collection and analysis, and the strategic use of low-code tools in digitalizing after-sales services. As Grooss (2024) studied both internal maintenance cases and after-sales service cases but found that companies with after-sales service business models were more digitally mature, this research will focus its efforts on after-sales service. Consequently, this research aims to delve deeper into the identified areas, formulating the following research questions:

RQ1: What are the needs for technical development competences within information systems for supporting after-sale service processes in SMEs?

RQ2: How do SMEs manage data collection and analysis in after-sales service processes from a human perspective?

RQ3: How do SMEs utilize low-code tools for digitalization of after-sales service processes?

The remainder of this paper is structured as follows: Section 4.2 presents related work. Section 4.3 describes the methodology. Section 4.4 presents the results, which are analyzed in Section 4.5. Section 4.6 discusses the results. Section 4.7 concludes the paper.

4.2. Related work

4.2.1. Technical human capital for information systems

The established literature contains numerous studies underlining the importance of human capital within digitalization. This is highlighted by Naushad & Sulphey (2020), who identify technological self-efficacy as one of the most influential factors for adopting information system technologies. This represents the ability of companies to educate themselves about digital technologies to implement them in meaningful contexts. Genest and Gamache (2020) also highlight that companies must provide adequate training to facilitate employee education and keep them up-to-date on relevant digital technologies. Here, Moeuf et al. (2020) highlight the importance of training that supports the specific requirements of the company in the context of their operations and future for digitalization.

These examples view the topic from a rather holistic perspective and are not specific about what competences are needed. Other papers are more specific. For example, Welte et al. (2020) point to the development of internal skills and the use of external consultants as one of the most important approaches for machine learning projects. Schlegel and Kraus (2023) reviewed 119 job advertisements for positions within robotic process automation (i.e., a software technology that automates manual business processes), which is quite important for digital transformation. They found that competence within computer sciences, informatics, and business informatics are the highest in-demand skills working with this technology. Cetindamar Kozanoglu and Abedin (2021) investigate the "digital literacy" of employees for digital transformation, which describes employees' skills, knowledge, and abilities in working with digital technologies. By conducting a systematic literature review and brainstorming with experts, the authors highlight, among other factors, information, and data literacy as important aspects. They emphasize that digitally literate employees' knowledge of digital technologies can extend to applying them in relevant business contexts (Cetindamar Kozanoglu & Abedin, 2021).

4.2.2. Competences, behavior, and change within digital data collection and analysis

Continuous collection and analysis of digital data have proven to be a necessity for success in digitalization, as this is the foundation for digital technologies (Dutta et al., 2020; Pinciroli et al., 2023; Somohano-Rodríguez et al., 2022; Zonta et al., 2020). Data collection and analysis is key to predictive maintenance methods, where sensor data is used to predict life cycles (Battistoni et al., 2023; Khan et al., 2022). Technologies such as the IoT have greatly enabled data collection, and IoT devices are becoming more common in maintenance processes, where the collection and broadcasting of digital data can aid in monitoring asset health and forecasting life-expectancy (Rastogi et al., 2020; Velmurugan et al., 2022). This data can be processed by other digital technologies, such as cloud computing and artificial intelligence (AI) to uncover patterns and predict the future health status of assets (Bona et al., 2021; Pinciroli et al., 2023; Rastogi et al., 2020). With the increasing accessibility of data collection technology solutions (Rastogi et al., 2020), a continuing aspect relates to organizational and human management of data, which can be considered more vital to manage than digital technologies (Teichert, 2019).

The increase of digitalization has resulted in changes to the role of the maintenance operator, which now also consists of supervising automated systems through monitoring systems (Bona et al., 2021). Generally, employees now must process more digital information, which can lead to information overload (Okkonen et al., 2019). This is related to current interfaces and IT infrastructures not being geared to processing the shear amount of data needed for industry 4.0 technologies (Bona et al., 2021; Okkonen et al., 2019), but also to a lack of data analytics competences and poor habits (Okkonen et al., 2019). Breaking poor habits and changing ways of working can be challenging, as these are often deeply embedded in cultural contexts (Chanias et al., 2019; Leso et al., 2023). In the literature, this is commonly highlighted as one of the most important aspects of organizational factors (Teichert, 2019), where the inclusion of employees, facilitation of innovation, and incentives for success are vital for the success of digitalization (Kilimis et al., 2019; Roblek et al., 2021; Soluk & Kammerlander, 2021).

To summarize, it is clear that the technological aspect is only one side of the coin. However, the integration of these advanced systems within organizational contexts creates a unique set of challenges, mainly concentrated around the human element. Despite advances in technology, the efficacy of digital tools in after-sales service processes is heavily contingent on the competencies, behaviors, and adaptability of the employees who operate them. The ability of SMEs to manage and harness the potential of digital data collection effectively hinges not just on the implementation of cutting-edge technologies but also on the cultivation of a workforce that is skilled, adaptable, and receptive to change.

4.2.3. Behavior, strategic efforts, and competences within low-cost proof-of-concepts

Low-cost prototyping in combination with exploring existing data and information system resources have previously proven effective for digitalization of business processes in SMEs. For example, Amaral and Peças (2021) present two case studies in which they do exactly this to digitalize a paper-based Kanban system, using a simple web-platform. Xing et al. (2020) present a similar example in which low-cost hardware and open-source computation platforms are used to monitor machine tools in an SME.

While more and more technologies are becoming available for companies to use (Pinciroli et al., 2023), it is relevant to investigate how SMEs use them (Bies et al., 2022). Low-code application development a relevant topic within this area. Low-code platforms are often found as cloud-based platforms where users can develop custom applications with minimal code (Di Ruscio et al., 2022). These platforms can be powerful enablers for Citizen Developers, which allows business users to develop their own digital solutions in full or in part. This can empower employees to give more to the digital transformation, as it provides an entry point without a high technical barrier (Elshan et al., 2023). According to Sanchis et al. (2020), experts predict that low-code technologies may be essential for efficient work and remaining competitive.

Bies et al. (2022) conducted a survey of SMEs along with expert interviews to investigate if low-code application development could function as a driver for digital innovation in SMEs. They found that low-code application development has profit potential for SMEs, as long as the applications are developed for clearly defined contexts, improve the collaborative working culture in SMEs, and ensure coherence between functionality, quality, and security in business applications. They end their paper by calling for more research on the application of low-code technologies in SMEs. Elshan et al. (2023) found that low-code platforms can unlock tools for digitizing data, streamlining digital systems, and automating processes, while also providing results faster than through traditional development.

4.3. Methodology

This paper presents the findings for a multiple case study with six Danish SMEs. To collect data for the study, semi-structured interviews were completed with SMEs that manufacture and/or sell products that they also service as part of an after-sales service business model. The companies meet the requirements of an SME as per the definition of the European Commission, which means that the companies should have under 250 employees or less than 50 million EUR yearly profit or less than 43 million EUR on their balance sheet. Furthermore, the companies must have an after-sales service business model, in which the company is paid to service physical assets at customer locations.

This study sought to identify how the research questions raised in the previous section have been managed by SMEs that have successfully implemented a digital technology solution in the business processes for their after-sales service. To set a common ground for discussion, all companies were interviewed about the implementation of Field Service Management systems in their business. This was chosen as these systems facilitate most of the companies' after-sale service business processes.

The companies were selected based on having recently implemented such a technological solution. Potential participants were primarily identified through the websites of IT vendors or service partners, where customer cases and/or references were published. The companies were then contacted by phone and asked to participate in the interview. The interviewees from the companies were all service managers and/or technical managers. These were chosen as they have the primary oversight of the after-sales service business and are responsible for the effective and efficient operations thereof. This ensured that the interviews would focus on the business application of such systems and not the technical aspects. Prior to the interviews, participants were informed of the purpose of the interview and the overall topics of discussion. Information about the interviewed companies can be found in Table 4.1.

At each interview, the participants were asked open-ended questions related to the research topics, which invited the participants to guide the discussion in whatever direction they felt was important. Depending on the depth of the answers, further questions were asked about the same topic or a new topic was brought up if the participant did not provide new or deeper answers. After the interview, participants were asked if they could refer colleagues in the industry, who have gone through a similar process, thus opening up the opportunity for snowball sampling. The interviews were meticulously analyzed and thematically coded to align with the guiding research questions. This process involved an iterative approach where initial codes were generated from the data, capturing key concepts and categories as they emerged from the interviewees' responds. These codes were then organized into potential themes that resonated with the research objectives.

To ensure the themes developed were both reflective of the data and relevant to the research questions, a recursive process of reviewing and refining the themes was undertaken. Patterns within the data were identified and themes were constructed to encapsulate these patterns, providing a structured narrative that could address the research questions. Each theme was defined and named to accurately represent its essence within the context of the research.

Table 4.1: Information about the case companies

Case	Business	No. of employees	Title of main stakeholder interviewee
Case A	Water facilities	56	Service Manager
Case B	Heat pumps	62	Service and Technical Manager
Case C	Coffee machine maintenance	67	Technical Service Manager
Case D	Food packaging	55	Planning Manager
Case E	Climate systems	200	Service and Support Manager
Case F	Coffee machine maintenance	198	Service Manager

4.4. Results

The following sections presents the results from the interviews, which have been structured according to the three research questions presented in the Background and Research Question section.

4.4.1. Technical human capital for information systems

Across the interviewed companies, there was a notable division in opinion regarding the necessity for technical information system skills. Cases A and B did not perceive a need for full-time employees (FTEs) dedicated to technical IT competencies, citing insufficient workload to justify such positions. They expressed a preference for individuals who understand business processes and system interactions over those with purely technical development skills. Case A, in particular, underscored their preference for younger employees, like student workers, assuming their inherent understanding of technology.

Case A reported a past challenge where an employee tasked with managing IT system integration struggled due to a lack of appropriate skills. This case also highlighted the advantages of hiring younger workers for their quicker learning curve and better grasp of IT systems. Despite some concerns about the transient nature of student workers, both Case A and B acknowledged the benefits they brought to their organizations. Case B and F, while echoing the sentiment about limited work for FTEs in development roles, also shared their inclination to employ external consultants, especially those with substantial experience, to circumvent issues encountered with inexperienced consultants previously.

Contrastingly, Case C showed a strong interest in having in-house development capabilities. They recognized the potential cost optimization and untapped opportunities that internal competencies could offer, particularly for developing solutions within the Microsoft technology ecosystem, which they primarily use. Case D, on the other hand, was firmly against the idea of internal technical development skills, choosing to rely exclusively on external consultants to focus on core business processes. This approach was similar to that of Cases A and B in terms of not finding enough workload for a full-time developer. Case E and F also preferred external consultants for all development needs, reflecting a broader trend of outsourcing technical development roles in favor of focusing on core business activities and flexible, expert-driven solutions. An overview of the thematic codes related to technical human capital can be found in Table 4.2

Table 4.2: Thematic codes related to technical human capital for information systems

id	Theme	Description	Example quotes from data.
TDC-1	Insufficient workload for FTE	There is not enough work for an FTE.	Case A, B, D
TDC-2	Prioritization of conceptual skills	The company prefers to have a person employed who knows the business and processes, rather than having a developer.	All cases
TDC-3	Young employees	Preference to employ younger employees based on the assumption that they understand technology in their context, for example student workers.	Case A, B
TDC-4	Consultants	Preference to use consultants as they are flexible as resources and up to date on required knowledge	Case B, D, E

TDC-5	Technical development skills	Preference for having internal development skills in the company	Case C
TDC-6	Solution development, configuration, and customization	The company use external service partners and/or consultants for configuring and developing IT solutions	All cases

4.4.2. Competences, behavior, and change within digital data collection and analysis

The interviewed companies consistently encounter challenges in obtaining timely, high-quality data from field technicians who often overlook documentation and reporting tasks in favor of service completion. Case A reveals that many technicians perceive documentation as an extra burden rather than an integral part of their job. This attitude results in inadequate or missing summaries of work, despite having efficient information systems for data reporting.

Cases B and C have improved their data quality by demonstrating the practical consequences of poor documentation to technicians, emphasizing the necessity of comprehensive reporting. Case B notes a sense of underutilization of data by technicians, while Case C has streamlined their data collection systems to be user-friendly for tradesmen, focusing only on essential data but acknowledging the need for increased data collection in the future.

Case D highlights an industry-specific scenario where strict documentation requirements have ingrained a higher standard of data quality. Here, a noticeable variance in skill levels among technicians is observed, with younger technicians being more adept with information systems but less thorough in reporting compared to their older counterparts, who provide more detailed and well-articulated service reports.

Case E reports variability in data quality among technicians, necessitating continuous dialogue and training. Despite the capability of technicians to collect and document data, a common challenge across all cases is ensuring the accuracy and completeness of this documentation. The companies recognize the importance of training focused on the implications of poor documentation, rather than just the mechanics of data collection. An overview of the thematic codes related to the huan aspect of digital data collection and analysis can be found in Table 4.3

Table 4.3: Thematic codes related to human aspect of digital data collection and analysis

id	**Theme**	**Description**	**Cases Illustrating Theme**
DCA-1	Challenges in Data Quality and Reporting	All companies face issues with obtaining timely, high-quality data from field technicians, who often deprioritize documentation and reporting tasks.	All cases
DCA-2	Technicians' Perception of Documentation	Many technicians view documentation as an extra burden rather than a critical aspect of their job. This affects the quality and completeness of data reported.	All cases
DCA-3	Importance of Practical Training	Companies report the effectiveness of using practical examples to demonstrate the consequences of poor documentation, suggesting a focus on practical, consequence-oriented training.	Case A, B, C, D

DCA-4	System Usability and Data Collection Focus	Emphasis on designing user-friendly data collection systems and focusing on essential data only to facilitate easier reporting by technicians.	Case C, D
DCA-5	Variation in Skill Levels Among Technicians	Differences in skill levels and reporting quality among technicians, often influenced by age, with younger technicians being more tech-savvy but less thorough.	Case D, E
DCA-6	Consensus on Capability with Challenges in Execution	General agreement that technicians are capable of data collection and documentation, but challenges exist in ensuring it is done correctly and thoroughly.	All cases

4.4.3. Behavior, strategic efforts, and competences within low-cost proof-of-concepts

The interviewed companies generally avoid using low-code tools, except for business intelligence (BI) purposes, particularly Microsoft Power BI. This tool is primarily used by Cases B, C, and D to develop visual reports from business data derived from Field Service Management (FSM) systems or Enterprise Resource Planning (ERP) systems, aiding decision-making in after-sales service processes. Specifically, Cases B and D utilize BI mainly for the presentation and measurement of Key Performance Indicators (KPIs) within structured processes and ad-hoc analysis. Case C, however, stands out by employing BI and data science practices in more exploratory contexts, with business controllers managing and presenting data to derive actionable insights.

The development of BI reports is generally handled outside the after-sales service organization. Case B delegates this to the Chief Financial Officer (CFO) and student workers, Case C to business controllers, and Case D to the IT department, with occasional involvement from the service manager. Case A entirely outsources these skills to external consultants. Case F reported great success from having a student worker to conduct explorative data analysis.

The use of data visualization, particularly in Case B, has improved technician behavior. Administrative KPIs are shared across staff, publicly showcasing both good and poor performance, which initially met resistance but eventually led to collective improvements and awareness of mistakes.

Despite a general lack of use of low-code tool prototyping, there remains a consensus on welcoming ideas to improve system use and data collection. Most companies, excluding Case E, actively involve technician ambassadors to gather and present operational challenges, seeking potential improvements. These ideas are typically discussed in quarterly technician meetings (absent in Case E), where they are assessed by service managers for potential implementation. New functionalities are often outsourced to external system vendors without undergoing prototyping or preliminary testing, based primarily on the perceived benefits by managers. Case B describes this process as relying on "gut feeling," where multiple inputs, including differing technician preferences, are considered. An overview of the thematic codes related to the use of low-code tools can be found in Table 4.4.

Table 4.4: Thematic codes related to the use of low-code tools

id	Theme	Description	Companies Illustrating Theme
PoC-1	Limited Use of Low-Code Tools	General reluctance to engage in low-code tools, except for business intelligence purposes.	All Cases
PoC-2	Business Intelligence for Decision-Making	Use of Microsoft Power BI and other tools for developing visual reports to guide decision-making in after-sales service processes.	Case B, C, D, F
PoC-3	Focus on KPIs and Performance Measurement	Business intelligence is mainly used for presentation and measurement of key performance indicators (KPIs) to improve performance and awareness.	Case B, D, F
PoC-4	Exploratory Use of Business Intelligence	Business intelligence used in more exploratory contexts to uncover actionable insights.	Case C, F
PoC-5	Technician Engagement in System Improvement	Recruitment of technician ambassadors to collect and present operational pain points for system improvements.	All Cases except E
PoC-6	Regular Technician Meetings for Feedback	Holding quarterly technician meetings to discuss ideas and pain points, leading to system improvements.	All Cases except E

4.5. Synthesis of thematic analysis

The thematic analysis revealed three distinct, interrelated aspects—skill location, solution process, and data maturity. Each case demonstrated different approaches to digitalization innovation, yet distinct patterns were clear. Essentially, there is a noticeable progression in solution phases and shifts in skill location that align with the advances in data maturity, aiming to balance costs with anticipated benefits.

Based on the thematic analysis, the following model has been synthesized (Figure 4.1). The Skill location axis classifies the positioning of competencies as they relate to the organizational boundary. Here, "Internal" denotes competencies that are inherent to the organization, embodied by employees with permanent contracts who contribute to daily operations. "Temporary" represents transient skills provided by non-permanent staff, such as student workers, whose understanding of current technologies is valuable yet not retained long-term. "External" indicates skills sourced from outside the organization, like consultants, representing the most distant relationship in terms of skill permanence.

The Solution process axis represents the maturity level of technical solution development. Here, "Exploration" represents early-stage activities where the organization identifies potential issues and solutions, involving internal staff to leverage their knowledge of the business. "Prototyping" represents the phase of hands-on development using low-code or business intelligence tools to create preliminary models and visualizations that can inform decision-making. Lastly, "Full-Scale Solution" represents the advanced stage of development, where solutions are fully integrated into the organizational infrastructure, addressing specific problems through comprehensive software development.

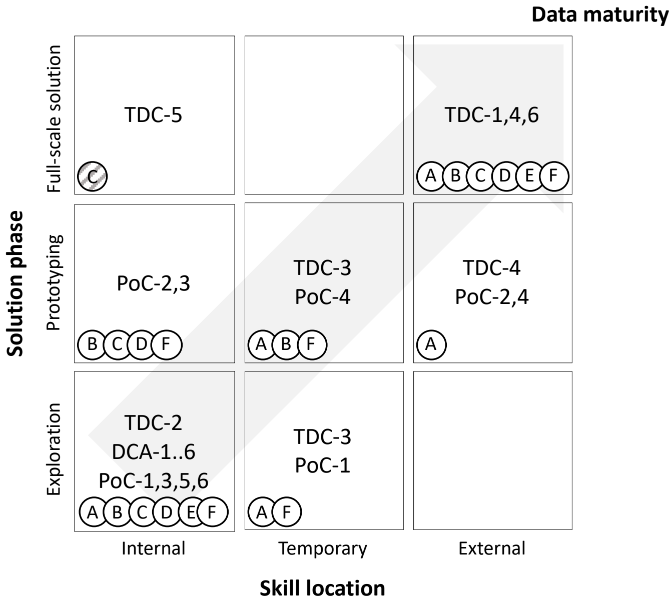

Figure 4.1: Visualization of the model based on the thematic analysis.

The analysis illustrates that companies invest considerable effort in enhancing their business processes and optimizing data collection methods. This groundwork is not primarily about developing new systems or technological solutions. Instead, it's about establishing a foundation that will enable these advancements. The focus is less on technology itself and more on shaping behaviors that support the adoption and facilitation of technological growth. Essentially, companies are channeling their resources to create a conducive foundation that developers can effectively build upon.

As they advance in data maturity, organizations begin to unlock new opportunities for development. This progression is depicted in the model by a relationship between ascending the axes and increased data maturity — the higher the position on the axes, the greater the data sophistication in terms of its quality and volume is required. The cases examined suggest that a certain threshold of data quality within a company is a prerequisite for the successful development of comprehensive, full-scale solutions. This implies that no matter the quantity of improvement ideas generated during the exploratory phase, their translation into implemented, full-scale solutions could be hindered if the underlying data quality is poor. Therefore, a higher level of data maturity can be a precondition for innovation in information systems, a point previously raised in the findings of (Battistoni et al., 2023).

The Internal/Exploration" level represents when the organization is actively exploring possible problems and solutions and combines these with external trends using internal skills and participants from the specific areas of investigation.

This is represented by the theme that focus on the prioritizing conceptual skills (TDC-2) over technical development skills and the themes of data collection and analysis (DCA-1..6). These themes had in common that they were focused around improving behavior and change through demonstrating practical examples and internal collaboration to improve business processes. Here, there is a limited use of Low-Code tools (PoC-1) and instead there is a focus on increasing performance in business processes through collaboration (PoC-3) and how different initiatives can help the company develop in these (PoC-6,7). Moving to the Internal/Prototyping phase, there's an emphasis on utilizing business intelligence tools for developing visualizations that aid in decision-making and operational improvements, aligning with the use of administrative KPIs (PoC-2,3). This is achieved using inhouse competences. At the Internal/Full-Scale Solution stage, the aspiration is to internally develop complete, solutions. Although Case C desires these capabilities in-house, currently they do not possess them, underscoring a gap between ambition and reality (TDC-5).

The Temporary/Exploration level is characterized by engaging younger, tech-savvy employees for their fresh perspectives on technology trends, not necessarily as developers but as informed contributors (TDC-3, PoC-1). This is similar at the Temporary/Prototyping level, but with more hands-on activities using primarily business intelligence tools to explore company data to gain new insights (TDC-3/PoC-4). No themes were found related to the Temporary/Full-scale solution level nor the External/Exploration level.

The External/Prototyping level sees the utilization of consultants as flexible resources, proficient at addressing specific, short-term project needs, reflecting a strategic choice for flexibility and specialized expertise. Lastly, the External/Full-Scale Solution cell indicates the reliance on external service providers for software development and configuration (TDC-4), driven by the realization that such tasks cannot justify the employment of a full-time staff member (TDC-1). This approach is common among the companies, including Case C, which, despite its interest in developing internal capabilities, aligns with the others in outsourcing these tasks.

4.6. Discussion

This section aims to answer the research questions based on the synthesis of the thematic analysis. This will be followed by a presentation of theoretical and practical implications.

4.6.1. The need for technical development competences in SMEs

The investigation into the technical development competencies required for supporting after-sale service processes in SMEs reveals a nuanced approach to skill acquisition. The interviews indicate a general consensus among companies, except for Case C, that internal technical development skills are not essential. Instead, the emphasis is on acquiring and nurturing conceptual skills, particularly those related to exploration. These skills are deemed more vital for companies to retain than development skills, as they directly contribute to problem-solving and innovation within the organization.

This paper concurs with the perspective presented by (Cetindamar Kozanoglu & Abedin, 2021), which posits that digital literacy exceeds mere technical skills, encompassing broader conceptual competencies that involve social, educational, and work-related facets of engaging with digital technologies. The observed disinterest in technical development skills among SMEs underscores this stance, emphasizing the greater pertinence of conceptual abilities. Furthermore, this insight enriches the comprehension of the specific skill sets required for Industry 4.0 and digital endeavors within the context of SMEs (Horváth & Szabó, 2019; Moeuf et al., 2020; P. Senna et al., 2023; Roblek et al., 2021).

4.6.2. Managing data collection and analysis: A human perspective

SMEs approach the management of data collection and analysis in after-sales service processes through a combination of practical demonstration and participatory methods.

They emphasize the importance of these processes by showcasing real-world consequences of inadequate data management. This approach aims to contextualize the technicians' role in the broader business perspective, highlighting how their work directly contributes to organizational improvements. Additionally, SMEs prioritize open communication with their technicians. By actively listening to their experiences and challenges, management seeks to co-develop digital solutions that streamline their tasks. This collaborative approach is crucial in tailoring tools that genuinely address the technicians' needs.

However, the results also indicate a careful balance to be maintained. While accommodating technician feedback is important, management also asserts the need for discipline in data collection practices. They urge technicians to prioritize accuracy and thoroughness in their reporting, emphasizing that these tasks, while seemingly mundane, are essential and manageable with proper time allocation. Through this blend of demonstration, collaboration, and guidance, SMEs strive to optimize data collection and analysis in after-sales services, ensuring it is both efficient and human-centered. This enhances comprehension of the ways in which SMEs can adapt their organizational structures and modify work processes to meet the data requirements of Industry 4.0 initiatives. Such adaptations are significantly influenced by the organizational culture, which stands as a critical factor and challenge in this context (Chanias et al., 2019; Leso et al., 2023; Okkonen et al., 2019; Teichert, 2019).

4.6.3. Using low-code tools for digitalization of after-sales service processes

In examining how SMEs utilize low-code tools for the digitalization of after-sales service processes, it was observed that their application is not as widespread as expected. Instead of leveraging low-code platforms for broad digitalization initiatives, SMEs are primarily using tools like Microsoft Power BI for specific tasks such as exploratory and ad-hoc data analysis. These tasks are often managed ad-hoc by departments like finance or by student workers, rather than being integrated into a wider digital strategy.

The use of student workers for these tasks, despite their limited domain knowledge and temporary employment, indicates a preference for renewable short-term access to skills that can perform exploratory work and development, while contributing with new perspectives and ideas. However, this approach presents challenges due to the temporary nature of such skills within the organization, supporting the notion of (Sanchis et al., 2020). Consequently, it is recommended that companies invest in cultivating exploratory skills internally, to yield the benefits described by (Amaral & Peças, 2021; Su et al., 2023; Yilmaz et al., 2023). This strategy ensures a continual expansion of knowledge and capability within the company, while allowing it to address future challenges effectively and maintain a focus on core business areas.

4.6.4. Theoretical implications

The novel theoretical implication of this paper lies in the extended understanding that data maturity, skill location, and choice of solution process are tightly connected and chosen based on the experiences. To specify this novelty, we propose a triadic relationship as a self-reinforcing system of otherwise diverse aspects. In this system, how an SME decides to position themselves in terms of solution phase and skill location—and how they manage these—influence their data quality. Simultaneously, an increasing level of data maturity is required to develop prototypes and full-scale solutions. This paper thus proposes SMEs manage these aspects as a system and not individually.

From a more direct perspective, this research offers insights into digitalization of after-sales service activities in SMEs. This is highly relevant as the industrial revolution is currently providing increasingly more accessible technologies. These have brought an increased awareness to servitization of business models - a well-known and vital business area for SMEs. This research translates highly relevant research problems into this context, contributing with specific knowledge to be applied to this central business areas. Specifically, this research adds to the understanding of the competence need in SMEs, how SMEs engage with data maturity improvements, and how SMEs employ Low-Code tools in their after-sales service activities.

4.6.5. Practical limitations

To address practical implications, this study can be used to guide SMEs on where to allocate resources for digital transformation. This study explicitly highlights that SMEs should focus less on building technical development skills, but instead concentrate their efforts on increasing their collective data maturity through exploration and prototyping to be able to deliver high-quality inputs to external development companies. This knowledge of conscious decision-making can help SMEs optimize their digitalization efforts and increase success rates in deploying new digital services.

4.6.6. Limitations and future work

The research conducted here analyzed digitalization of after-sales service processes in SMEs based on six cases. The empirical data that were collected consisted of one semi-structured interview per case company. Although the analysis of the interviews resulted in a clear definition of patterns, this was limited to three interconnected themes based on the theoretical framework presented by Grooss (2024). The study was specifically designed to investigate a particular subset of SMEs currently going through the process of implementing a specific type of information system. The selection of these cases was also based on leads from previous cases and through snowball sampling, ensuring compliance with the research design. This leads to several limitations and opportunities for future research.

First, this research did not compare the results to studies with SMEs that have demonstrated a high level of digital maturity or to large organizations. While larger corporations are not within scope of the SME focus, comparative analyses could shed further light on the nature of SME digitalization. The main interest would be to compare if the approach holds for cases that have a high level of internal skills and/or cases that have more financial capital available, as well as how organizations manage skill location over their own developmental progress.

Second, the research also did not consider the various forms and phases of solution development in sufficient depth to fully conclude the methodologies used by the studied cases. It was often unclear in which specific phase a case operated. Specifically, exploration and prototyping are often fluid concepts used by the cases when describing solution development and not as discrete cases as illustrated in the abstract model in Figure 4.1. There was, however, still a clear distinction between the two levels.

Finally, the research only investigated three of the themes described by Grooss (2024). It is unclear if other themes would have created a wider entanglement resulting in a more complex model than that described in Figure 4.1. Additional themes and combinations of themes should be studied to better understand data maturity as a measure of progression in solution phases and skill location.

4.7. Conclusion

This paper explored three different aspects of the digitalization of after-sales service processes in SMEs. The study sought to describe the needs for technical development competences, how SMEs manage data collection and analysis from a human perspective, and how SMEs utilize low-code tools for digitalization. This was achieved by conducting semi-structured interviews with service managers from six different Danish SMEs and focused on the implementation of Field Service Management systems to provide a common denominator across the interviews. The interviews underwent a thematic analysis, from which an integrative model was developed. The model visualizes the relationship between skill location, solution process and data maturity.

In the context of SMEs, the study revealed a nuanced approach to technical development competencies for supporting after-sale service processes. Internal technical development skills were not deemed essential by most companies. Instead, there was a greater emphasis on fostering conceptual and exploration skills, which were considered more crucial for problem-solving and innovation.

Regarding data collection and analysis in after-sales services, it appears that SMEs employ a mix of practical demonstrations and participatory methods. This approach stresses the significance of these processes, showcasing the real-world impacts of poor data management. It aims to contextualize the roles of technicians within the broader business framework, underlining their direct contribution to organizational improvements. SMEs prioritize open communication with their technicians, co-developing digital solutions that address their challenges and streamline tasks. However, there is a need for balance, with management emphasizing the importance of disciplined data collection and thorough reporting.

The study also examined the use of low-code tools in the digitalization of after-sales services. Contrary to expectations, the adoption of these tools was limited, primarily to tasks such as exploratory and ad-hoc data analysis using platforms like Microsoft Power BI. These tasks were often handled by specific departments or student workers, which indicates a preference for temporary, renewable access to skills linked to new ideas and perspectives. However, the transient nature of these skills presents challenges, which suggests a need for SMEs to develop exploratory skills internally. This approach would ensure a sustainable expansion of capabilities and knowledge, while allowing SMEs to tackle future challenges effectively and maintain their focus on core business areas.

4.8. References

Amaral, A., & Peças, P. (2021). SMEs and Industry 4.0: Two case studies of digitalization for a smoother integration. *Computers in Industry*, *125*, 103333. https://doi.org/10.1016/j.compind.2020.103333

Battistoni, E., Gitto, S., Murgia, G., & Campisi, D. (2023). Adoption paths of digital transformation in manufacturing SME. *International Journal of Production Economics*, *255*. https://doi.org/10.1016/j.ijpe.2022.108675

Bies, L., Weber, M., Greff, T., & Werth, D. (2022). A Mixed-Methods Study of Low-Code Development Platforms: Drivers of Digital Innovation in SMEs. *International Conference on Electrical, Computer, Communications and Mechatronics Engineering, ICECCME 2022*. https://doi.org/10.1109/ICECCME55909.2022.9987920

Bona, G. Di, Cesarotti, V., Arcese, G., & Gallo, T. (2021). Implementation of Industry 4.0 technology: New opportunities and challenges for maintenance strategy. *Procedia Computer Science*, *180*(2019), 424–429. https://doi.org/10.1016/j.procs.2021.01.258

Castelo-Branco, I., Oliveira, T., Simões-Coelho, P., Portugal, J., & Filipe, I. (2022). Measuring the fourth industrial revolution through the Industry 4.0 lens: The relevance of resources, capabilities and the value chain. *Computers in Industry*, *138*. https://doi.org/10.1016/j.compind.2022.103639

Cetindamar Kozanoglu, D., & Abedin, B. (2021). Understanding the role of employees in digital transformation: conceptualization of digital literacy of employees as a multi-dimensional organizational affordance. *Journal of Enterprise Information Management*, *34*(6), 1649–1672. https://doi.org/10.1108/JEIM-01-2020-0010

Chanias, S., Myers, M. D., & Hess, T. (2019). Digital transformation strategy making in pre-digital organizations: The case of a financial services provider. *Journal of Strategic Information Systems*, *28*(1), 17–33. https://doi.org/10.1016/j.jsis.2018.11.003

de la Fuente, A., González-Prida, V., Crespo, A., Gómez, J. F., & Guillén, A. (2018). *Advanced Techniques for Assets Maintenance Management*. *51*(11), 205–210. https://doi.org/10.1016/j.ifacol.2018.08.260

Di Ruscio, D., Kolovos, D., de Lara, J., Pierantonio, A., Tisi, M., & Wimmer, M. (2022). Low-code development and model-driven engineering: Two sides of the same coin? *Software and Systems Modeling*, *21*(2), 437–446. https://doi.org/10.1007/s10270-021-00970-2

Dolatabadi, S. H., & Budinska, I. (2021). Systematic literature review predictive maintenance solutions for smes from the last decade. *Machines*, *9*(9). https://doi.org/10.3390/machines9090191

Dutta, G., Kumar, R., Sindhwani, R., & Singh, R. K. (2020). Digital transformation priorities of India's discrete manufacturing SMEs – a conceptual study in perspective of Industry 4.0. *Competitiveness Review: An International Business Journal*, *30*(3), 289–314. https://doi.org/10.1108/CR-03-2019-0031

Elshan, E., Dickhaut, E., & Ebel, P. (2023, November). *An Investigation of Why Low Code Platforms Provide Answers and New Challenges*.

Genest, M. C., & Gamache, S. (2020). Prerequisites for the implementation of industry 4.0 in manufacturing SMEs. *Procedia Manufacturing*, *51*, 1215–1220. https://doi.org/10.1016/j.promfg.2020.10.170

Ghobakhloo, M., Fathi, M., Iranmanesh, M., Maroufkhani, P., & Morales, M. E. (2021). Industry 4.0 ten years on: A bibliometric and systematic review of concepts, sustainability value drivers, and success determinants. *Journal of Cleaner Production*, *302*, 127052. https://doi.org/10.1016/j.jclepro.2021.127052

Grooss, O. F. (2024). Digitalization of maintenance activities in small and medium-sized enterprises: A conceptual framework. *Computers in Industry*, *154*, 104039. https://doi.org/10.1016/j.compind.2023.104039

Hawkridge, G., Mukherjee, A., McFarlane, D., Tlegenov, Y., Parlikad, A. K., Reyner, N. J., & Thorne, A. (2021). Monitoring on a shoestring: Low cost solutions for digital manufacturing. *Annual Reviews in Control*, *51*, 374–391. https://doi.org/10.1016/j.arcontrol.2021.04.007

Horváth, D., & Szabó, R. Z. (2019). Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities? *Technological Forecasting and Social Change*, *146*(October 2018), 119–132. https://doi.org/10.1016/j.techfore.2019.05.021

Jiwangkura, S., Sophatsathit, P., & Chandrachai, A. (2020). Industrial internet of things implementation strategies with HCI for SME Adoption. *International Journal of Automation and Smart Technology*, *10*(1), 153–168. https://doi.org/10.5875/ausmt.v10i1.2108

Kagermann, H., & Wahlster, W. (2022). Ten Years of Industrie 4.0. In *Sci* (Vol. 4, Issue 3). MDPI. https://doi.org/10.3390/sci4030026

Khan, M., Ahmad, A., Sobieczky, F., Pichler, M., Moser, B. A., & Bukovsky, I. (2022). A Systematic Mapping Study of Predictive Maintenance in SMEs. *IEEE Access*, *10*, 88738–88749. https://doi.org/10.1109/ACCESS.2022.3200694

Kilimis, P., Zou, W., Lehmann, M., & Berger, U. (2019). A survey on digitalization for SMEs in Brandenburg, Germany. *IFAC-PapersOnLine*, *52*(13), 2140–2145. https://doi.org/10.1016/j.ifacol.2019.11.522

Kim, M., Lim, C., & Hsuan, J. (2023). From technology enablers to circular economy: Data-driven understanding of the overview of servitization and product–service systems in Industry 4.0. In *Computers in Industry* (Vol. 148). Elsevier B.V. https://doi.org/10.1016/j.compind.2023.103908

Leso, B. H., Cortimiglia, M. N., & Ghezzi, A. (2023). The contribution of organizational culture, structure, and leadership factors in the digital transformation of SMEs: a mixed-methods approach. *Cognition, Technology and Work*, *25*(1), 151–179. https://doi.org/10.1007/s10111-022-00714-2

Masood, T., & Sonntag, P. (2020). Industry 4.0: Adoption challenges and benefits for SMEs. *Computers in Industry*, *121*, 103261. https://doi.org/10.1016/j.compind.2020.103261

Moeuf, A., Lamouri, S., Pellerin, R., Tamayo-Giraldo, S., Tobon-Valencia, E., & Eburdy, R. (2020). Identification of critical success factors, risks and opportunities of Industry 4.0 in

SMEs. *International Journal of Production Research*, *58*(5), 1384–1400. https://doi.org/10.1080/00207543.2019.1636323

Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S., & Barbaray, R. (2018). The industrial management of SMEs in the era of Industry 4.0. *International Journal of Production Research*, *56*(3), 1118–1136. https://doi.org/10.1080/00207543.2017.1372647

Naushad, M., & Sulphey, M. M. (2020). Prioritizing technology adoption dynamics among SMEs. *TEM Journal*, *9*(3), 983–991. https://doi.org/10.18421/TEM93-21

Okkonen, J., Vuori, V., & Palvalin, M. (2019). Digitalization Changing Work: Employees' View on the Benefits and Hindrances. *Advances in Intelligent Systems and Computing*, *918*, 165–176. https://doi.org/10.1007/978-3-030-11890-7_17

P. Senna, P., Barros, A. C., Bonnin Roca, J., & Azevedo, A. (2023). Development of a digital maturity model for Industry 4.0 based on the technology-organization-environment framework. *Computers and Industrial Engineering*, *185*. https://doi.org/10.1016/j.cie.2023.109645

Pagalday, G., Zubizarreta, P., Uribetxebarria, J., Erguido, A., & Castellano, E. (2018). Efficient development and management of after sale services. *Procedia Manufacturing*, *19*, 18–25. https://doi.org/10.1016/j.promfg.2018.01.004

Peillon, S., & Dubruc, N. (2019). Barriers to digital servitization in French manufacturing SMEs. *Procedia CIRP*, *83*, 146–150. https://doi.org/10.1016/j.procir.2019.04.008

Pinciroli, L., Baraldi, P., & Zio, E. (2023). Maintenance optimization in industry 4.0. *Reliability Engineering and System Safety*, *234*. https://doi.org/10.1016/j.ress.2023.109204

Pirola, F., Boucher, X., Wiesner, S., & Pezzotta, G. (2020). Digital technologies in product-service systems: a literature review and a research agenda. *Computers in Industry*, *123*, 103301. https://doi.org/10.1016/j.compind.2020.103301

Rastogi, V., Srivastava, S., Mishra, M., & Thukral, R. (2020). Predictive Maintenance for SME in Industry 4.0. *2020 Global Smart Industry Conference (GloSIC)*, 382–390. https://doi.org/10.1109/GloSIC50886.2020.9267844

Roblek, V., Meško, M., Pušavec, F., & Likar, B. (2021). The Role and Meaning of the Digital Transformation As a Disruptive Innovation on Small and Medium Manufacturing Enterprises. *Frontiers in Psychology*, *12*(June), 1–18. https://doi.org/10.3389/fpsyg.2021.592528

Sanchis, R., García-Perales, Ó., Fraile, F., & Poler, R. (2020). Low-code as enabler of digital transformation in manufacturing industry. *Applied Sciences (Switzerland)*, *10*(1). https://doi.org/10.3390/app10010012

Schlegel, D., & Kraus, P. (2023). Skills and competencies for digital transformation – a critical analysis in the context of robotic process automation. *International Journal of Organizational Analysis*, *31*(3), 804–822. https://doi.org/10.1108/IJOA-04-2021-2707

Soluk, J., & Kammerlander, N. (2021). Digital transformation in family-owned Mittelstand firms: A dynamic capabilities perspective. *European Journal of Information Systems*, *November*. https://doi.org/10.1080/0960085X.2020.1857666

Somohano-Rodríguez, F. M., Madrid-Guijarro, A., & López-Fernández, J. M. (2022). Does Industry 4.0 really matter for SME innovation? *Journal of Small Business Management*, *60*(4), 1001–1028. https://doi.org/10.1080/00472778.2020.1780728

Su, J., Zhang, Y., & Wu, X. (2023). How market pressures and organizational readiness drive digital marketing adoption strategies' evolution in small and medium enterprises. *Technological Forecasting and Social Change*, *193*. https://doi.org/10.1016/j.techfore.2023.122655

Teichert, R. (2019). Digital Transformation Maturity: A Systematic Review of Literature. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, *67*(6), 1673–1687. https://doi.org/10.11118/actaun201967061673

Tortora, A. M. R., Maria, A., Valentina, D. P., Iannone, R., & Pianese, C. (2021). A survey study on Industry 4.0 readiness level of Italian small and medium enterprises. *Procedia Computer Science*, *180*, 744–753. https://doi.org/10.1016/j.procs.2021.01.321

Velmurugan, K., Saravanasankar, S., & Bathrinath, S. (2022). Smart maintenance management approach: Critical review of present practices and future trends in SMEs 4.0. *Materials Today: Proceedings*, *62*, 2988–2995. https://doi.org/10.1016/j.matpr.2022.02.622

Weking, J., Stöcker, M., Kowalkiewicz, M., Böhm, M., & Krcmar, H. (2020). Leveraging industry 4.0 – A business model pattern framework. *International Journal of Production Economics*, *225*(December 2019). https://doi.org/10.1016/j.ijpe.2019.107588

Welte, R., Estler, M., & Lucke, D. (2020). A method for implementation of machine learning solutions for predictive maintenance in small and medium sized enterprises. *Procedia CIRP*, *93*, 909–914. https://doi.org/10.1016/j.procir.2020.04.052

Xing, K., Liu, X., Liu, Z., Mayer, J. R. R., & Achiche, S. (2020). Low-Cost Precision Monitoring System of Machine Tools for SMEs. *Procedia CIRP*, *96*, 347–352. https://doi.org/10.1016/j.procir.2021.01.098

Yilmaz, G., Salter, L., McFarlane, D., & Schönfuß, B. (2023). Low-cost (Shoestring) digital solution areas for enabling digitalisation in construction SMEs. *Computers in Industry*, *150*. https://doi.org/10.1016/j.compind.2023.103941

Zonta, T., da Costa, C. A., da Rosa Righi, R., de Lima, M. J., da Trindade, E. S., & Li, G. P. (2020). Predictive maintenance in the Industry 4.0: A systematic literature review. *Computers and Industrial Engineering*, *150*(October), 106889. https://doi.org/10.1016/j.cie.2020.106889

Chapter 5. Reflections, implications, and conclusion

This final chapter aims to offer reflections on the outcomes and methodologies employed in the thesis, complemented by a personal contemplation. It will then proceed to present the scientific and practical implications, laying out suggestions for future research directions.

5.1. Reflections on results

This thesis has explored how SMEs can engage in the fourth industrial revolution through incremental digitalization. To achieve this, the research was structured around answering five key research questions.

A key finding of this thesis is the importance of exploiting existing resources, which aligns with the resource constraints typical of SMEs. This focus helps to navigate the limited skill sets and financial resources available in such enterprises. By delving into the operational context of SMEs, the research provided insights into the available data and IT infrastructure, advocating for an incremental approach to digitalization. The developed framework emphasizes low-cost prototyping, underscoring the necessity of practical execution in the implementation of digital strategies. This framework is, to the extent of current understanding, the first to support the specific resource scarcity in SMEs and address their unique needs.

Reflecting on this specific focus, it was clear that the companies largely possessed more data than they would think, and that there was a substantial amount of unredeemed potential in it. The companies had generally been collecting production and maintenance data for years without fully leveraging it. In some instances, even basic production scheduling data could offer valuable insights into asset health, providing a more reliable basis for decision-making than mere guesswork. However, these possibilities were often overlooked due to the companies' intense focus on their daily operations and a lack of dedicated personnel to explore these data resources.

Despite these insights, it's crucial to acknowledge certain limitations. Often, the available production and maintenance data were insufficient to entirely replace maintenance planning and the deep knowledge possessed by technicians and operators. These professionals' extensive experience and familiarity with the machinery invariably proved more effective than the data alone. However, the developed prototypes did aid in enhancing their work, contributing noticeable improvements to the processes. Yet, it was evident that, given the current state of data quality and information systems, the expertise of experienced technicians and operators remains irreplaceable.

This experience also brings to light limitations in the framework itself, as the benefits of exploiting existing resources eventually reach a plateau in terms of operational performance improvements. At this juncture, more sophisticated data collection methods and digital technologies become necessary. This infers that there is a need to investigate how this type of incremental digitalization can develop into full-blown digital transformation activities with more sophisticated technologies.

From a technological standpoint, the control of master data repeatedly emerged as a critical factor. The research strongly emphasizes that without high-quality master data, any digital initiative is ineffective. This is echoed in the literature and confirmed in the study's findings. This observation is not novel in itself, as it is well-known that Industry 4.0 and digitalization are highly data-driven (Horváth & Szabó, 2019; Matt & Rauch, 2020). However, beyond reinforcing this premise, this thesis highlights that any digitalization efforts in SMEs are highly dependent on effective digital data collection mechanisms and that this data is well managed in systems and databases. With this, this thesis stands with the literature that highlights technology management as basic enablers for digitalization, suggesting that this is where SMEs focus their initial energy. Reflecting on the contrasting experiences with the different companies, there was a stark difference in data management practices. Some companies possessed well-structured, voluminous data systematically collected over extended periods. This data richness facilitated a smooth collaboration, which made it possible to dive directly into prototyping development. Contrastingly, some companies had a rudimentary approach to data handling, often resorting to jotting down notes and storing them in physical folders. In these instances, it was challenging to scope good cases, as most of the three-month period would have to be spend on collecting new system data or trying to salvage the existing. This contrast not only highlighted the varying levels of digital maturity among SMEs but also underscored the critical importance of systematic data collection and management as a precursor to effective digitalization efforts. This is also part of the reason to focus on after-sales service companies for the final paper, as they simply had better data collection mechanisms.

Another significant aspect discussed in the thesis is resource allocation. The research advocates for SMEs to concentrate their resources on their strengths. The suggestion is for SMEs to avoid in-house development of digital solutions, opting instead for external vendors and service partners. This approach allows SMEs to focus on their core competencies, like innovating business processes and enhancing data maturity, providing valuable input for future development efforts. The thesis promotes the idea of retaining agility by outsourcing technical expertise while preparing the organization internally to collaborate effectively with developers.

Reflecting on this perspective, it's important to consider the context of resource scarcity in SMEs. At first glance, it might appear counterintuitive for financially cautious SMEs to consider outsourcing expertise. Yet, the reality is that any digital initiative comes with associated costs, necessitating investment in terms of both time and money. For companies lacking the requisite skills or financial resources to embark on digital projects, the strategic allocation of human resources becomes even more critical. By effectively managing this aspect, SMEs can concentrate on their core revenue-generating activities while simultaneously acquiring knowledge about developing new digital initiatives. Over time, this approach could enable them to incrementally build the expertise necessary to make informed decisions about digital technology implementation.

This thesis has not only developed theoretical abstractions from industrial case companies but also reflects the extensive effort involved in the research process. This includes the time-intensive tasks of identifying and recruiting companies, scoping individual case studies, understanding their business operations, studying their digital infrastructure and data foundations, and developing digital prototypes. Although these efforts are only implicitly represented in the primary papers, they are detailed in the supporting conference papers. These papers contribute to the call for pragmatic research by offering practical examples of digitalization in SMEs for others to draw inspiration from.

While these cases constitute a substantial portion of the thesis, the abstractions and insights collected across the cases have been more informative for the model's development. Consequently, the included papers focus less on the engineering efforts and more on the abstraction of knowledge, reflecting the thesis's overarching goal of contributing to the broader understanding of digital transformation in SMEs, rather than the problem-solving itself.

5.2. Reflection on research methodologies

This research has embraced a participatory approach to pragmatically examine the digitalization of maintenance activities in SMEs. This methodology has been instrumental in offering deep insights while also presenting some inherent challenges, which have significantly shaped the research findings.

The primary advantage of this approach has been the ability to engage closely with the subject matter. By being closely involved with the problems faced by SMEs, the research facilitated a thorough understanding of the realities and complexities within these enterprises' digital infrastructure. This proximity to the problem allowed for an exploration of deeply rooted issues and participation in their resolution, thus providing unique insights into the context of digitalization in SMEs. The approach has provided a sense of groundedness and authenticity to the project, ensuring that the research remains relevant to the industry and that the solution space has been realistic to the SMEs.

However, this approach also encountered challenges, particularly in data collection. The evolving nature of data collection meant that new realizations in later case studies were not always anticipated in earlier ones, leading to some difficulties in retrospectively collecting data from completed cases. The lack of a predefined focus during data collection resulted in a more opportunistic and context-driven process. While this method revealed data relevant to the immediate context, it also made it challenging to determine the comprehensiveness of the data collected. To address this in the individual cases, the research employed a form of triangulation, repeatedly asking the same questions across different contexts until consistent answers were obtained. This method ensured a degree of reliability and robustness in the findings despite the unstructured nature of the data collection.

Another severely challenging aspect of the methodology relates to the identification of potential case companies. The initial screening relied on publicly available information such as the number of employees, profit, and balance sheet. This gave only an indication of the case companies, which then required further investigation. Next, the company's website was investigated to learn more about their business, which would further indicate the relevance of the company. However, it was not until direct contact with the company was made that it was possible to determine their relevance. As the project went on, this identification process became more straightforward, as learnings from the case studies made it easier to assess the fit of the next. In future research, it may be beneficial to undertake a qualitative study based on semi-structured interviews with a variety of companies. This approach could involve a more generalized and accessible sampling method, utilizing publicly available information from databases or company websites. Conducting interviews with these companies would not only provide a foundational understanding of the topic but also serve as a means to identify and recruit suitable candidates for more detailed, in-depth studies.

Despite these challenges, the participatory approach was considered essential for this study. Capturing the essence of business activities in a quantitative model might oversimplify their complexity. Hence, this research aimed to authentically reflect the reality of SME digitalization, prioritizing a contextual understanding over numerical abstraction.

Looking forward, there are several areas for improvement and reflection. Streamlining future case studies to minimize variability and developing a more structured methodology for conducting these studies could enhance their comparability and analytical depth. An important area of further investigation involves exploring the relationship between digitalization efforts and operational performance, a gap noted in the current literature. This could inform strategies for transitioning from incremental digitalization to complete digital transformation.

Lastly, for researchers in the field of business and technology, it is crucial to maintain their roles as observers, learners, and educators. Involvement should remain academic and not distort the consultancy industry, and it is essential to continue to base theorization on case study outcomes to make meaningful contributions to the knowledge base.

5.3. Scientific novelty and significance

This thesis contains several elements of scientific novelty.

First, the structured literature review presents 11 focus areas for SME digitalization. From these focus areas, three specific recommendations are developed to guide future research. Furthermore, this review also officially recommends shifting towards pragmatic research for digitalization research in SMEs. The structured literature review generally finds its novelty in proposing a future research agenda based on the shortcomings of the contemporary research.

Second, a key aspect of this research is the development of a novel framework for driving digital initiatives in SMEs, particularly focusing on the scarcity of resources. This framework is tailored to the specific context of SMEs, offering a nuanced understanding rather than a generic solution suitable for broader Industry 4.0 implementation. To be more precise, one of the innovative elements of this research is its focus on the often-overlooked data resources within SMEs. It discusses how SMEs can leverage their existing data more effectively to enhance their level of digitalization. This research is among the first to conceptualize and articulate the utilization of these data resources, especially in relation to other technology aspects, such as System Integration and Information Flow, and Digital Data Collection and Analysis. This provides valuable insights into how SMEs can harness their inherent data for digital advancement.

Third, this thesis also underscores how SMEs should manage their digitalization efforts from a human perspective. Specifically, it highlights how SMEs should focus human resources on co-creation processes and prototyping rather than doing in-house technical development of digital technology solutions. This distinction distributes the overarching competence requirements between the company's workforce and external vendors and collaborators.

Fourth, this research stands out for its pragmatic approach, combining practical case studies drawn from multiple studies with theoretical insights. This dual approach effectively bridges the gap between industry practice and academic theory, contributing to a more integrated understanding of digitalization in specific business areas.

Lastly, a distinctive feature of this research is its focus on maintenance and asset management within SMEs, an area that has not been extensively explored in existing literature. By delving into these specific aspects, the research sheds light on critical, yet often neglected, facets of digitalization in SMEs, thereby contributing a novel dimension to the field.

5.4. Practical relevance

This thesis finds its practical relevance in multiple aspects. First, the thesis emphasizes that companies can indeed explore their existing data and information system infrastructure to increase their digital maturity. Second, it provides a framework that can function as a roadmap for SMEs to incrementally digitalize their business processes within maintenance and after-sales service. These insights can guide future digitalization initiatives for SMEs. Third, the thesis specifically highlights how SMEs can allocate internal resources based on data maturity, to manage digitalization efforts effectively. Lastly, the supporting work of this thesis provides inspiration for specific initiatives that SMEs can adopt.

5.5. Future research

Based on the findings and discussion of this thesis, the following summarizes potential future research topics:

- **Refinement in conducting case studies:** It is recommended to develop a more systematic method for executing in-depth case studies across various companies. This would involve focusing on specific technologies, problem areas, or solution spaces in a more streamlined manner to enhance the depth and relevance of theoretical insights. This could also contribute to a more efficient research process.
- **Expansion of case studies:** Although this thesis is grounded in the analysis of four in-depth case studies, which is commendable compared to many existing models and frameworks, there is value in conducting additional case studies. Doing so could further solidify the robustness and validity of the findings.
- **Transition from incremental to comprehensive digital transformation:** The current thesis primarily addresses incremental digitalization through the utilization of existing resources as a pathway toward complete digital transformation. However, it stops short of detailing how organizations might progress to more advanced technological implementations. Future research should delve into how this progression can be effectively achieved, marking the shift from incremental changes to embracing full-fledged Industry 4.0 transformations.
- **Application in other business areas:** This thesis concentrates highly on maintenance and after-sales service business aspects of SMEs. Future research could investigate how the findings translate to other business areas.
- **Application in larger enterprises:** While this research concentrates on SMEs, extending the investigation to larger enterprises could be enlightening. Such a study could explore how the potential lack of resource constraints characteristic of SMEs influences the outcomes in larger organizational contexts.

5.6. Personal reflection

This section is a self-reflection, so it is written in first-person.

The journey of conducting this thesis, particularly through the lens of case studies, has been a profoundly educational experience, shaping my development as an independent researcher. At the outset of this project, the ambitious notion was to develop a project that could "solve digitalization in SMEs." However, it quickly became evident that the subject was far more complex than initially anticipated.

The opportunity to undertake this thesis and the responsibilities that came with it have taught me invaluable lessons about engaging with industry from an academic perspective. Entering as an external entity with no direct stakes in the company presented unique challenges. The success of such an endeavor largely relies on the researcher's personality - the ability to communicate effectively, empathize with different perspectives, and gain trust. Being adaptable, almost chameleon-like is crucial when integrating into diverse company cultures. Each new corporate environment demands a different set of adaptations, making trust and likability essential qualities for a researcher. Gaining trust is not just about being a trustworthy individual; it's about demonstrating to the company that their investment of time and resources in the research will yield tangible benefits for them. These skills were not a part of my repertoire at the start of this project, and I definitely haven't mastered them now. These are just my observations from engaging with numerous different companies, from which I have been rejected by many, to end up with my four in-depth case studies.

Throughout this process, I've become highly aware of the value that close industry connections bring to the research base. However, the success of these collaborations is not just about the research itself; it's significantly influenced by the social interactions between the companies and the university, particularly the researchers involved. It's a delicate balance of providing academic insights while ensuring relevancy and applicability to the industry partners.

This experience has also required me to re-evaluate and challenge my initial perceptions of conducting business and technology research. The complexities and nuances of carrying out meaningful case studies in industrial settings have sparked numerous reflections and learning moments. This thesis has not just been a journey of academic exploration but also one of personal and professional growth, highlighting the complicated balancing act between academia and industry in the realm of research.

5.7. Conclusion

This PhD thesis has answered the research questions presented in Section 1.3 through three research papers. The project began with a comprehensive, structured literature review to determine recommendations for adopting digital technologies in SMEs. From this review, 11 focus areas were identified, spanning three main domains: Technology, Organization, and Environment. Based on these insights, four in-depth single case studies were conducted with Danish SMEs, specifically focusing on the digitalization of maintenance activities. These case studies were instrumental in developing a conceptual framework that describes the maturity stages of digitalization in SME maintenance activities. Subsequently, three research questions were formulated, addressing the low-performing aspects observed in the initial case studies. These questions were explored through semi-structured interviews with service managers from five Danish SMEs operating with after-sales service business models, leading to a series of enlightening findings.

The developed conceptual framework advocates for low-cost prototyping and practical implementation strategies, specifically tailored to the resource scarcity in SMEs. This approach is innovative in its focus on SMEs' unique needs and emphasizes the significance of incremental digitalization as a viable strategy for these companies.

A significant finding is the underutilization of existing data and resources in SMEs. Despite having access to years of production and maintenance data, the companies failed to leverage this resource fully, often due to a focus on immediate operational demands and a lack of dedicated personnel for data exploration. However, where data was systematically collected and effectively managed, it proved invaluable in guiding digitalization efforts. The research also highlights the critical role of high-quality master data in the success of digital initiatives.

A key recommendation of this thesis is the strategic outsourcing of technical expertise, enabling SMEs to focus on their core competencies and gradually build digital capabilities. This approach aligns with the necessity of managing limited resources wisely and underscores the importance of human resource allocation in driving digital initiatives.

In conclusion, this thesis contributes to the understanding of digitalization of maintenance and after-sales service activities in SMEs by offering a novel framework, emphasizing the effective use of existing resources, and advocating for an incremental approach to digitalization. These insights provide a valuable roadmap for SMEs navigating the complexities of digital technology implementation. The experiences and challenges encountered in this research journey also underscore the dynamic interplay between academia and industry, highlighting the importance of practical, case-based research in advancing the understanding of digitalization in SMEs.

5.8. References for Chapter 1 and 5

Amaral, A., & Peças, P. (2021). SMEs and Industry 4.0: Two case studies of digitalization for a smoother integration. *Computers in Industry*, *125*, 103333. https://doi.org/10.1016/j.compind.2020.103333

Anderl, R., & Fleischer, J. (2015). Guideline Industrie 4.0. *VDMA Verlag*, 32. industrie40.vdma.org

Andulkar, M., Le, D. T., & Berger, U. (2018a). A multi-case study on Industry 4.0 for SME's in Brandenburg, Germany. *Proceedings of the 51st Hawaii International Conference on System Sciences*, 4544–4553. https://doi.org/10.24251/HICSS.2018.574

Andulkar, M., Le, D. T., & Berger, U. (2018b). A multi-case study on Industry 4.0 for SME's in Brandenburg, Germany. *Proceedings of the 51st Hawaii International Conference on System Sciences*, 4544–4553. https://doi.org/10.24251/HICSS.2018.574

Azhar, S., Ahmad, I., & Sein, M. K. (2010). Action Research as a Proactive Research Method for Construction Engineering and Management. *Journal of Construction Engineering and Management*, *136*(1), 87–98. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000081

Bakkari, M., & Khatory, A. (2017). Industry 4.0: Strategy for more sustainable industrial development in smes. *Proceedings of the International Conference on Industrial Engineering and Operations Management*, 1693–1701.

Battistoni, E., Gitto, S., Murgia, G., & Campisi, D. (2023). Adoption paths of digital transformation in manufacturing SME. *International Journal of Production Economics*, *255*. https://doi.org/10.1016/j.ijpe.2022.108675

Bidan, M., Rowe, F., & Truex, D. (2012). An empirical study of IS architectures in French SMEs: integration approaches. *European Journal of Information Systems*, *21*(3), 287–302. https://doi.org/10.1057/ejis.2012.12

Bouwman, H., Nikou, S., & de Reuver, M. (2019). Digitalization, business models, and SMEs: How do business model innovation practices improve performance of digitalizing SMEs? *Telecommunications Policy*, *43*(9), 101828. https://doi.org/10.1016/j.telpol.2019.101828

Brodny, J., & Tutak, M. (2022). Digitalization of Small and Medium-Sized Enterprises and Economic Growth: Evidence for the EU-27 Countries. *Journal of Open Innovation: Technology, Market, and Complexity*, *8*(2). https://doi.org/10.3390/joitmc8020067

Castelo-Branco, I., Oliveira, T., Simões-Coelho, P., Portugal, J., & Filipe, I. (2022). Measuring the fourth industrial revolution through the Industry 4.0 lens: The relevance of resources, capabilities and the value chain. *Computers in Industry*, *138*. https://doi.org/10.1016/j.compind.2022.103639

CEN. (2017). *CEN EN 13306-2017 - Maintenance terminology*. www.ds.dk

Coghlan, D., & Brannick, T. (2005). *Doing action research in your own organization* (2nd edition). Sage Publications Ltd.

Collatto, D. C., Dresch, A., Lacerda, D. P., & Bentz, I. G. (2018). Is Action Design Research Indeed Necessary? Analysis and Synergies Between Action Research and Design Science Research. *Systemic Practice and Action Research*, *31*(3), 239–267. https://doi.org/10.1007/s11213-017-9424-9

Colli, M., Berger, U., Bockholt, M., Madsen, O., Møller, C., & Wæhrens, B. V. (2019). A maturity assessment approach for conceiving context-specific roadmaps in the Industry 4.0 era. *Annual Reviews in Control*, *48*, 165–177. https://doi.org/10.1016/j.arcontrol.2019.06.001

Crupi, A., Del Sarto, N., Di Minin, A., Gregori, G. L., Lepore, D., Marinelli, L., & Spigarelli, F. (2020). The digital transformation of SMEs – a new knowledge broker called the digital innovation hub. *Journal of Knowledge Management*, *24*(6), 1263–1288. https://doi.org/10.1108/JKM-11-2019-0623

De Marco, C. E., Martelli, I., & Di Minin, A. (2020). European SMEs' engagement in open innovation When the important thing is to win and not just to participate, what should innovation policy do? *Technological Forecasting and Social Change*, *152*(December 2019), 119843. https://doi.org/10.1016/j.techfore.2019.119843

Decker, A. (2017). Industry 4.0 and SMEs in the Northern Jutland Region. In *Value Creation in International Business* (pp. 309–335). Springer International Publishing. https://doi.org/10.1007/978-3-319-39369-8_13

Di Bella, L., Katsinis, A., Lagüera-González, J., Odenthal, L., Hell, M., Lozar, B., European Commission. Joint Research Centre., & European Commission. Directorate-General for Internal Market, I. (2023). *Annual report on European SMEs 2022/2023*. https://doi.org/10.2760/028705

Doyle, F., & Cosgrove, J. (2019). Steps towards digitization of manufacturing in an SME environment. *Procedia Manufacturing*, *38*(2019), 540–547. https://doi.org/10.1016/j.promfg.2020.01.068

Du, L., Cheng, L., & Liu, C. (2021). Process Mining for Wind Turbine Maintenance Process Analysis: A Case Study. *5th IEEE Conference on Energy Internet and Energy System Integration: Energy Internet for Carbon Neutrality, EI2 2021*, 3274–3278. https://doi.org/10.1109/EI252483.2021.9713329

Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative Inquiry*, *12*(2), 219–245. https://doi.org/10.1177/1077800405284363

Ganzarain, J., & Errasti, N. (2016). Three stage maturity model in SME's toward industry 4.0. *Journal of Industrial Engineering and Management*, *9*(5), 1119. https://doi.org/10.3926/jiem.2073

Genest, M. C., & Gamache, S. (2020). Prerequisites for the implementation of industry 4.0 in manufacturing SMEs. *Procedia Manufacturing*, *51*, 1215–1220. https://doi.org/10.1016/j.promfg.2020.10.170

Ghobakhloo, M., & Ching, N. T. (2019). Adoption of digital technologies of smart manufacturing in SMEs. *Journal of Industrial Information Integration*, *16*(October), 100107. https://doi.org/10.1016/j.jii.2019.100107

Ghobakhloo, M., & Iranmanesh, M. (2021). Digital transformation success under Industry 4.0: a strategic guideline for manufacturing SMEs. *Journal of Manufacturing Technology Management*, *32*(8), 1533–1556. https://doi.org/10.1108/JMTM-11-2020-0455

Goedertier, S., de Weerdt, J., Martens, D., Vanthienen, J., & Baesens, B. (2011). Process discovery in event logs: An application in the telecom industry. *Applied Soft Computing*, *11*(2), 1697–1710. https://doi.org/10.1016/j.asoc.2010.04.025

Grooss, O. F. (2022). Advancing maintenance strategies through digitalization: A case study. *Procedia Computer Science*, *217*, 1522–1531. https://doi.org/10.1016/j.procs.2022.12.352

Grooss, O. F. (2023). Advancing maintenance strategies through digitalization: A case study. *Procedia Computer Science*, *217*, 1522–1531. https://doi.org/10.1016/j.procs.2022.12.352

Grooss, O. F. (2024). Digitalization of maintenance activities in small and medium-sized enterprises: A conceptual framework. *Computers in Industry*, *154*, 104039. https://doi.org/10.1016/j.compind.2023.104039

Grooss, O. F., Presser, M., & Tambo, T. (2022a). Balancing Digital Maturity and Operational Performance - Progressing in a Low-digital SME Manufacturing Setting. *Procedia Computer Science*, *200*, 495–504. https://doi.org/10.1016/j.procs.2022.01.247

Grooss, O. F., Presser, M., & Tambo, T. (2022b). Balancing Digital Maturity and Operational Performance - Progressing in a Low-digital SME Manufacturing Setting. *Procedia Computer Science*, *200*, 495–504. https://doi.org/10.1016/j.procs.2022.01.247

Grooss, O. F., Presser, M., & Tambo, T. (2022c). Surround yourself with your betters: Recommendations for adopting Industry 4.0 technologies in SMEs. *Digital Business*, *2*(2), 100046. https://doi.org/10.1016/j.digbus.2022.100046

Hansen, E. B., & Bøgh, S. (2021). Artificial intelligence and internet of things in small and medium-sized enterprises: A survey. *Journal of Manufacturing Systems*, *58*, 362–372. https://doi.org/10.1016/j.jmsy.2020.08.009

Hevner, A. R. (2007). *A Three Cycle View of Design Science Research*. *19*(2), 87–92.

Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design Science in Information System Research. *MIS Quarterly*, *28*(1), 75–105.

Høj Brasen, L. P., Groos, O. F., & Tambo, T. (2021). Comparison between data maturity and maintenance strategy: A case sutdy. *Procedia CIRP*, *104*, 1918–1923. https://doi.org/10.1016/j.procir.2021.11.324

Horváth, D., & Szabó, R. Z. (2019). Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities? *Technological Forecasting and Social Change*, *146*(October 2018), 119–132. https://doi.org/10.1016/j.techfore.2019.05.021

Jayashree, S., Reza, M. N. H., Malarvizhi, C. A. N., & Mohiuddin, M. (2021). Industry 4.0 implementation and Triple Bottom Line sustainability: An empirical study on small and medium manufacturing firms. *Heliyon*, *7*(8), e07753. https://doi.org/10.1016/j.heliyon.2021.e07753

Kagermann, H., Lukas, W.-D., & Wahlster, W. (2011). Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution. *VDI Nachrichten*.

Kagermann, H., & Wahlster, W. (2022). Ten Years of Industrie 4.0. In *Sci* (Vol. 4, Issue 3). MDPI. https://doi.org/10.3390/sci4030026

Karray, M. H., Chebel-Morello, B., & Zerhouni, N. (2014). PETRA: Process Evolution using a TRAce-based system on a maintenance platform. *Knowledge-Based Systems*, *68*, 21–39. https://doi.org/10.1016/j.knosys.2014.03.010

Kergroach, S. (2020). Giving momentum to SME digitalization. *Journal of the International Council for Small Business*, *1*(1), 28–31. https://doi.org/10.1080/26437015.2020.1714358

Lookanen, E. (2003). Commission Recommendation of 6 May 2003 concerning the definition of micro, small and medium-sized enterprises. *Official Journal of The European Union*, 36–41.

Masood, T., & Sonntag, P. (2020). Industry 4.0: Adoption challenges and benefits for SMEs. *Computers in Industry*, *121*, 103261. https://doi.org/10.1016/j.compind.2020.103261

Matt, D. T., & Rauch, E. (2020). SME 4.0: The Role of Small- and Medium-Sized Enterprises in the Digital Transformation. In *Industry 4.0 for SMEs* (pp. 3–36). Springer International Publishing. https://doi.org/10.1007/978-3-030-25425-4_1

Matt, D. T., Rauch, E., & Zsifkovits, H. (2020). SME 4.0: The Role of Small- and Medium-Sized Enterprises in the Digital Transformation. In *Industry 4.0 for SMEs* (pp. 3–36). Springer International Publishing. https://doi.org/10.1007/978-3-030-25425-4_1

Mittal, S., Khan, M. A., Romero, D., & Wuest, T. (2018). A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs). *Journal of Manufacturing Systems*, *49*(November), 194–214. https://doi.org/10.1016/j.jmsy.2018.10.005

Moeuf, A., Lamouri, S., Pellerin, R., Tamayo-Giraldo, S., Tobon-Valencia, E., & Eburdy, R. (2020). Identification of critical success factors, risks and opportunities of Industry 4.0 in SMEs. *International Journal of Production Research*, *58*(5), 1384–1400. https://doi.org/10.1080/00207543.2019.1636323

Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S., & Barbaray, R. (2018a). The industrial management of SMEs in the era of Industry 4.0. *International Journal of Production Research*, *56*(3), 1118–1136. https://doi.org/10.1080/00207543.2017.1372647

Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S., & Barbaray, R. (2018b). The industrial management of SMEs in the era of Industry 4.0. *International Journal of Production Research*, *56*(3), 1118–1136. https://doi.org/10.1080/00207543.2017.1372647

Nowotarski, P., & Paslawski, J. (2017). Industry 4.0 Concept Introduction into Construction SMEs. *IOP Conference Series: Materials Science and Engineering*, *245*(5), 052043. https://doi.org/10.1088/1757-899X/245/5/052043

Oliff, H., & Liu, Y. (2017). Towards Industry 4.0 Utilizing Data-Mining Techniques: A Case Study on Quality Improvement. *The 50th CIRP Conference on Manufacturing Systems Towards*, *63*(7), 167–172. https://doi.org/10.1016/j.procir.2017.03.311

P. Senna, P., Barros, A. C., Bonnin Roca, J., & Azevedo, A. (2023). Development of a digital maturity model for Industry 4.0 based on the technology-organization-environment framework. *Computers and Industrial Engineering*, *185*. https://doi.org/10.1016/j.cie.2023.109645

Pacchini, A. P. T., Lucato, W. C., Facchini, F., & Mummolo, G. (2019). The degree of readiness for the implementation of Industry 4.0. *Computers in Industry*, *113*. https://doi.org/10.1016/j.compind.2019.103125

Putnik, G. D., Manupati, V. K., Pabba, S. K., Varela, L., & Ferreira, F. (2021). Semi-Double-loop machine learning based CPS approach for predictive maintenance in manufacturing system based on machine status indications. *CIRP Annals*, *70*(1), 365–368. https://doi.org/10.1016/j.cirp.2021.04.046

Quatrini, E., Costantino, F., di Gravio, G., & Patriarca, R. (2020). Condition-based maintenance-An extensive literature review. In *Machines* (Vol. 8, Issue 2). MDPI AG. https://doi.org/10.3390/MACHINES8020031

Rassool, R., & Dissanayake, R. (2019). DIGITAL TRANSFORMATION FOR SMALL & MEDIUM ENTERPRISES (SMES): WITH SPECIAL FOCUS ON SRI LANKAN CONTEXT AS AN EMERGING ECONOMY. *International Journal of Business and Management*, *Vol.7*(No. 4), pp.55-76.

Rastogi, V., Srivastava, S., Mishra, M., & Thukral, R. (2020). Predictive Maintenance for SME in Industry 4.0. *2020 Global Smart Industry Conference (GloSIC)*, 382–390. https://doi.org/10.1109/GloSIC50886.2020.9267844

Ribeiro, J., Fontes, T., Soares, C., & Borges, J. L. (2020). Process discovery on geolocation data. *Transportation Research Procedia*, *47*, 139–146. https://doi.org/10.1016/j.trpro.2020.03.086

Saunders, M., Lewis, P., & Thornhill, A. (2016). *Research Methods For Business Students* (Seventh Ed). Pearsons Education Limited.

Schlegel, D., & Kraus, P. (2023). Skills and competencies for digital transformation – a critical analysis in the context of robotic process automation. *International Journal of Organizational Analysis*, *31*(3), 804–822. https://doi.org/10.1108/IJOA-04-2021-2707

Sevinç, A., Gür, Ş., & Eren, T. (2018). Analysis of the Difficulties of SMEs in Industry 4.0 Applications by Analytical Hierarchy Process and Analytical Network Process. *Processes*, *6*(12), 264. https://doi.org/10.3390/pr6120264

Skare, M., de las Mercedes de Obesso, M., & Ribeiro-Navarrete, S. (2023). Digital transformation and European small and medium enterprises (SMEs): A comparative study using digital economy and society index data. *International Journal of Information Management*, *68*. https://doi.org/10.1016/j.ijinfomgt.2022.102594

Sommer, L. (2015). Industrial revolution - industry 4.0: Are German manufacturing SMEs the first victims of this revolution? *Journal of Industrial Engineering and Management*, *8*(5), 1512–1532. https://doi.org/10.3926/jiem.1470

Stentoft, J., Adsbøll Wickstrøm, K., Philipsen, K., & Haug, A. (2021). Drivers and barriers for Industry 4.0 readiness and practice: empirical evidence from small and medium-sized manufacturers. *Production Planning and Control*, *32*(10), 811–828. https://doi.org/10.1080/09537287.2020.1768318

Sundberg, L., Gidlund, K. L., & Olsson, L. (2019). Towards Industry 4.0? Digital Maturity of the Manufacturing Industry in a Swedish Region. *2019 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 731–735. https://doi.org/10.1109/IEEM44572.2019.8978681

Ulas, D. (2019). Digital Transformation Process and SMEs. *Procedia Computer Science*, *158*, 662–671. https://doi.org/10.1016/j.procs.2019.09.101

van der Aalst, W. M. P., Reijers, H. A., Weijters, A. J. M. M., van Dongen, B. F., Alves de Medeiros, A. K., Song, M., & Verbeek, H. M. W. (2007). Business process mining: An industrial application. *Information Systems*, *32*(5), 713–732. https://doi.org/10.1016/j.is.2006.05.003

Vial, G. (2019). Understanding digital transformation: A review and a research agenda. *Journal of Strategic Information Systems*, *28*(2), 118–144. https://doi.org/10.1016/j.jsis.2019.01.003

Welte, R., Estler, M., & Lucke, D. (2020). A method for implementation of machine learning solutions for predictive maintenance in small and medium sized enterprises. *Procedia CIRP*, *93*, 909–914. https://doi.org/10.1016/j.procir.2020.04.052

Williams, C. A., Schallmo, D., & Scorcavacca, E. (2022). How Applicable Are Digital Maturity Models to SMEs?: A Conceptual Framework and Empirical Validation Approach. *International Journal of Innovation Management*, *26*(03). https://doi.org/10.1142/S1363919622400102

Williams, C., & Lang, K. (2019). Digital Maturity Models for Small and Medium-sized Enterprises : A Systematic Literature Review Daniel Schallmo Luke Boardman. *ISPIM Innovation Conference –, June*.

Xu, M., David, J. M., & Kim, S. H. (2018). The Fourth Industrial Revolution: Opportunities and Challenges. *International Journal of Financial Research*, *9*(2), 90. https://doi.org/10.5430/ijfr.v9n2p90

Zonta, T., da Costa, C. A., da Rosa Righi, R., de Lima, M. J., da Trindade, E. S., & Li, G. P. (2020). Predictive maintenance in the Industry 4.0: A systematic literature review. *Computers and Industrial Engineering*, *150*(October), 106889. https://doi.org/10.1016/j.cie.2020.106889

Chapter 6. Appendix

6.1. Appendix 1: Essentials for Digitalizing Maintenance Activities in SMEs

The following paper is a part of the supporting work for this thesis.

The paper was presented at the 5th International Conference on Industry 4.0 and Smart Manufacturing in Lisbon, Portugal in November 2023. It is currently in press and will be published in Spring 2024 in Procedia Computer Science by Elsevier.

The content of this appendix is directly copied from this paper.

Abstract: Numerous research has for long studied the challenges and opportunities within digitalization of Small and Medium-sized Enterprises (SMEs). While SMEs are financially limited compared to larger organization, previous research has succeeded in identifying potential focus areas that allow SMEs to participate in the industrial progression. Among these, pragmatic research on exploitation of existing resources have been highlighted. Therefore, this paper intends to report the findings of a single case study in a Danish SME, where the objective is to understand how technological sub-factors influence the prototyping of digital initiatives for advancing maintenance activities. The study begins with mapping the maintenance activities, along with the IT infrastructure. From here, relevant data is analyzed to understand their shortcomings, where the most dominant relates to how technicians report service orders. The paper concludes by identifying two sets of three technological sub-factors that strongly influence the digitalization of the case company's maintenance activities.

Keywords: Digitalization, SME, Industry 4.0, Condition Based Maintenance

6.1.1. Introduction

With digitalization being tremendously popular within business and technology research, the "how to digitalize" is a common question among especially small and medium-sized enterprises (SMEs). Where larger corporations often have extensive resources to explore new technologies, SMEs typically operate on much stricter budgets. This makes it difficult to engage in digital initiatives and develop their businesses, both operationally and digitally. Not only is this unideal for the SMEs, but it also hinders the collective progress towards Industry 4.0 across European SMEs (Sommer, 2015). This is inherently problematic as SMEs are the backbone of the European economy, why it is vital that they main competitive - where industrial progression is a major factor (Andulkar et al., 2018b; Matt & Rauch, 2020). This has risen concerns, questions and research propositions across both industry and academia (Amaral & Peças, 2021; Grooss et al., 2022c; Sommer, 2015). Through the last decade, research on Industry 4.0 and digitalization has been multi-facet, focusing on the topic from different angles. Where some papers explore the topic from social science perspectives, such as human capital and sustainability (Jayashree et al., 2021), others focus on the development of specific technologies (Welte et al., 2020). However, common for the research on Industry 4.0, is the interrelation between technological development, human and organizational factors, and their surrounding environments. This is clear from the numerous digital maturity models that can be found in the literature. These are usually based on a linear scale, that embodies different domains, covering technology, organization, and environment, which is used to assess companies' digital maturity (C. A. Williams et al., 2022). In terms of progressing SMEs in digitalization, this often leaves the question of where to begin, as the many directions can seem overwhelming to SMEs (Sommer, 2015). While the voluminous nature of Industry 4.0 implies complexity and cohesion among the sub-topics, some authors propose focus areas specific to SMEs. This can be found in (Amaral & Peças, 2021). The authors conduct two case studies on digitalization in SMEs, where the focus is to overcome some of the known barriers to Industry 4.0. This is achieved through low-cost prototypes and solutions, that aims to digitalize analogue processes. To measure progress, they deploy the framework of (Anderl & Fleischer, 2015), which is highly technology focused. Lastly, the authors suggests that practical case studies are vital for closing the gap between academia and industry. The specific attention to technological factors can likewise be found in (Sundberg et al., 2019). Here, the authors assess digital maturity across Swedish manufacturing companies. Despite that the results conclude that several smaller organizations have very little digital presence, organizational capabilities were generally graded higher than technological factors. The authors infer that the companies can "talk the talk" but cannot "walk the walk" towards Industry 4.0 (Sundberg et al., 2019). Similar is concluded in (Grooss et al., 2022c), who also suggest that academia adopts practical, technology-based research methods, to provide actionable insights to SMEs and to document how they can digitalize. Therefore, this paper will have a pragmatic take on digitalization, which will be studied through a case study on maintenance activities in a Danish SME. The remaining section are structured as follows: Section 2 describes related work. Section 3 describes the methodology for this paper. Section 4 presents the results. Section 5 discuss the results and Section 6 concludes the paper.

6.1.2. Related work

Different maintenance strategies and terminology have been manifested by (CEN, 2017), which has allowed for a unified language for the understanding of maintenance activities and for the development of maintenance processes has been studied vastly through the years. The attention is credited to maintenance being a sensitive business area for companies, as equipment availability, product quality, and costs, greatly impact profit (Zonta et al., 2020). This can also be observed in (Quatrini et al., 2020), who find that an optimal condition-based maintenance strategy can generate significant benefits in terms of competitiveness, increasing system availability, reducing of maintenance costs, increasing product quality and benefit safety management. In relation to digitalization, (Høj Brasen et al., 2021) introduces a conceptual framework that proposes a relationship between data maturity and maintenance strategies. The paper suggests that companies can advance to more advanced maintenance strategies by improving their data maturity, which has later been further explored in two case studies. The collective attention to maintenance and asset management has led to much research where different approaches are taken to utilize technologies to advance maintenance activities. This has especially been accelerated by the rapid development within Industry 4.0, which has introduced advanced technologies that collectively increases digitalization across companies. Especially noticeable is the advancement of Predictive Maintenance (PdM) where Internet of Things (IoT) technologies, data science and Machine Learning (ML) are combined to develop algorithms that can predict future breakdowns or component malfunctions (Quatrini et al., 2020; Rastogi et al., 2020). While these technologies are highly sophisticated, they have started to become more democratized, which has allowed SMEs to participate. Examples of this can be seen in (Rastogi et al., 2020; Welte et al., 2020). (Rastogi et al., 2020) presents recent trends of PdM in SMEs. The authors analyse more than 55 papers and observes a series of patterns that they consider as crucial parameters in PdM for the Industry 4.0 domain space. These include remaining useful life (RUL), downtime and cost reduction, performance, and scheduling optimization. The authors also specify that RUL and anomaly detection are given most attention, as they lead to other benefits, and that Machine Learning and Deep Learning are among the most prevalent technologies. However, data is key to succeeding with this, which can also be observed in (Welte et al., 2020). The authors present a method for implementing ML projects in SMEs. Their model proposes a step for checking data availability which includes defining the optimal data set, checking for available data, resolution and reliability and lastly comparing this to the first to derive its importance. Here, the takeaway is to assess if the data is suitable in terms of consistency, frequency and resolution. This is up to domain experts to evaluate. The data would most typically consist of process data, such as vibrations, temperature and/or acoustic signals. Lastly, the authors also conclude that maintenance history is important.

While these papers represent research within cutting edge technologies, it is important to still account for the problematic nature of SMEs in regard to Industry 4.0 context. SMEs remains profit-oriented and risk-averse, which still poses challenges to the introduction and implementation of advanced technologies. Previous case studies have attempted to facilitate this. (Grooss et al., 2022b) suggest that companies balance their effort in advancing their digital maturity with the operational benefits. In this case study, existing Enterprise Resource Planning (ERP) data was utilised to improve maintenance activities of injection moulds from time-based to cycle based. This was possible by approximating the RUL cycles between services. A similar case was conducted in (Grooss, 2023). Here, existing system data and service reports was attempted to be used for predicting remaining useful lifecycles of container cranes. The paper found that while the system data was rich and informative, the service reports, containing information about breakdowns and repairs, was extremely deficient and of low quality. This disallowed the use of this data for predicting future breakdowns.

Instead, some data could be used to alert technicians about warnings from the systems, which improved some maintenance activities from reactive to preventive. This case study could indicate that there is some relevance to look into approaches that focus less on developing new technologies for SMEs and more on utilizing existing resources. This is also a convenient segue to introduce *process mining*. Process mining is defined as the automatic construction of models that can explain patterns and behaviour in event logs (van der Aalst et al., 2007). ERP systems, and other high-level IT system, typically log all business transactions and actions taken by the system users. This mean that there will often be a vast amount of data available in these systems, which can be used for secondary purposes. In process mining, this data is exploited to derive interaction between processes, process steps and people in the processes. By using mapping software, it is possible to extract how administrative processes work and who interacts with who (van der Aalst et al., 2007).

As much research has been done within process mining, a lot of issues have also been uncovered, especially regarding noise in the data (Goedertier et al., 2011; van der Aalst et al., 2007). For example, (van der Aalst et al., 2007) work from the assumptions that each event in the system refers to a real-world activity, that each event refers to a specific case, and that each event has one or more performers - humans interacting with the former. Lastly, they assume that each event has a timestamp that positions them in a time space. This also means that only data that has been correctly logged will benefit the process mining. Events that have not been logged can therefore not be included, and this may create some distortion in the results. IT systems may also force certain interaction patterns, which may cause the process model to reflect system architecture rather than organizational behavior (van der Aalst et al., 2007).

Yet, process mining has demonstrated results through time. For instance, (Karray et al., 2014) develop a knowledge-oriented maintenance platform which is based on semantics. The system aims to extract knowledge from the use of systems and how the user interacts with these, as may represent experience from maintenance operators - specific to each maintained system. This knowledge is discovered through repetitive interactions with processes, which allows companies to uncover patterns by experienced operators and formalise and share experience with the rest of the organization. Similarly, (Ribeiro et al., 2020) propose a methodology for extracting process states from geolocation data. Through this data they manage to gain insights about process behaviours in different contexts. The authors highlights that this is most useful when the processes are highly structured, meaning that one can predict that the process is executed the same way every time. Lastly, (Du et al., 2021) present a case study on applying process mining for wind turbine maintenance based on event logs. The authors conduct process mining across three different processes, uncovered process insights, that allowed for improving efficiency in some maintenance processes.

6.1.3. Methodology

Previous work suggests that research on digitalization of SMEs should take a pragmatic and technology focused, as the development of basic enablers are important for closing the gap between research and academia. Likewise, SMEs should focus on exploiting existing resources. Specifically, previous work (Grooss, 2023; Grooss et al., 2022c) have identified three technology dimensions, which are found to be important for the digitalization of maintenance activities in SMEs. These are: System Integration and Information Flow, Digital Data Collection and Analysis, and Low-Cost Proof-of-Concepts. To make these more specific, this paper will attempt to specify these more through the following research question:

Which technological sub-factors influence the prototyping of digital initiatives for advancing maintenance activities in SMEs?

This research takes a pragmatic and participatory approach, which will be conducted through a single, exploratory case study with a Danish SME, much like as in (Amaral & Peças, 2021). The case study will begin by mapping maintenance activities according to the framework presented by (Høj Brasen et al., 2021). Next, it will be derived what data and information is required for advancing the maintenance activities. Next, the IT infrastructure and information flow relevant to the maintenance activities will be mapped. Lastly, relevant maintenance data will be reviewed. The data collection will be completed using a mix-method design and will rely on interviews with observations and semi-structured interviews with relevant stakeholders, combined with qualitative and quantitative data extractions from relevant IT systems. The case company will be referred to as CASE. CASE manufactures, installs, and services perimeter fencing (PF) systems, consisting of fencing and manual or automatic sliding gates. Typical customers span from kinder gardens to air force bases.

6.1.4. Results

The following section will account for the results of the case study.

6.1.4.1. Maintenance activities

Mapping the service and maintenance activities, using the conceptual framework by (Høj Brasen et al., 2021), reveals that CASE primarily operates within Corrective and Time-based maintenance strategies. Service and maintenance can be done for several reasons. The majority of service and maintenance is based on service contracts, where the customer commits to a yearly subscription for CASE to regularly visit the PF systems to conduct service and maintenance. These subscriptions exist in different variety, based on the customer needs. Some customers consider perimeter safety as high risk and therefore requires rapid or instant response time from CASE technicians, where others can wait until the next day or longer. An overview of the service contracts can be found in Table 6.1. Services are not planned based on technician experience, yet technicians may conduct extra maintenance, based on subjective, experience-based decisions. Some customers do not have any service contract with CASE, which means that CASE only visits the PF systems when directly requested from a customer. Generally, unplanned breakdowns occur for two reasons. Either as a result of wear and tear, causing one or more components to fail, or due to external forces. Every once in a while, a PF system may be subject to vandalism or accidents, where truck drivers or forklift operators accidentally collide with the PF system. Regardless, when these occur, the customer contacts CASE, who must then include sudden breakdowns into the service planning.

Table 6.1: Overview of service contract levels

Level	Content
0	No service contract. Service/Maintenance only per customer request, No phone support
1	Yearly (or other interval) service and repair, Repair within office hours, Warranty according to legislation, Condition report after service, Fixed hourly rates
2	Phone support within business hours, Technician on site within 8 hours of breakdown within business hours, Warranty according to legislation, Condition report after service, Fixed hourly rates,
3	Phone support within business hours, Technician on site within 4 hours of breakdown within business hours, Warranty according to legislation, Condition report after service, Fixed hourly rates,
4	Phone support within business hours, Technician on site within 4 hours of breakdown (24/7/365), Warranty according to legislation, Condition report after service, Fixed hourly rates

Based on the maintenance activities and (CEN, 2017) and (Høj Brasen et al., 2021), some data is needed for advancing the maintenance activities for a PF system. First, it is vital to determine when the PF system was deployed to operational state, as this is the point in time from where the cycle wear initiates. Second, to accurately calculate the mean time to failure (MTF) for components in the system, information about their individual lifetime is vital. Lastly, in order to ensure correct calculations, it must be possible to distinguish between components being replaced as a result of wear and tear and as a result of external forces.

6.1.4.2. System Integration and Information Flow

IT Infrastructure

The IT systems at CASE can be divided into categories of supported and unsupported by the organization (Figure 6.1). The supported IT portfolio is centered around a 2017 version of Microsoft Dynamics Business Central (MDBD) Enterprise Resource Planning (ERP) system. MDBD is used by most business units across CASE and holds most business-critical data. The system stores data in an on-premises SQL-database hosted by an external IT partner, residing in the same building as CASE. Fully integrated to the ERP system is a Field Service Management (FSM) system, which technicians use to interact with work orders and to record resource usage (work hours and components).

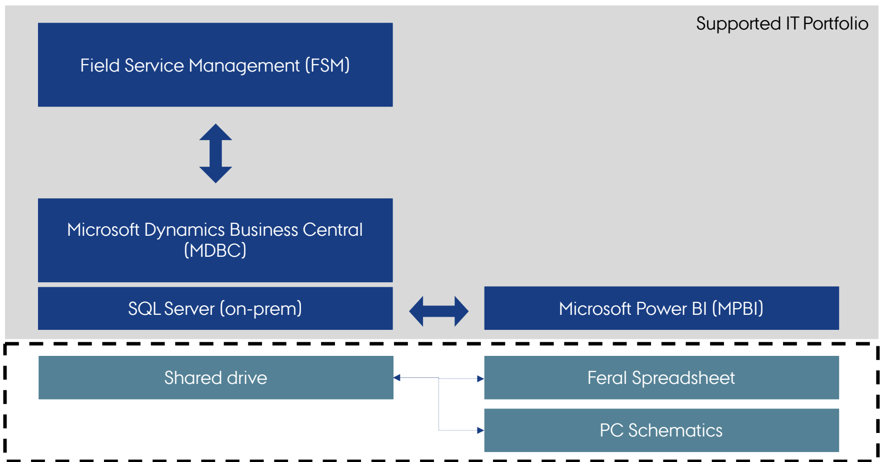

Figure 6.1: Overview of IT Infrastructure related to maintenance activities.

The FSM system is custom developed by an external IT partner. The system uses the database of MDBD and has no own database to store data in. Besides these, CASE uses

Microsoft Power BI for business intelligence and reporting purposes. Outside the supported IT portfolio is a feral spreadsheet, which is used by the technical department. This has been developed and meticulously maintained by two employees for approximately 30 years. The spreadsheet is used to register new serial numbers whenever a PF system is sold. The serial numbers are generated manually sequentially to the last and denoted in the spreadsheet along with a short description of the PF system along with some other order information. Most of these are redundant as they already exist in the ERP system. The last system is used to create electrical schematics called "PC Schematics". Per Danish legislation, CASE must provide electrical schematics for each variation of the PF systems. CASE manages this by creating a unique scheme for each sold PF system, so they can be updated if changes are made to the PF system later in time.

Flow of information

Whenever a PF system is sold from a sales order, a service item is created in the ERP system. This creates a digital "journal" with historical data for the service item. This is used for managing invoicing, service planning, work orders and resource consumption. By reviewing the processes of creating and managing service items, it becomes clear that there no information on service items that reliably determines the configuration of the PF system that is sold. The only indication of this, is free-text information, written as short description in note forms. The actual configuration can be found on the original sales order, where each sold PF system has their own Bill-of-Materials (BOM), which has a unique identification number. However, neither the original sales order ID nor the configuration ID are transferred to the service item, which makes it difficult to back-trace through the ERP system.

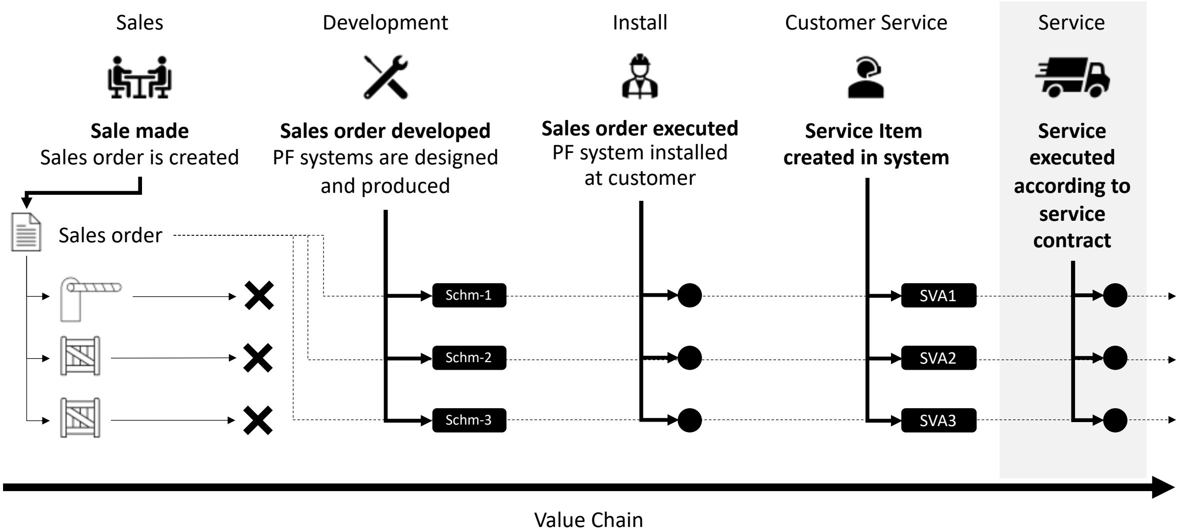

Figure 6.2: Overview of value chain related to maintenance activities.

PC Schematics have a component database, which contains information about each electrical component, such as size and connections points. As the database is a single file stored on a shared folder, it does not have any integration to the items table in the ERP system. That means that each component is created in both systems, often given different IDs and descriptions, which makes it difficult to link them across the two systems. This has been visualized in Figure 6.2.

6.1.4.3. (Digital) Data Collection and Analysis

Input quality

There are some issues related to the entry of data on service reports. The service order consists of some master data from the ERP system such as date, customer information and PF systems to service. After completing the work, the technician must populate the service order with time and components used. This is important for inventory and invoicing purposes. Specifically, the technicians can assign resources (time and components) to the service order, without specifying which PF system each has been used on. As the technicians finds it easier and faster to just assign all resources to the service order, instead of specifying it to the individual PF systems, valuable information is lost. Despite having large amounts of data on services and historical events. Technicians indicated that this occurs because they do not allocate time to specify this, and that they may not be aware of the importance of data discipline.

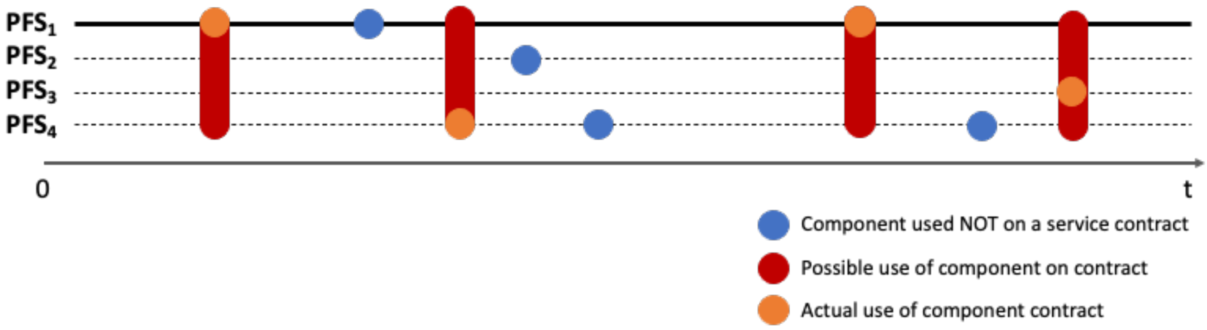

Figure 6.3: Visual representation of input quality problem.

Furthermore, this challenges the validity of potential RUL calculations, as component replacements are not correctly positioned in time. Given an example of a service order with four service items for a technician to service. All replaced components used on the entire order may be assigned to the first service item in the list (PFS_1), and not to the service items where they belong. As a result, some PF system records will have to many component replacements in their history, while others will have too little. This creates a distorted image of the MTF and RUL calculations for the components, as the time in between each component replacement will be wrong. This will also cause more sophisticated prediction models to fail, as the historical data simply does not correctly reflect the reality. Furthermore, this polluted data is also used for service budgeting, indicating that these may suffer from low validity as well. A visualization of the problem can be seen in Figure 6.3.

Installation dates

There also appears to be some data pollution regarding installation dates of the PF systems. Each service item has a field to hold the date of installation. This date should represent the 'birth' of the PF system at the customer and also represents the day from which the warranty begins. However, by exploring the population of the installation dates, it is clear that there are some discrepancies in the data. First of all, the earliest installation date is in September 1992, but no new system is registered until June 1997. This sporadic pattern can be observed all the way to August 2007, where in 5 months, suddenly more than 500 PF systems are installed. Furthermore, there are 484 PF systems without an installation date, making up for approximately 17%. Lastly, in the last quarter of 2022, only 1 PF system was installed. Without further investigating the validity of the remaining dates, it seems confident to declare that this does not reflect the reality, but merely is a case of unreliable data. Upon further investigation it became clear, some of this data is mainly polluted from system settings and administrative processes. Firstly, the ERP system logs all data changes to a PF system log. This includes when a PF system is moved in between statuses, yet for unknown reasons, it does not log when a PF system is moved into the "Installed" status. This could have been a way to mend the polluted installation dates if this was logged. However, it wouldn't help much as the service department sets the status to "Installed" when they create the service items - regardless of if they are installed or not. This is the result of lack of a process for revisiting the service item once it is installed, as they would not otherwise be moved to "Installed" after installation.

Service types

It is essential to be able to distinguish between types of service orders to correctly identify if a service order is related to a planned service, an internal malfunction, or an external damage. Planned service orders are relatively simple to identify, as these service orders are associated with a service contract IDs. Service orders with a populated service contract field can therefore be classified as "Planned service", and as "Unplanned service" if the field is empty. The challenges arise when attempting to subcategories "Unplanned services" as either "Internal malfunction" or "External damage". There is no immediate information on a service order that holds this information, other than the description field, which is free text. This makes it difficult to segment the service order further. To address this, CASE has taken upon themselves to start using a specific cost code on the service order invoices, which is only used for external damage incidents, such as accidents, vandalism and/or insurance claims. The cost code represents a post-accident safety check of the PF system, to ensure that it continues to live up to Danish regulations. This makes it possible to isolate these service orders. While this is a promising solution, it is important to note that it is relatively new and does not contribute to the segmentation of historical data. Furthermore, it is important to note that this solution is only as reliable as the administrative process, which is subject to human error.

6.1.5. Discussion

It was found that the integration between the IT systems, made it easy to track data in real-time between systems. As most IT systems was centered around the ERP platform, it became the main data resource. This meant that data from different business units, working in different platforms, all worked through the same system, centralizing most of the data. This made it very easy to locate and extract data for analysis and prototyping, as most could be found one place. By default, instantly getting read rights to one main SQL database, provided fast prototyping to the process. Furthermore, having the option to manually extract data through the UI of the systems, made it possible to instantly analyze data through spreadsheets or local scripts. This made it possible to develop cleaning and manipulation scripts that could function as proof-of-concepts and be easily scaled for future use. In other systems, this was more complicated than in others. For example, extracting from the ERP tables could be done through the UI using in-built functions, where other systems only allowed for this on entry-based levels. In those cases, the data preprocessing seemed significantly more complex and time consuming. Similar was observed in (Grooss, 2023), where all prototyping was done using csv-exports, which was easily extracted from SQLs. Similar could be observed in (Grooss et al., 2022b), where production planning data and service reports was utilized to estimate RUL on injection molds. Here, the data was also centralized in the case company's ERP system, which made it easy to acquire through a single access point. Instances where integrations between data sources were lacking, also advocates for their importance. In the example of CASE, this was manifested by the lack of integration between the ERP platform and PC Schematics.

However, this did not seem to influence the quality and relevance of the data, as both high- and low-quality data could be found in both supported and unsupported systems. For example, the feral spreadsheet proved to contain valuable data, linking critical information across core business processes. While CASE's effort to maintain this feral information system has proven extremely valuable, it is also associated with certain risks in regard to the employees' job statuses, health and/or habits. Another example of this can be found in (Grooss, 2023), where a spreadsheet was used to denote breakdown on container cranes. The spreadsheet contained some macros that would manipulate the data to calculate OEE, which would also be used as basis for invoicing. Unknown reasons resulted in these macros to malfunction, which meant that OEE and invoicing processes was significantly obstructed, preventing critical invoicing. The feral nature of the spreadsheet made it difficult to repair, as the original creator of the code provided no documentation or support options. Furthermore, advancing the maintenance activities was highly dependent on historical data, as this is a basic requirement for conducting any type of forecasting. While the historical data of CASE is vast, there are also some challenges in regard to data validity.

The pollution of the service records, caused by the poor data discipline of technicians, corrupts future similar initiatives. While data can be cleaned or preprocessed, backtracking registration errors and correcting them, requires some method of validation. In this instance, this would mean that technicians would have to remember what was exchanges and when, which in itself is an impossible task. Again, similar can be observed in the case from (Grooss, 2023), where the lack of any detailed service records made it impossible to know how and what had been repaired. While there were work orders for all the work completed, these carried basically no information about the work, and was only used for time keeping and invoicing purposes, thereby wasting potential for use in maintenance planning. This cements the notion of not only extensively recording historical data, but also ensuring that the records accurately represent real-life events. This has also been seen in the domain of process mining, where barriers have already been found to include incomplete logs, noise, and history-dependent behavior (Goedertier et al., 2011). So, while rigorous data discipline is a known challenge within data driven technologies, such as predictive maintenance, this discussion infers that data discipline within maintenance activities has to extend from collecting process data and into supporting business processes. From a business process perspective, this suggests that processes should be designed to support the maintenance activities directly, but also indirectly ensure high quality data feedback, that can be used for future digital initiatives.

Outside the experiments, the staff indicated that some business processes would be easier with more historical data. For example, due to the missing installation dates, both technicians and administrative staff have a hard time identifying the age of the system, which can otherwise be used to assess the condition of different components relative to time. However, it was also found that the ERP system would log the different states of production orders yet would not record when a PF system was moved from "Planned" to "Installed". This made it difficult to estimate when the PF systems were installed. For example, the feral spreadsheet was extremely rich on useful information, containing attributes that allowed for mostly mending a vital missing link in the ERP data. The data from this spreadsheet was unknown to most in the organization. Some knew about the existing of the feral spreadsheet, but not what data could be found there, while some others never knew it existed. Vice versa, there was also redundant information, manually duplicated from other systems. While this didn't directly support the prototyping processes, it may have supported other business processes. The assessment of the information richness is interesting in its own, as this is highly context specific, and can be difficult to assess for future projects.

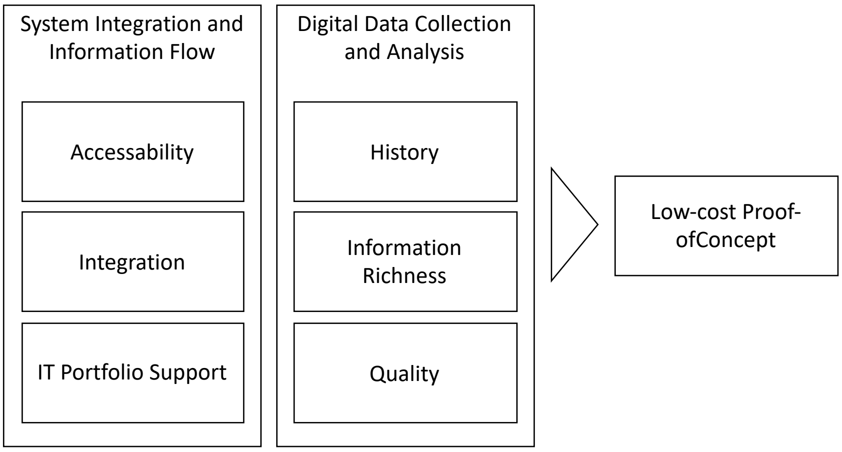

Figure 6.4: Conceptual framework describing technological sub-factors.

Based on the recommendations by (Grooss et al., 2022c), the related work, and the results of the case study, the following model has been composed. The model (Figure 6.4) intends to conceptualize how different technological sub-factors influence the prototyping process. Where the previous work by (Grooss et al., 2022c), presented the three technological factors as interrelated, yet separate, recommendations, this model propose that SI&IF and DDCA feeds into LC PoC. This formalization is derived from the observations that SI&IF and DDCA highly represent resources, where LC PoC represents processes, which are dependent on these resources. Based on the results of the case study and the discussion, three sub-factors have been identified for each of the two main factors, which should generally seek to be increased. For SI&IF, these are "IT Portfolio Support", "Integration" and "Accessibility". IT Portfolio Support represents the importance of systems being supported by the formal organizational IT portfolio, which deems important, as this ensures continuous operations and development of the systems to support future organizational functions. By this, it should also be understood that feral information systems should be avoided as much as possible. Integration represents the importance of system inter-operability. In this case study it was found that systems with well-integrated dataflows made it easy to combine this data. Lastly, Accessibility represents the importance of system data being accessible for processing. For DDCA the identified sub-factors are "History", "Information Richness" and "Quality". History represents the importance of continuously collecting data. In this and previous case studies, it was found that the lack of historical data, such as date of deployment, would pollute any life cycle calculations. Information Richness represents the importance of relevance to the data and that information can be extracted from this. In the case studies it was found that having a lot of data is not enough, but also that the data is relevant to the specific use-case. In this and previous case studies there are examples of massive amounts of data, but that this did not turn out to be useful to the digitalization of the maintenance activities.

Therefore, it is important to consider what data is relevant to which parts of the maintenance activities. Lastly, Quality represents the importance of data accurately representing real-life events. In the case study it was found that a main challenge was the simple in-accurate datapoints. Quality covers not only that the datapoints are measured accurately, but also recorded accurately. While other resources, such as human resources also feed into the prototyping process, and these are important, this model only considers technology factors for a start.

6.1.6. Conclusion and future work

The paper sought out to conceptualize a holistic framework for digitalizing maintenance activities in SMEs. The work commenced from previous work, where three technological factors was identified: System Integration and Information Flow, Digital Data Collection and Analysis and Low-Cost Proof-of-Concepts. These were used as the focal point for a case study with a Danish SME, that aimed to further specify the factors.

The case study started out with mapping the maintenance activities according to the model by (Høj Brasen et al., 2021). Sequentially, it was identified what data was required to increase the digital maturity of the maintenance activities. From here, the case company's IT infrastructure and data were analyzed to uncover how these would influence the digitalization of the maintenance activities. Here, it was uncovered that there are some inherent issues in how technicians would register service reports. To strengthen the empirical foundation of the conceptual framework, future research should replicate similar studies across multiple case studies. Additionally, it is crucial not to overlook organizational factors, which are not addressed by the current framework. Therefore, future research should strive to incorporate organizational and technological factors into a coherent framework that facilitates their interrelatedness.

6.1.7. References

Sommer L. Industrial revolution - industry 4.0: Are German manufacturing SMEs the first victims of this revolution? Journal of Industrial Engineering and Management [Internet]. 2015 Nov 28;8(5):1512–32. Available from: http://www.jiem.org/index.php/jiem/article/view/1470

Matt DT, Rauch E, Zsifkovits H. SME 4.0: The Role of Small- and Medium-Sized Enterprises in the Digital Transformation. In: Industry 40 for SMEs [Internet]. Cham: Springer International Publishing; 2020. p. 3–36. Available from: https://doi.org/10.1007/978-3-030-25425-4_1

Andulkar M, Le DT, Berger U. A multi-case study on Industry 4.0 for SME's in Brandenburg, Germany. In: Proceedings of the 51st Hawaii International Conference on System Sciences [Internet]. 2018. p. 4544–53. Available from: http://hdl.handle.net/10125/50463

Grooss OF, Presser M, Tambo T. Surround yourself with your betters: Recommendations for adopting Industry 4.0 technologies in SMEs. Digital Business. 2022;2(2):100046. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2666954422000266

Amaral A, Peças P. SMEs and Industry 4.0: Two case studies of digitalization for a smoother integration. Comput Ind [Internet]. 2021 Feb;125:103333. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0166361520305674

Jayashree S, Reza MNH, Malarvizhi CAN, Mohiuddin M. Industry 4.0 implementation and Triple Bottom Line sustainability: An empirical study on small and medium manufacturing firms. Heliyon [Internet]. 2021;7(8):e07753. Available from: https://doi.org/10.1016/j.heliyon.2021.e07753

Welte R, Estler M, Lucke D. A method for implementation of machine learning solutions for predictive maintenance in small and medium sized enterprises. Procedia CIRP [Internet]. 2020;93:909–14. Available from: https://doi.org/10.1016/j.procir.2020.04.052

Williams CA, Schallmo D, Scorcavacca E. How Applicable Are Digital Maturity Models to SMEs?: A Conceptual Framework and Empirical Validation Approach. International Journal of Innovation Management [Internet]. 2022 Apr 30;26(03). Available from: https://www.worldscientific.com/doi/10.1142/S1363919622400102

Anderl R, Fleischer J. Guideline Industrie 4.0. VDMA Verlag [Internet]. 2015;32. Available from: industrie40.vdma.org

Sundberg L, Gidlund KL, Olsson L. Towards Industry 4.0? Digital Maturity of the Manufacturing Industry in a Swedish Region. In: 2019 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM) [Internet]. IEEE; 2019. p. 731–5. Available from: https://ieeexplore.ieee.org/document/8978681/

CEN. CEN EN 13306-2017 - Maintenance terminology [Internet]. 2017. Available from: www.ds.dk

Zonta T, da Costa CA, da Rosa Righi R, de Lima MJ, da Trindade ES, Li GP. Predictive maintenance in the Industry 4.0: A systematic literature review. Comput Ind Eng [Internet]. 2020;150(October):106889. Available from: https://doi.org/10.1016/j.cie.2020.106889

Quatrini E, Costantino F, di Gravio G, Patriarca R. Condition-based maintenance-An extensive literature review. Vol. 8, Machines. MDPI AG; 2020.

Høj Brasen LP, Groos OF, Tambo T. Comparison between data maturity and maintenance strategy: A case sutdy. Procedia CIRP [Internet]. 2021;104:1918–23. Available from: https://doi.org/10.1016/j.procir.2021.11.324

Rastogi V, Srivastava S, Mishra M, Thukral R. Predictive Maintenance for SME in Industry 4.0. In: Proceedings - 2020 Global Smart Industry Conference, GloSIC 2020. Institute of Electrical and Electronics Engineers Inc.; 2020. p. 382–90.

Grooss OF, Presser M, Tambo T. Balancing Digital Maturity and Operational Performance - Progressing in a Low-digital SME Manufacturing Setting. Procedia Comput Sci [Internet]. 2022;200:495–504. Available from: https://doi.org/10.1016/j.procs.2022.01.247

Grooss OF. Advancing maintenance strategies through digitalization: A case study. Procedia Comput Sci [Internet]. 2023;217:1522–31. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1877050922024371

van der Aalst WMP, Reijers HA, Weijters AJMM, van Dongen BF, Alves de Medeiros AK, Song M, et al. Business process mining: An industrial application. Inf Syst. 2007 Jul;32(5):713–32.

Goedertier S, de Weerdt J, Martens D, Vanthienen J, Baesens B. Process discovery in event logs: An application in the telecom industry. Appl Soft Comput [Internet]. 2011

Mar;11(2):1697–710. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1568494610001055

Karray MH, Chebel-Morello B, Zerhouni N. PETRA: Process Evolution using a TRAce-based system on a maintenance platform. Knowl Based Syst. 2014;68:21–39.

Ribeiro J, Fontes T, Soares C, Borges JL. Process discovery on geolocation data. In: Transportation Research Procedia. Elsevier B.V.; 2020. p. 139–46.

Du L, Cheng L, Liu C. Process Mining for Wind Turbine Maintenance Process Analysis: A Case Study. In: 5th IEEE Conference on Energy Internet and Energy System Integration: Energy Internet for Carbon Neutrality, EI2 2021. Institute of Electrical and Electronics Engineers Inc.; 2021. p. 3274–8.

Appendix 2: Co-author statement Chapter 2

AARHUS BSS — SCHOOL OF BUSINESS AND SOCIAL SCIENCES, AARHUS UNIVERSITY

Declaration of co-authorship*

Full name of the PhD student: Oliver Fuglsang Grooss

This declaration concerns the following article/manuscript:

Title:	Surround yourself with your betters: Recommendations for adopting Industry 4.0 technologies in SMEs
Authors:	Oliver Fuglsang Grooss, Mirko Presser, Torben Tambo

The article/manuscript is: Published ☒ Accepted ☐ Submitted ☐ In preparation ☐

If published, state full reference: Grooss, O. F., Presser, M., & Tambo, T. (2022). Surround yourself with your betters: Recommendations for adopting Industry 4.0 technologies in SMEs. Digital Business, 2(2), 100046. https://doi.org/10.1016/j.digbus.2022.100046

If accepted or submitted, state journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No ☒ Yes ☐ If yes, give details:

The PhD student has contributed to the elements of this article/manuscript as follows:

A. Has essentially done all the work
B. Major contribution
C. Equal contribution
D. Minor contribution
E. Not relevant

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	A
2. Planning of the experiments/methodology design and development	A
3. Involvement in the experimental work/clinical studies/data collection	A
4. Interpretation of the results	A
5. Writing of the first draft of the manuscript	B
6. Finalization of the manuscript and submission	C

Signatures of the co-authors

Date	Name	Signature
21/12/2023	Mirko Presser	[signature]
21/12/2023	Torben Tambo	[signature]

In case of further co-authors please attach appendix

Date: 21/12/2023

[signature]

*As per policy the co-author statement will be published with the dissertation.

Appendix 3: Co-author statement Chapter 4

SCHOOL OF BUSINESS AND SOCIAL SCIENCES
AARHUS UNIVERSITY

Declaration of co-authorship*

Full name of the PhD student: Oliver Fuglsang Grooss

This declaration concerns the following article/manuscript:

Title:	Digitalization of After-Sales Service Processes in SMEs - Perspectives of Skill Location, Solution Processes and Data Maturity
Authors:	Oliver Fuglsang Grooss, Mirko Presser

The article/manuscript is: Published ☐ Accepted ☒ Submitted ☐ In preparation ☐

If published, state full reference:

If accepted or submitted, state journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No ☒ Yes ☐ If yes, give details:

The PhD student has contributed to the elements of this article/manuscript as follows:

- A. Has essentially done all the work
- B. Major contribution
- C. Equal contribution
- D. Minor contribution
- E. Not relevant

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	A
2. Planning of the experiments/methodology design and development	A
3. Involvement in the experimental work/clinical studies/data collection	A
4. Interpretation of the results	B
5. Writing of the first draft of the manuscript	A
6. Finalization of the manuscript and submission	B

Signatures of the co-authors

Date	Name	Signature
21/12/2023	Mirko Presser	

In case of further co-authors please attach appendix

Date: 21/12/2023

Signature of the PhD student

*As per policy the co-author statement will be published with the dissertation.

Appendix 4: Co-author statements for supporting work

AARHUS BSS | SCHOOL OF BUSINESS AND SOCIAL SCIENCES
AARHUS UNIVERSITY

Declaration of co-authorship*

Full name of the PhD student: Oliver Fuglsang Grooss

This declaration concerns the following article/manuscript:

Title:	Comparison between data maturity and maintenance strategy: A case study
Authors:	Lucas Peter Høj Brasen, Oliver Fuglsang Grooss, Torben Tambo

The article/manuscript is: Published ☒ Accepted ☐ Submitted ☐ In preparation ☐

If published, state full reference: Høj Brasen, L. P., Groos, O. F., & Tambo, T. (2021). Comparison between data maturity and maintenance strategy: A case sutdy. Procedia CIRP, 104, 1918–1923. https://doi.org/10.1016/j.procir.2021.11.324**

If accepted or submitted, state journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No ☐ Yes ☒ If yes, give details: May also be included in the PhD dissertation of Lucas Peter Høj Brasen

The PhD student has contributed to the elements of this article/manuscript as follows:

A. Has essentially done all the work
B. Major contribution
C. Equal contribution
D. Minor contribution
E. Not relevant

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	C
2. Planning of the experiments/methodology design and development	C
3. Involvement in the experimental work/clinical studies/data collection	C
4. Interpretation of the results	C
5. Writing of the first draft of the manuscript	C
6. Finalization of the manuscript and submission	C

Signatures of the co-authors

Date	Name	Signature
21/12/2023	Lucas Peter Høj Brasen	Lucas PH Brasen
21/12/2023	Torben Tambo	Torben Tambo

In case of further co-authors please attach appendix

Date: 21/12/2023

*As per policy the co-author statement will be published with the dissertation.
**The publisher has misspelled the title and the co-author name. It is in progress to have this mended.

AARHUS BSS SCHOOL OF BUSINESS AND SOCIAL SCIENCES
AARHUS UNIVERSITY

Signature of the PhD student

*As per policy the co-author statement will be published with the dissertation.
**The publisher has misspelled the title and the co-author name. It is in progress to have this mended.

AARHUS BSS SCHOOL OF BUSINESS AND SOCIAL SCIENCES
AARHUS UNIVERSITY

Declaration of co-authorship*

Full name of the PhD student: Oliver Fuglsang Grooss

This declaration concerns the following article/manuscript:

Title:	Balancing Digital Maturity and Operational Performance - Progressing in a Low-digital SME Manufacturing Setting
Authors:	Oliver Fuglsang Grooss, Mirko Presser, Torben Tambo

The article/manuscript is: Published ☒ Accepted ☐ Submitted ☐ In preparation ☐

If published, state full reference: Grooss, O. F., Presser, M., & Tambo, T. (2022). Balancing Digital Maturity and Operational Performance - Progressing in a Low-digital SME Manufacturing Setting. Procedia Computer Science, 200, 495–504. https://doi.org/10.1016/j.procs.2022.01.247

If accepted or submitted, state journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No ☒ Yes ☐ If yes, give details:

The PhD student has contributed to the elements of this article/manuscript as follows:

A. Has essentially done all the work
B. Major contribution
C. Equal contribution
D. Minor contribution
E. Not relevant

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	A
2. Planning of the experiments/methodology design and development	A
3. Involvement in the experimental work/clinical studies/data collection	A
4. Interpretation of the results	A
5. Writing of the first draft of the manuscript	A
6. Finalization of the manuscript and submission	C

Signatures of the co-authors

Date	Name	Signature
21/12/2023	Mirko Presser	
21/12/2023	Torben Tambo	

In case of further co-authors please attach appendix

Date: 21/12/2023

*As per policy the co-author statement will be published with the dissertation.