Vaasan yliopisto
UNIVERSITY OF VAASA

Veikka-Aleksi Koskinen

Guiding the Transition: A Roadmap for Smart Manufacturing in the Era of Industry 4.0

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Author: Veikka-Aleksi Koskinen
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ABSTRACT:

Technological advances have transformed and made production more efficient in recent decades, leading to significant improvements in productivity. The current Fourth Industrial Revolution, known as Industry 4.0, aims to enable smart manufacturing in production plants. At the core of Industry 4.0 is the use of advanced technologies such as the Internet of Things, Cloud Computing, Big Data analytics and Autonomous robots. The seamless integration of advanced technologies and systems can significantly improve production efficiency and optimise processes. The impact of the Fourth Industrial Revolution can be seen in globally competitive markets as companies seek to digitise their production to improve efficiency and meet the demands of the competitive environment.

Digitalisation of production requires significant technological expertise, capability, and investment from companies. Such a holistic transformation is challenging due to several factors. A roadmap can be used to clarify the transition phase and future objectives. By providing an overview, the roadmap can help to identify the various gaps and areas to focus on. This will help to ensure that the company's technology investments, communication and processes are implemented in a timely and appropriate manner.

This study will be carried out as a Design Science Research in collaboration with a case company. The aim of the study is to create a roadmap for the company to identify digital advances towards smarter manufacturing. Digitalisation goals will be collected from different departments to create a comprehensive overview. The data will be collected through semi-structured interviews. Based on the information collected and analysed, a roadmap will be drawn up.

After the research, the company will have a roadmap outlining its digitalisation objectives, and by analysing these, it can set clear priorities. It also provides the information needed to update the roadmap and refine the digital vision for managing and improving operations.

KEYWORDS: Industry 4.0, Smart Manufacturing, Roadmap, Roadmapping, Design Science Research

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Abbreviations

AM	Additive Manufacturing

CPS	Cyber-Physical System
DSR	Design Science Research
ERP	Enterprise Resource Planning
ICT	Information and Communication Technologies
IIoT	Industrial Internet of Things
IoT	Internet of Things
MES	Manufacturing Execution System
PLC	Programmable Logic Controller
SM	Smart Manufacturing

1 Introduction

In this first chapter of the thesis, the topic and the importance of the study are presented, along with the problem area and the research gap. The methodology employed in the study is also described in this chapter. Finally, this chapter introduces the case company that is the focus of the empirical part of this study.

1.1 Background and theoretical framework

Technological developments have played a key role in changing industrial productivity since the start of the industrial revolution in the 19th century (Rüßmann et al., 2015). Throughout the eras, numerous innovations and technological advances have significantly improved production. In today's competitive global markets, where most firms operate, it is crucial to operate efficiently (Rojko, 2017). Rojko (2017) also notes that the demands of the competitive environment, especially for manufacturing firms, can only be met by using modern production methods.

Technologies such as the Internet of Things (IoT), big data, and the rapid development of cloud computing have increased the potential for more efficient production and transformation towards smart factories (Bi et al., 2022). In different companies, the change can be seen, for instance, in the increased use of data, as business relevant data is of higher quality in terms of volume, variety and velocity (Bi et al., 2022). This development is only possible with new technology, which requires, among other things, a new type of system architecture and technical expertise (De Carolis et al., 2017).

The ongoing fourth industrial revolution in Europe is widely referred to as Industry 4.0 (Rojko, 2017). At its simplest, Industry 4.0 means the use of new advanced technologies and networking in production, allowing among others to optimise production efficiency, reduce production downtime and reduce waste (Frank et al, 2019). The concept of Industry 4.0 is attracting great interest in companies, and no wonder, as Bauernhansl et al. (2016) predict that it will reduce production and logistics costs by 10-30% and quality management costs by 10-20%. The Industry 4.0 market is estimated to be worth 52.17 billion dollars in 2023 and to reach 182.01 billion dollars by 2028 (MarketsAndMarkets, 2021). There is a growing understanding among companies of the importance of Industry 4.0 and their willingness to move towards it and invest in the technology that makes it possible.

Integrating new technologies and processes to replace existing ones brings numerous challenges (Phaal et al., 2013). Challenges in adopting new technologies often include a lack of knowledge and problems with connectivity of existing equipment and systems. Because it is not easy to adopt new technology, companies may postpone adopting new technology into their business as long as possible (André, 2019). However, not using new technology can be fatal, especially for the productivity of the manufacturing company.

The adoption of new technologies and any digital transition in companies is a time-consuming process (De Carolis et al., 2017). This is why researchers stress that implementing digital transformation requires careful planning. Sufian et al. (2021) argue that the journey towards smarter manufacturing requires a well-structured roadmap, which, in simple terms, is a strategic plan that outlines the steps or milestones needed to achieve a specific goal or project. This is supported by Davis et al. (2012) because they state that Industry 4.0 involves a lot of complex technology that requires research, development, and design to implement. Oeztmel & Gursev (2020) state that companies must first understand the concept of Industry 4.0 and the benefits it will bring to their business, and then create a clear roadmap for the future manufacturing environment.

While Industry 4.0 and its potential benefits are still theoretical for many manufacturing companies, both small and large companies are increasingly being forced to digitise their production processes. To make this transformation, it is necessary to develop a strategic "game plan" to steer digitalisation towards predefined objectives. In this context, a roadmap proves to be a valuable strategic tool to facilitate the achievement of future goals (Moehrle et al., 2013). In summary, in an environment defined by rapid technological development, global markets and fierce competition, firms need to keep up with technological changes and market trends to succeed (Schuh et al., 2013).

Industry 4.0 introduce digital technologies that will significantly improve production processes by increasing efficiency, improving product quality, and increasing flexibility (Butt, 2020). However, the transition to this advanced manufacturing paradigm is complex and requires continuous effort and planning. The transition requires new strategies and organisational models, involving changes in infrastructure, operations, human resources, and management practices. The development of a roadmap is essential to plan this transition in a systematic way and to align technological developments with business objectives.

Effectively managing the digital transformation of Industry 4.0 requires a deep understanding of the company's current state, needs and readiness to adopt new technologies (De Carolis et al., 2017). Success depends on readiness and strategic alignment of new technologies with overall business objectives. Despite the lack of standardised guidelines for developing roadmaps, which makes the development of a universal model challenging (Phaal et al., 2004), tailored roadmaps are crucial. They help organisations to anticipate and plan for technological change and ensure sustainable success in a rapidly evolving industrial environment.

1.2 Research objectives and methodology

The main purpose of the thesis is to clarify the possibilities of digitalisation of production for the case company and to guide its future actions towards smarter manufacturing. This thesis creates a roadmap that considers the future goals and needs of digitalisation in different departments of the company. The roadmap will help to align future developments and facilitate the planning and implementation of digitalisation projects. The thesis also aims to produce a description of the roadmap process that can be reused later to update the roadmap or another division of the company.

The research will employ the design science research methodology proposed by Peffers et al. (2007). This methodology was chosen due to its strong capability to create artefacts, which in this thesis will be the roadmap. Additionally, semi-structured interviews will be utilised as a data collection method. The interviews will gather information from different departments about their level of digitisation and their objectives. Interviews are also used to define the objectives and scope of the study and finally, to evaluate the artefact.

Two research questions have been set for the study, the first of which can be answered using the theoretical framework. The first question aims to identify the opportunities that Industry 4.0 brings and to deepen the understanding of its importance. To answer the second research question, a comprehensive empirical part is required, in which a roadmap is created for a case company.

RQ1: What is Industry 4.0 and how to benefit from it?
RQ2: What factors need to be considered and what gaps may arise during the digital transformation of the factory in the case company?

There is extensive literature on roadmapping and Industry 4.0 technologies, including the digitisation of production. However, there is no definitive guidance on how a company should create a roadmap to facilitate the transition towards smarter production. While the roadmapping process logically varies from one situation to another, practical benchmarks and real-world business examples are scarce, with most resources presenting theoretical models.

This thesis aims to develop a roadmap for the case company, integrating theoretical insights from the literature while considering the company's specific needs. By doing so, it seeks to provide a practical example of the roadmapping process within a real business context, which could potentially serve as a model for other units within the case company in the future.

1.3 Structure of the study

Chapters two form the theoretical framework of the thesis. Chapter 2.1 deals with Industry 4.0 and chapter 2.2 with the roadmap. These chapters will help to gather sufficient knowledge to carry out the empirical part of the study. Chapter three deals with research methods and introduces the data collection methodology of the study. Chapter four presents the research conducted in this thesis, following the sequence suggested by Peffers et al. (2007). Finally, chapter five discusses and evaluates the artefact created.

1.4 Case company Introduction

The case company is the world's leading international manufacturer of electric motors and a pioneer in the development of energy-efficient electric motors. The division for which this master's thesis is being commissioned develops and manufactures customised IEC low voltage motors for all industries and applications worldwide.

The unit manufactures highly customised motors according to customer orders. This makes it difficult for the unit to implement a truly automated production process, as the individual electric motors produced in the unit may differ significantly from each other. The case company has a strong desire for continuous improvement in various areas, from product development to digitalisation of production. The challenge, especially in the field of production digitalisation, is the large number of product variants.

2 Theoretical framework

The theoretical framework for this study was developed by collecting information from previous studies. Most of the articles used in this thesis are taken from scientific publications and databases in the field. The first section of the theoretical framework focuses on the Fourth Industrial Revolution. Information has been drawn from peer-reviewed publications on industry, manufacturing, engineering and technology. The second part of the theoretical framework consists of understanding the purpose and benefits of the roadmap and the process of its creation. The purpose of the theoretical framework is to provide relevant information to the researcher on the topic and to assist in conducting empirical research.

2.1 The fourth Industrial Revolution

The efficiency of factory production began to improve in the 19th century when steam engines accelerated production (Ajayi et al., 2023). Subsequently, the advent of electrification led to the birth of mass production in the early 20th century. In the next phase from the 1970s onwards, production has accelerated by automation. Then, in the so-called fourth industrial revolution, technological developments brought intelligent IT systems, sensors and other inventions that improved production efficiency and ways of production in factories.

As a result of advanced technology and digitalisation, many of people's daily activities have changed, both in their everyday lives and at work. In industry, this is seen in efforts to improve production methods through information and communication technologies (André, 2019). Traditional production methods are therefore being made more efficient through the great potential of technology and the economic benefits it brings.

In 2011, the German government introduced the concept of Industry 4.0; the concept, which name indicates that it is related to the fourth technological revolution (Rojko, 2018). Industry 4.0 can be seen as a strategic initiative by the German government to maintain Germany's strong position as a leading industrial country. According to Rojko (2018), Industry 4.0 is fundamentally centred on the exploration of novel technologies and paradigms. This includes the use of Internet of Things (IoT), integration of technical and business processes in organisational structures, the digitalisation and virtual representation of concrete environments, and the creation of smart factories equipped with advanced industrial tools and products.

It is worth noting that the terms used when talking about the digitalisation of production and related activities are often slightly different. However, the content of the different terms is mostly the same, as they all focus on how developments and innovations in information and communication technologies (ICT) can transform modern production. Only the way it is referred to varies, whether it is referred to as "Smart Manufacturing (SM)", "Industrial Internet of Things (IIoT)" or "Industry 4.0", as in Europe (André, 2019; Bi et al., 2021). Although many nations other than Germany use different names, but there is a consensus on the content of Industry 4.0 (Gunal & Karatas, 2019).

Industrial development and digitalisation are deemed crucial not just in Germany but worldwide. One notable example is the "Made in China 2025" initiative introduced by the Chinese Ministry of Industry and Information Technology in 2015 (ISDP, 2018). This initiative, developed in collaboration with industry professionals, seeks to comprehensively revamp Chinese industry, drawing significant inspiration from the German Industry 4.0 model while tailoring solutions to meet Chinese requirements and preferences. The revamped manufacturing sector prioritises innovation, sustainability, and green energy. Ten key sectors, including information technology, automated machine tools and robotics, have been identified. China aims to transition from low-cost to high-quality products, challenging Germany, and Japan's dominance by 2035 and becoming the leading global manufacturing superpower by 2049 (Rojko, 2018).

In the United States, in 2012, General Electric company introduced the concept of the Industrial Internet or Industrial Internet of Things, abbreviated as "IIoT" (Parris, n.d.; Rojko, 2018). It represents a close integration of the physical and digital worlds, combining big data analytics and the Internet of Things. The scope of this concept is broader than Industry 4.0, covering sectors such as healthcare, the public sector, transport, mining and so on. The extensive reach of the Industrial Internet is evidenced by Parris' (n.d.) estimation suggesting that up to 46% of the global economy could derive benefits from its implementation.

Today, most companies are keen to take advantage of new technologies and keep up to date with new innovations. According to Andrén (2019), this is not at all surprising, as in today's global and competitive market, companies need to be able to operate efficiently to succeed. Following chapters will discuss in more detail the technologies that enable Industry 4.0 and the concept in general, which is an essential concept for this thesis and the case company.

2.1.1 Enabling technologies for Industry 4.0

The aim of Industry 4.0 and other initiatives such as the previously presented "Made in China 2025" is to use new technologies to make production more efficient (Frank et al., 2019). There are various technologies and innovations that enable the concept of Industry 4.0 and thus the possibility to enhance production. Different literature and studies define the technologies enabling Industry 4.0 sometimes the same and sometimes with slight differences. Gunal and Karatas (2019) in their study highlight the challenge of pinpointing specific technologies associated with Industry 4.0. The difficulty arises from the continuous emergence of new technologies, which expands the list beyond initial classifications. However, the same enabling technologies are often mentioned in almost all the literature, mainly just the scope of the list varies.

Industry 4.0 is a broad concept, and understanding it requires defining the technologies that enable it. The fact that the concept can be defined in broad terms or from specific perspectives also has an impact on the definition. The development of Industry 4.0 and the technological advances that enable it offer viable solutions to the growing IT needs of the manufacturing industry (Xu et al., 2018). Lee et al. (2015) emphasise that one of the major concerns of this new industrial stage is the complex technology and technological architecture. Therefore, in the realm of Industry 4.0, understanding the concept is greatly facilitated by awareness of the technologies that underpin it. Consequently, this thesis emphasises the importance of acquainting oneself with these diverse technologies to fully comprehend the challenges and opportunities inherent in Industry 4.0.

Rüßmann et al. (2015) present that Industry 4.0 is mainly linked to nine technological advances, which are Internet of Things, cybersecurity, cloud computing, additive manufacturing (AM), augmented reality (AR), big data analytics, autonomous robots, simulation, and horizontal and vertical system integration. An identical list of nine technologies is also presented by Pozzi et al. (2023), Gunal and Kartas (2019), and SAP (n.d. -a). This list of nine technologies is currently the most comprehensive list of technologies enabling Industry 4.0. Ajayi et al. (2023) and IBM (n.d.) present a slightly shorter list, but the content can be said to be the same.

The fourth industrial revolution is mostly based on the technologies presented in Figure 1. Many of the technologies mentioned above are already in use in industry, but the aim of this new era is to create production where individual, efficient and optimised modules are connected and integrated into automated production. The technologies presented are essential to achieve this goal and offer new strategic improvements in areas such as cost optimisation and quality improvement (Pozzi et al., 2023).

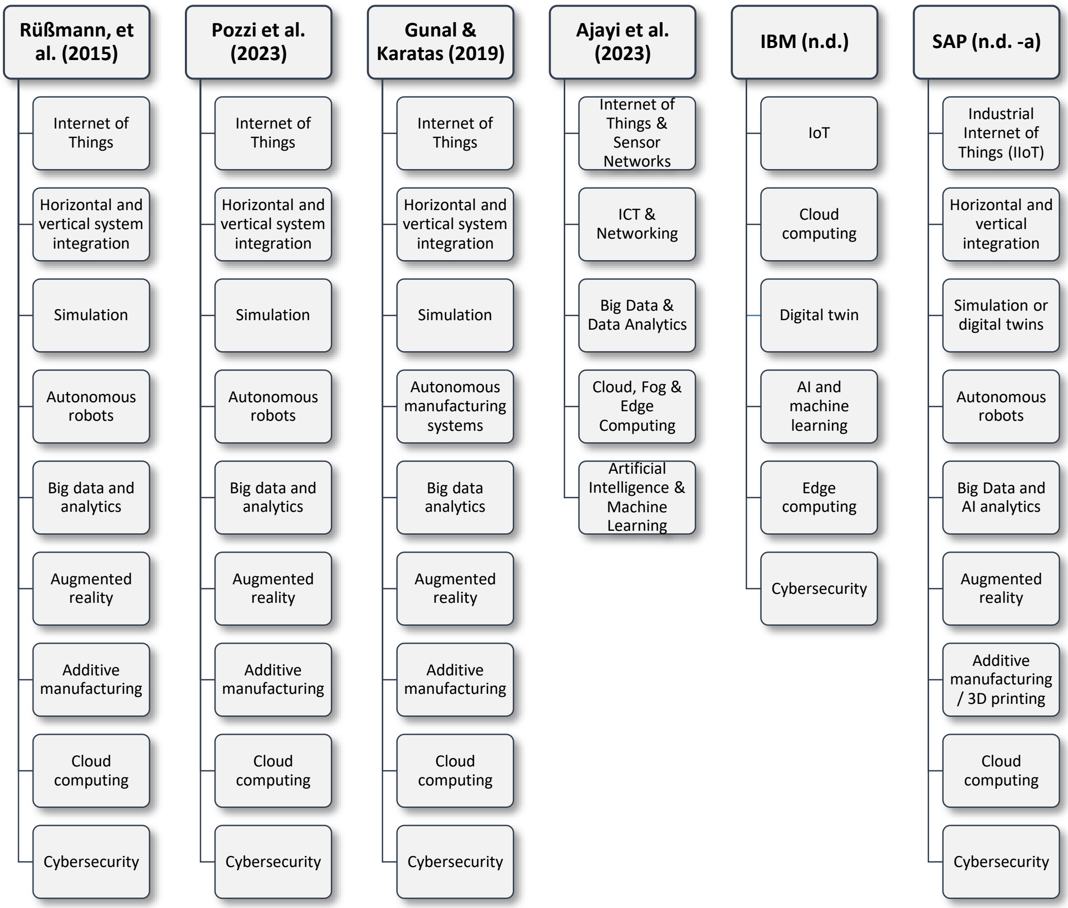

Figure 1. Technologies for Industry 4.0.

Frank et al. (2019) present a slightly different model of the technologies required for Industry 4.0. The model is based on the premise that the concept is divided into two main layers. The first layer is the so-called "front-end technologies", and the second layer is the "base technologies". The first, front-end technologies layer in Frank et all's (2019) model, consists of four distinct dimensions, each representing a subset of technological advances. The researchers stress that the key dimension of the front-end technology layer is smart manufacturing, while other dimensions are linked to it. The second layer, known as base technologies, focuses on connectivity and intelligence enhancements for the front-end technologies, encompassing vital components like the IoT and advanced analytics.

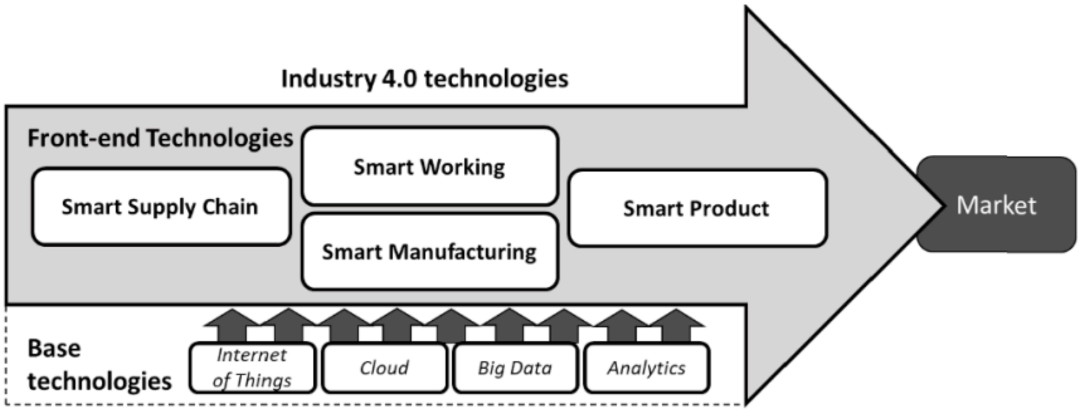

Figure 2. Industry 4.0 technologies (Frank et al., 2019).

The Internet of Things can be seen as one of the key technologies in the era of Industry 4.0 (Ahuett-Garza & Kurfess, 2018; Wang et al., 2015; Xu et al., 2018). Ajayi et al. (2023) argues that, in a very simplified way, IoT can be defined as the process of connecting everyday objects to the Internet. The essential elements of this IoT definition include connectivity, which pertains to networking; embedded, which denotes the integration of miniaturized devices with inherent sensing and actuation capabilities; and uniquely identifiable, implying distinct addresses via either IPv6 or Media Access Control (MAC) addresses (Ahuett-Garza & Kurfess, 2018). Overall, IoT is present in many contexts, and it is a technology that is being used in a big number of ways nowadays. One important factor for the increased adoption of IoT sensors is their reduced price (Ahuett-Garza & Kurfess, 2018).

Big data refers to a substantial volume of data in diverse formats (variety), generated rapidly (velocity), characterized by high quality (veracity), and possessing significant value (Ahuett-Garza & Kurfess, 2018). It originates from various sources, including social media, videos, images, web pages, and for instance data from IoT devices. Big data can be structured, semi-structured, quasi-structured or unstructured. However, it is challenging to store and process because it differs from traditional data structures and often exceeds the capacity of traditional computer systems. The significant potential of big data is generally seen in the fact that intelligent algorithms can still be used to analyse large amounts of structured and unstructured data (Oztemel & Gursev, 2020). Very closely related to big data is machine learning. It is good to understand that big data itself is not automatically of great value to a company. However, machine learning can be used to create models that can be used to find useful information from big data (Ahuett-Garza & Kurfess, 2018).

In many articles and literature, when discussing the main enabling technologies for Industry 4.0, Cyber-Physical System (CPS) is often mentioned (Oztemel & Gursev, 2020; Xu et al., 2018; Lee et al., 2015). The purpose of a cyber-physical system is to combine the "physical" and "cyber" dimensions. This means the analysis, statistics and computer modelling of real data extracted from physical systems (Ahuett-Garza & Kurfess, 2018). In other words, using the description of Trappye et al. (2016), CPS means that a mechanical device such as a lathe is equipped with the ability to observe the physical world and then the observation is used as data in a computer and is analysed and stored. The result of all this is that decisions and actions can be taken that affect processes in real time.

Xu et al. (2018) define CPS as a system in which individual computing units work in close cooperation. Each computing unit is in turn aware of and connected to the physical world around it. It is essential for the computing units to be connected to each other via the Internet and to be able to process data. Petrillo et al. (2018) describe CPS as a set of different technologies that create an intelligent system to help integrate objects that are physically distant from each other. They continue that the system aims to enable three different phases: data acquisition, data computation and aggregation, and finally decision support. This is only possible in the presence of interconnected sites which, through sensors, actuators, and network connectivity, can generate data and thus reduce the distances between the different sites.

Oztemel and Gursev (2020) explain CPS as the combination of computational and physical processes that are critical components of Industry 4.0 deployment. They include imaging and control functions into the appropriate systems. Oztemel and Gursev (2020) emphasize that it is essential and important to understand the ability of the CPS to respond. Given that Industry 4.0 relies heavily on intelligent, real-time connections among people, machines, and devices, Cyber-Physical Systems (CPS) play a crucial role within Industry 4.0. In the industrial context, CPS aims to enhance productivity across all levels (Ahuett-Garza & Kurfess, 2018).

The exclusion of Cyber-Physical Systems (CPS) from Figure 1 is logically justified. While CPS is occasionally depicted in the literature as a standalone technology, it truly represents a fusion of various technologies, such as IoT, cloud computing, and big data, that collectively enable the emergence of the Industry 4.0 cyber-physical system concept (Wang et al., 2015).

Lee et al. (2015) present an illustrative 5C model, shown in figure3, that describes the functionality of the Cyber-Physical System. The model not only illustrates the functionality but can also be seen as providing guidelines for the implementation of the CPS in a factory. Lee et al.'s (2015) model consists of five stages, and each stage is described next based on their research.

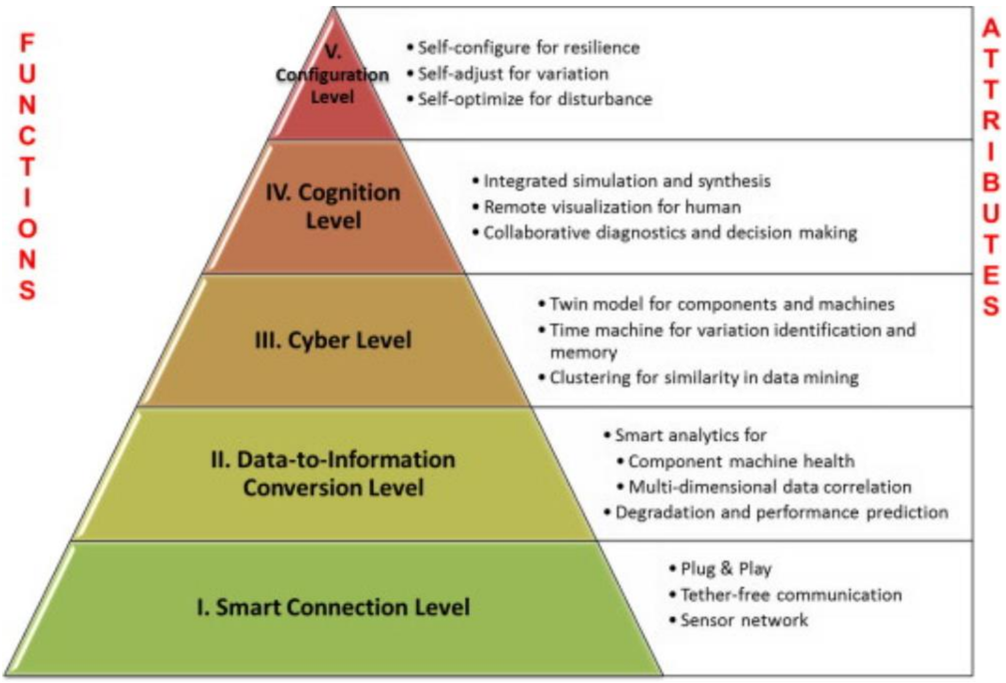

Figure 3. 5C architecture for implementation of Cyber-Physical System (Lee et al., 2015).

The first layer is Connection. This layer is crucial because it establishes the foundation upon which the entire system is built. The Connection layer involves linking machines and their components to collect essential and precise data relevant to the operation of the equipment. The data collected is not limited to the information provided by the sensors, but also includes information from other systems, such as PLCs and manufacturing software like ERP or MES. Specialized protocols, often associated with IoT technology, facilitate the transfer of this information. In the next Conversion phase, data is transformed into meaningful information using techniques such as big data analytics and cloud computing. The Conversion layer plays a crucial role in extracting actionable intelligence from data, facilitating informed decision-making and system optimization.

Cyber layer is like a central brain, using software and algorithms to analyze data from connected machines. It helps compare machine performance and predict future behavior based on past data. This layer is crucial for understanding and managing the status of individual machines in a network. The Cognition level in CPS involves acquiring in-depth knowledge about the monitored system and effectively presenting it to expert users to enable informed decision-making. Users can for instance optimize operations by prioritizing servicing tasks based on comparative data and individual machine statuses. This level highlights the necessity of clear and useful images, such as infographics, in conveying acquired knowledge fully to users.

Configuration level acts as a link between the cyber and physical worlds, relaying information from digital systems to physical machinery. It serves as supervisory control, allowing machines to self-configure and adapt independently. This level functions as a Resilience Control System, applying corrective and preventive measures defined at the cognition level to the monitored system.

2.1.2 Core idea of Industry 4.0

To fully understand the core concept of Industry 4.0, it is important to understand the underlying technology. This chapter summarises the various definitions of Industry 4.0 that appear in the literature, with the aim of improving understanding of the topic now that the technology has been introduced.

Industry 4.0 refers to a new strategy to organizing manufacturing resources (André, 2019). This expanding business is the consequence of the combination of real-world products and items, digital design and administration, and the virtual world. At the core of Industry 4.0 is the use of various emerging technologies to improve production (Frank et al, 2019). They add that, ideally, all production-related activities will adopt intelligent approaches supported by ICT. Simply said, Industry 4.0 depends on the use of digital technologies to gather and analyse data in real time, hence delivering important information to the production system (Lee et al., 2015; Wang et al., 2016a).

Industry 4.0 means the seamless, real-time interconnection of people, machines, objects, and ICT systems, both horizontally and vertically, to enable dynamic control of complex systems (Trappey et al., 2016). Normally, a single factory has several physical and IT systems. These may include sensors, roller conveyors, production control and operations planning systems. Vertical integration means that these devices and systems are seamlessly and intelligently integrated at different levels, from sensors to ERP (Wang et al., 2016b). This makes it possible to achieve a self-organising system that is easy to configure dynamically. On the other hand, horizontal integration means cooperation between different companies where, material and information flows seamlessly (Wang et al., 2016b). This is important for production plants to organise logistics efficiently, for example. Figure 4 below illustrates the situation.

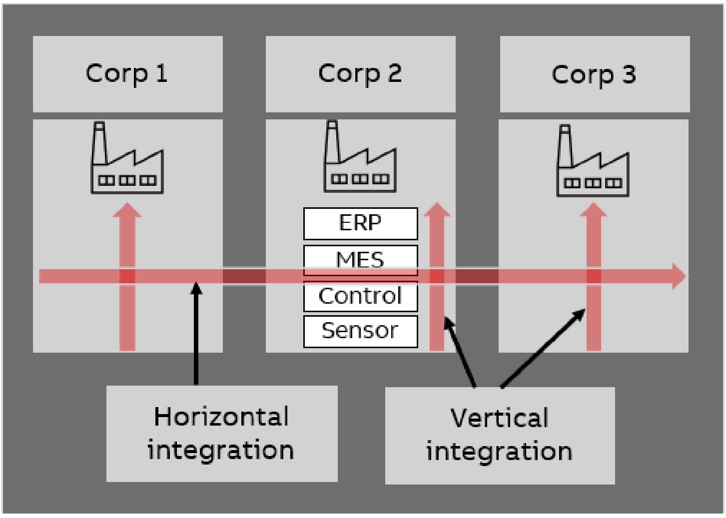

Figure 4. Illustration of integration and their relationship (adapted from Wang et al., 2016b).

To make Industry 4.0 a reality, it is important to note the inevitability of certain technologies. For example, Trappey et al. (2016) argue that Industry 4.0 is only possible with CPS, IoT and cloud computing. Xu et al. (2018), on the other hand, argue that IoT and CPS will be the pillars of the fourth industrial revolution, bringing together the world of production and networking. Baurnhansl et al. (2016) says at the centre of the Fourth Industrial Revolution is the Internet of Things and the new possibilities to connect resources, services and people for production based on cyber-physical systems in real time.

It is therefore essential to note that the focus of Industry 4.0 is not really on digitalisation, but on the potential for real-time networking of technical systems (Bauernhansl et al, 2016). Of course, real-time networking requires different kinds of digitalisation, such as various sensors for old-fashioned industrial machines, but the main purpose is not just to bring a huge number of high-tech intelligent machines, robots and so on into production.

According to Rojko (2017), Industry 4.0 is an approach that integrates business and manufacturing processes as well as all participants in a company's value chain, including suppliers and customers. André (2019) summarises that the shift towards Industry 4.0 is based on three pillars: digitisation of production, automation, automated data exchange.

These three pillars also sum up the purpose of Industry 4.0. Overall, the primary purpose of Industry 4.0 is to improve efficiency (Petrillo et al, 2018).

2.1.3 Impact of Industry 4.0 on factories

Earlier in this chapter, it is noted that the concept of Industry 4.0 is sometimes referred to in slightly different terms and with slightly different content. The terminology may not yet be fully established. For example, Xu et al. (2018) note that authors often use the terms Industry 4.0, smart factor, and smart manufacturing in similar contexts which leads to an assimilation of their meanings.

Ahuett-Garza and Kurfess (2018, p. 60) explains that: "Smart Manufacturing represents the implementation of Industry 4.0 on the manufacturing floor". Frank et al. (2019), on the other hand, argue that smart manufacturing is the original and primary goal of Industry 4.0. Therefore, it can be said that Smart Manufacturing is a concept strongly related to the Industry 4.0 concept. Smart factories in turn are defined as cyber-physical systems that use advanced technology to analyse data, drive automated processes, and gain knowledge while they progress (Wang et al., 2016a; SAP, n.d. -b). Strozzi et al. (2017) on the other hand studied the concept of a smart factory and defined it in their analysis as a manufacturing plant where the basic principles of Industry 4.0 are integrated and implemented. To clarify, Xu et al. (2018) state well that Industry 4.0 and its associated technologies will simply lead to the creation of smart factories. For this thesis, it is not necessary to go into the details of defining the terminology, but above all to understand how the fourth industrial revolution can change production, what can be gained from it and what should be considered in its implementation. In this chapter, we look at the features of smart factories resulting from Industry 4.0.

The role of Cyber-Physical Systems in the case of smart factories is highlighted by Wang et al. (2016a) and Xu et al. (2018). The backbone of smart factor is the CPS, which enables integration with physical elements such as the product to be manufactured, production equipment and information systems such as ERP and MES. In line with CPS, smart factories require the implementation of interconnections, interactions between objects, and the integration of technical and business processes (Xu et al., 2018). Trappye et al. (2016) emphasise the importance of high-quality process synchronisation to enable the production of high-quality products in a short time that meet customer requirements. This is crucial in a highly competitive global market. For a smart factory to succeed, it must be based on seamless vertical integration and networked systems (Wang et al., 2016a). According to Ajayi et al. (2023), it is important for the proper functioning of smart factories that information collected from real-time data sources interacts and interconnects with various entities such as production control and maintenance processes.

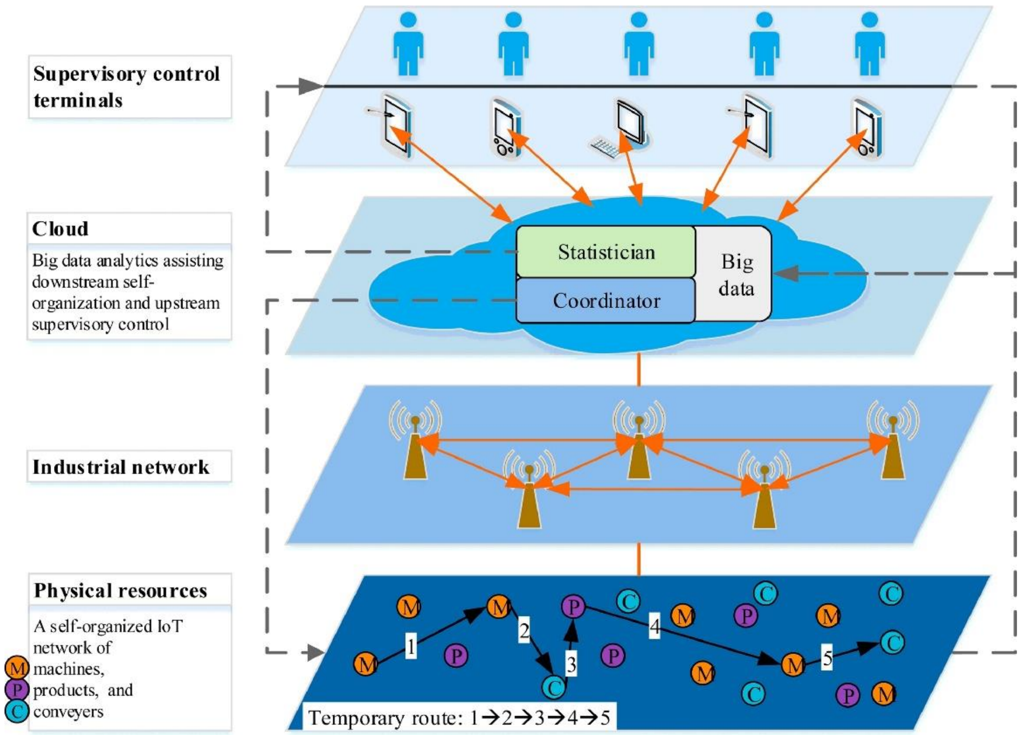

Figure 5. Layers of a smart factory (Wang et al., 2016a).

Wang et al. (2016a) describe the smart factory structure, as shown in Figure 5, by dividing it into four layers: physical resource layer, industrial network layer, cloud layer, and supervisory control terminal layer. The first layer, physical resources, describes the smart things that are interconnected through the second layer, industrial network. The third layer, the cloud, collects large amounts of data from physical resources and then interacts with people via control terminals. Thus, this kind of structure creates a networked world in which intangible information can move freely. This in fact creates a CPS in which physical objects and informational entities are closely linked. Such a framework in the factory enables flexible and agile production (Wang et al., 2016a).

Frank et al. (2019) studied the technologies necessary for smart manufacturing and divided the technologies into six categories, which are shown in Figure 6. The categories are described at a very general level and the technologies are more general solutions that refine the categories, rather than technological solutions, although the name might suggest that. The categories found in the figure are vertical integration, virtualization, automation, traceability, flexibility, energy management. Once the concept of Industry 4.0 is understood, the categories presented by Frank et al. (2019), especially for factory digitalization, are the entities that should be focused on.

Categories	Technologies for Smart Manufacturing
Vertical integration	Sensors, actuators and Programmable Logic Controllers (PLC)
	Supervisory Control and Data Acquisition (SCADA)
	Manufacturing Execution System (MES)
	Enterprise Resource Planning (ERP)
	Machine-to-machine communication (M2M)
Virtualization	Virtual commissioning
	Simulation of processes (e.g. digital manufacturing)
	Artificial Intelligence for predictive maintenance
	Artificial Intelligence for planning of production
Automation	Machine-to-machine communication (M2M)
	Robots (e.g. Industrial Robots, Autonomous Guided Vehicles, or similar)
	Automatic nonconformities identification in production
Traceability	Identification and traceability of raw materials
	Identification and traceability of final products
Flexibility	Additive manufacturing
	Flexible and autonomous lines
Energy management	Energy efficiency monitoring system
	Energy efficiency improving system

Figure 6. Smart Manufacturing technologies (Frank et al., 2019).

Figure 7 shows how and which technologies from different categories should be deployed to achieve a functioning Industry 4.0 production. This figure is a continuation of Figure 2, where Frank et al. (2019) presents the Front-end and Base technologies. The technologies listed in the figure are ordered from left to right according to the difficulty of implementation and the figure is classified into different phases. The content of this figure is an excellent illustration of how different Industry 4.0 technologies should be implemented in a company and the nature of the concept. The first point of stage 1 is namely vertical integration and as already referred to earlier, this is necessary for the CPS to be implemented. CPS is in turn the backbone of Industry 4.0. Stage 3, on the other hand, is additive manufacturing, for example, which in practice is only possible once the previous stages have been achieved. Stage 3 is called flexibilization, which includes, for example additive manufacturing but it is only possible once the previous stages have been achieved.

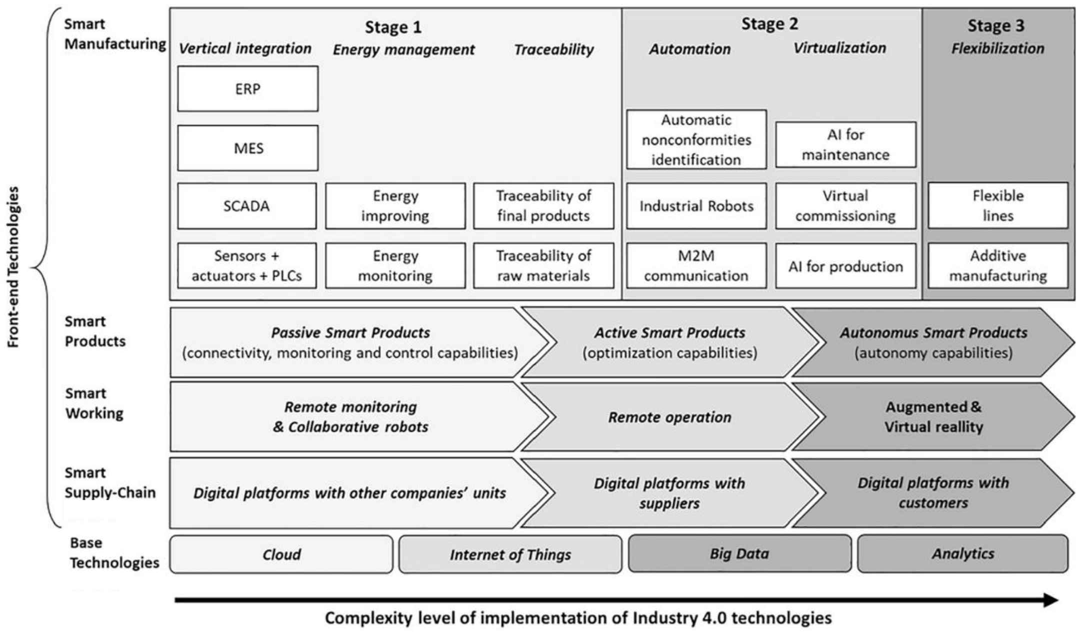

Figure 7. A framework for the progressive addition of technologies in Industry 4.0 (Frank et al., 2019).

Technologies such as Radio Frequency Identification (RFID) and the increasing use of sensors are essential for enhancing production automation (Strozzi et al., 2017). In practice, the utilization and quantity of sensors should be increased, which must be considered in information system solutions. Cloud computing is also essential because various types of data collected can be classified and analysed. With the help of intelligent algorithms, a large amount of diverse data can be analysed, which can be utilized for both production optimization and quality improvement (Oztemel & Gursev, 2018). For example, the temperature of a device collected by a temperature sensor and made available through a wireless internet connection can be analysed (Rojko, 2018; Bi et al., 2021). As a result of the analysis, for example, real-time preventive maintenance of machinery can be carried out. The collected data should also be used to identify production bottlenecks and inefficient material usage processes (Burns, 2019). Bauernhansl et al. (2016) state that based on big data, remarkably accurate future predictions can also be made from various perspectives. Artificial intelligence can also be used to find new innovations and train employees, among other things.

The 3D simulation of products and the creation of digital twins will increasingly play an important role in optimizing production lines and product design (Oztemel & Gursev, 2018; Burns, n.d.). Simulations enable the modelling of real-world data in virtual environments in real-time. This allows, for example, the efficiency of production lines and different layouts to be tested and compared with each other before actual implementation or modification.

In various manufacturing sectors, robots have been in use for years. Autonomous robots have facilitated humans in demanding precision tasks or, conversely, in very simple and monotonous tasks (Oztemel & Gursev, 2018). The adoption of Industry 4.0 principles often increases the use of autonomous robots, but the usefulness and number of robots in production can vary between industries (Rüßmann et al., 2015). Augmented reality, on the other hand, is predicted to facilitate working on production lines because it can replace outdated operating instructions or assembly instructions (Oztemel & Gursev, 2018). Additive manufacturing, in turn, can be a good solution for creating prototypes.

Without various software tools and their seamless vertical integration, it is not possible to operate an Industry 4.0 smart factory. ERP and MES systems are essential in integrating business-level and shop floor-level operations (Rojko, 2018). It would also be important to integrate ERP and MES systems with tools such as Customer Relationship Management and Business Intelligence.

In practice, the above-mentioned aspects are possible through Industry 4.0 technologies, but they are still rarely used in factories. However, it is important to be aware of the different possibilities and to develop a strategy for technology development through awareness, which is considered a necessary first step in technological change (Cotrino et al., 2020).

The biggest benefit for the industry is that Industry 4.0 will provide the ability to collect and analyse data between machines, enabling faster, more flexible, and more efficient processes to produce higher quality products at lower cost (Rüßmann et al., 2015). Burns (2019) adds two achievable aspects of Industry 4.0: reducing downtime and long-term cost reduction. Storzzi et al. (2017) highlight in their research that especially smart factories are safer for employees and more environmentally friendly.

An important part of Industry 4.0 is also cyber-physical systems, whose architecture leads to optimal distribution of functionalities (Bauernhansl et al., 2016). CPS enables the creation of dynamic production lines, where products move independently from one processing module to another. This also allows dynamic reconfiguration of production lines in real-time (Trappey et al., 2016). Intelligent production lines further improve efficiency and productivity through reduced raw material and energy consumption.

In summary, the benefits to production that can be achieved through Industry 4.0 are multidisciplinary. Not all the technologies associated with Industry 4.0 are new, but there is a desire to use them in a new way to optimize production in the best possible way. This basically means that through maximum optimization and learning from data, processes can be made more efficient and more seamless with each other, creating value creation from the start to the end of the whole business chain (Bauernhansl et al., 2016).

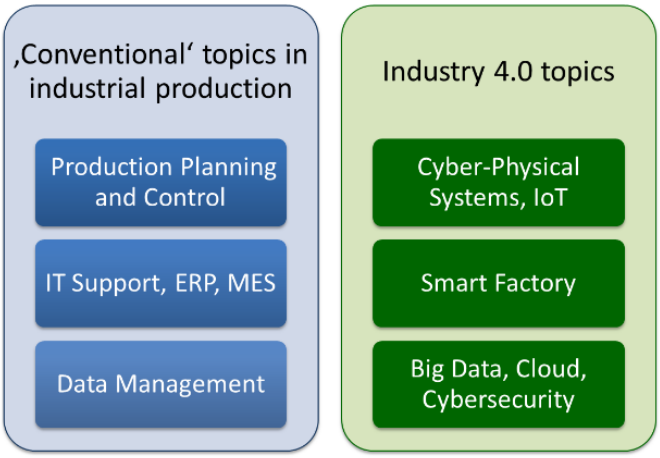

Figure 8 Comparison of topic in conventional industrial production and the Industry 4.0 topics (Rojko, 2018).

In Figure 8, Rojko (2018) illustrates that Industry 4.0 can also be imagined as a natural transformation of industrial production systems due to the development of digitalisation. It is not the main features that change, but the technology and approaches. Fundamentally, Industry 4.0 refers to the technological transition from embedded systems to cyber-physical systems (Xu et al., 2018). This means that IoT, machine-to-machine communication and CPS technologies integrate the virtual world with the physical world to create a new generation of industrial systems, like smart factories.

2.1.4 Challenges and barriers to implementing Industry 4.0

The deployment of Industry 4.0, while promising considerable advances in manufacturing, is accompanied by various barriers and challenges. Obviously, this is a significant change, both strategically and, above all, technologically. This is why issues such as security, cost of implementation, interoperability and architectural complexity need to be tackled.

According to Rojko (2018), most organisations will adopt Industry 4.0 by relying on existing devices and technologies. Only when creating a new manufacturing plant can it be designed from the outset according to the principles of Industry 4.0. Thus, one of the main challenges is how to integrate existing standards into the new concept. Davis et al. (2012) analysed several companies and identified what they consider to be the most challenging aspects of Industry 4.0 integration. In their study, the main concerns are: first, companies today are using distributed control systems architectures that do not support smart manufacturing. Second, the misuse and inefficient use of technologies and the lack of the right industrial infrastructure. This concern is justified, as the concept of Industry 4.0 implies a complex technical architecture for manufacturing systems, which is one of the primary concerns of this new phase of the industrial era (Lee et al., 2015; Ajayi et al., 2023; Bauernhansl et al., 2016).

Interoperability and connectivity are entities that is also seen as a challenge in Industry 4.0 (Rojko, 2018). It is easy to list the different technologies that should be adopted in factory, but it is also important to think about how to make solutions work together or connect them. However, the success of Industry 4.0 depends on real-time and wide-spread connectivity and interoperability, which is seen as a challenge to properly design (Carvalho, 2020; Ajayi et al., 2023).

As connectivity and the number of devices connected to the web increase, security threats are growing. Oztemel and Gursev (2018), among others, argue that in smart factories, highly sensitive information is being transmitted digitally. Therefore, companies may be suspicious of the idea of increasing security threats, for example when implementing numerous IoT devices (Bauernhansl et al., 2016; Ajayi et al., 2023; Ahuett-Garza & Kurfess, 2018). Bauernhansl et al. (2016) also highlight that there is also a need for a skilled workforce due to the novelty of the issue. Change can seem overwhelming and even impossible if a company does not have a skilled workforce. Particularly in developing countries, where production has previously relied on low-cost labour, this can be challenging, while Industry 4.0 in turn requires highly skilled professionals. A major barrier for many firms to the large-scale adoption of Industry 4.0 is the cost of implementation, which can be prohibitive, especially for small and medium-sized firms (Burns, 2019; Bauernhansl et al., 2016; Bi et al., 2021; Davis et al., 2012).

The main concern of firms is the maturity of technologies that are associated with Industry 4.0, such as CPS and AI and their concrete benefits (Bi et al., 2021). Bi et al. (2021) continue that sometimes there is also much concern about integration and the difficulty of systems. Although Industry 4.0 as a concept is attractive, there is still a long way to go to achieve full transition.

2.2 Roadmap: Tool for Transition

In a global competitive environment, a company that does not improve its performance will not succeed in the long term, which is why forecasting and planning for the future are essential for businesses. To help with this, a good tool is a roadmap, which is an excellent tool for planning and, above all, clarifying future developments (Nimmo, 2013). In all its simplicity, a roadmap is a visual representation of the path to achieve a vision for the future (see Moehrle et al., 2013; Cosner et al., 2007; Gindy et al., 2006). In turn, the process that produces a roadmap is called roadmapping (Cosner et al., 2007). Phaal and Muller (2009) describe the roadmap as a "strategic lens" that helps to see, understand, and communicate the business strategic issues of a complex enterprise. This is a good illustration of a roadmap, because when used correctly, it is like a tool that makes it easier to see what to do now and in the future.

The process of developing a roadmap starts with an assessment of the current situation, followed by a definition of the desired future situation (Phaal et al., 2004). In essence, the purpose of a roadmap is to outline a path from the current situation to the envisioned future, thereby closing the gap between the current situation and the expected future state. The process therefore requires the combination of two fundamental elements: the forecasting of future scenarios and the strategic planning of actions and initiatives. Roadmaps are very different in the sense that they can focus on outlining the future prospects of specific products, applications, or entire industries (IEEE, n.d.).

The term "roadmap" is commonly understood as a document that outlines a direction for the future. In turn, a technology roadmap (TRM) serves to describe, support, and plan technological management (Phaal et al., 2004). According to Moehrle et al. (2013), a TRM focuses on technology and can model different aspects such as the technological evolution of a single product, IT infrastructure improvements, phased software development, digital transformation and so on. They also state that a technology roadmap can be defined in two ways: either strictly, describing only the technologies, or more loosely, encompassing more than just technology. However, Phaal et al. (2013) note that the terminology is somewhat unclear, with no precise division, as roadmaps can be applied to many different contexts.

Previously, technology roadmaps mainly focused on the technological development of specific products (Phaal et al., 2013). Nowadays, technology roadmaps are used for a wide variety of purposes. Their versatility, usefulness, and flexibility in strategic planning have led to their increasing adoption. It is important to note that the most crucial aspect of creating a roadmap is its adaptability to the needs of the organization, which has resulted in a wide variety of roadmap types (Phaal & Muller, 2009). The impact of technology on the operation of organisations and businesses in all sectors is fundamental, further underlining the importance of integrating technology into all strategic planning.

Although firms are aware of the strategic importance of new technology, many still do not move towards it (González et al., 2008). González et al. (2008) further explain that while firms recognize the importance of planning for technology adoption, they often do not know how to implement it or how to integrate this knowledge into their management practices due to cultural, economic, structural, or other reasons. This leads to a situation where many companies are pursuing effective business and marketing strategies to gain a competitive advantage, while little attention is paid to technology strategies. As a result, the link between business and technology strategies is not strong enough, which has led to the widespread adoption of the concept of technology roadmapping to integrate technology into business strategy (Gerdsri et al., 2007). However, Blackwell et al. (2008) argue that there are some common features that lead an organisation to adopt roadmapping at the latest. Reasons include the complexity of the system under consideration, the uncertainty associated with forecasts and assumptions, and the complexity of the issue due to multiple stakeholders.

2.2.1 Structure of the roadmap

Phaal et al. (2004) present different types of technology roadmaps, such as the Strategic Planning roadmap, the Long-range roadmap, and the Service/Capability roadmap, emphasising that although their purposes may be diverse and their presentation varies, their ultimate purpose is the same. This supports the argument that roadmaps can be used for many different purposes and that they are highly editable.

Phaal and Muller (2009) argue that a roadmap architecture consists of two key dimensions: timelines and layers. The timelines, usually represented by the x-axis, include past, present, short-term, long-term, and future, depending on the situation. Layers, on the other hand, focus on specific areas and are often divided into three main parts. The top layer relates to the trends and drivers that drive the overall goals and objectives. Examples include external market trends and internal business drivers and objectives. The middle layer focuses on the concrete actions that need to be developed to respond to the trends and drivers. This may involve the development of products, services, infrastructure, or other activities. The bottom layer comprises the resources, such as technology and skills, needed to achieve the objectives outlined in the middle layer. It is important to define the architecture according to a specific purpose and to modify it, if necessary, for example by adding a different sub-layer (Phaal and Muller, 2009). Cosner et al. (2007) also mention that roadmaps can be very different because they need to be adapted to different circumstances. Phaal & Muller (2009) point out that too detailed architecture can complicate and limit the usefulness of the roadmap, while too little detail makes it difficult to organise the information.

Figure 9 shows the concept of a generalised technology roadmap structure by Phaal et al (2013). There are many different variables and points in the graph, but in principle the idea of the graph is very simple and includes the elements that were presented earlier. The model is read chronologically from left to right to describe time (x-axis). The left-hand edge is meant to describe the current situation, to answer the question "where are we now?" The right-hand side of the pattern describes the desired future, in other words, "where do we want to go?" The section in between describes the actions that need to be taken to achieve the future objectives.

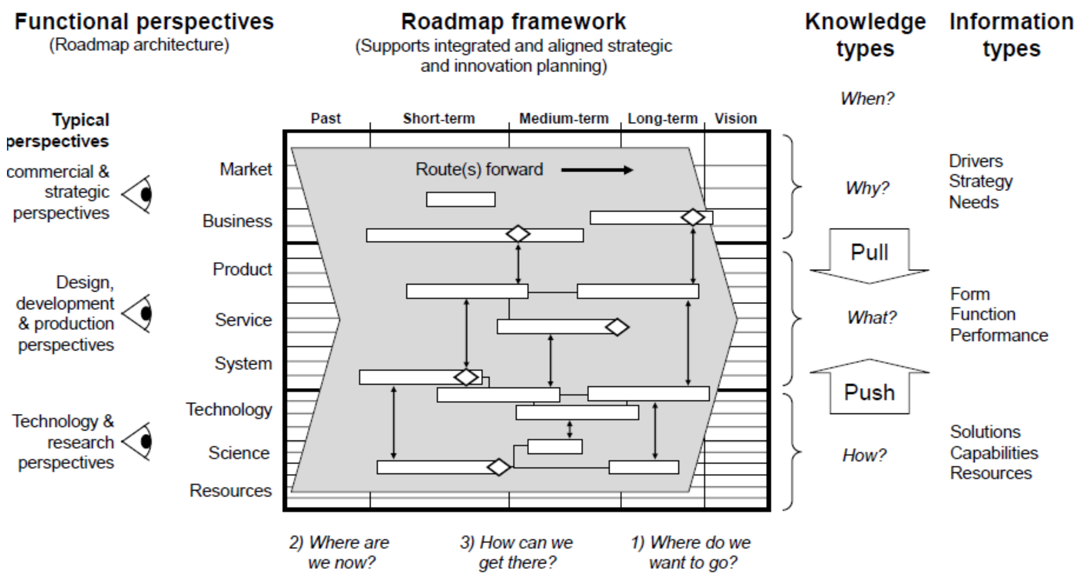

Figure 9. Generalised technology roadmap structure (Phaal et al., 2013).

The top layer in the Phaal et al. (2013) example seeks to answer the question "Why?", as it may include, for example, the company strategy that guides future improvements. The middle layer answers the question "What?". Depending on the purpose of the roadmap, this may include very different things, such as the different stages of manufacturing a particular product, different model versions of a particular product or developments in the product, or even specific digitisation improvements to the business. The bottom layer of the TRM describes the technologies and resources that the middle layer requires to move forward.

Blackwell et al (2008) reviewed hundreds of roadmaps in their study to identify best design practices. They found that the least effective roadmaps were overly complex, poorly structured and overloaded with content, leading to confusion. They also stress the importance of clear layering, noting that roadmaps with numerous unstructured boxes and excessive connections are particularly confusing. The roadmap should therefore be easy to read and as simple as possible but still contain all the necessary information.

2.2.2 Roadmapping process

According to Phaal et al. (2013), there is no universal strategy for developing roadmaps in different situations. This is because each roadmap needs to be specifically adapted to its context and purpose, as explained earlier. Although the process of developing a roadmap is highly customisable and can be implemented in many ways, it is not easy to implement. Gerdsri et al. (2007), among others, specifically studied the process of implementing a roadmap in different companies and found the process difficult in their study.

Even though the preparation of roadmaps is not easy, the researchers stress that the process of preparing roadmaps is even more important than the final product, the roadmap (see Phaal & Muller, 2009; Nimmo, 2013; Cosner et al., 2007). Phaal et al. (2004) explain this by the fact that so much valuable information is collected during the roadmapping process, which helps to understand and share information about common future directions. While the roadmap process and the roadmap to be developed in different contexts can vary widely, the researchers present some general "high-level" models for roadmap development. These models are presented next.

Phaal et al. (2004) present the T-plan fast-start method, which consists of three main steps. These are planning, roadmapping workshops and roll out. In the first planning phase, the business objectives of the whole roadmapping process must be precisely defined and the desired outcomes of the roadmap must be clarified. It is also important to define the practicalities, such as who will be involved in creating the roadmap and who will be responsible for its production. The second stage, the roadmapping workshops, simply involves creating the roadmap itself. This phase is divided by Phaal et al. (2004) into two different ways of implementation, the standard process, or the customized process. The standard process specifies that roadmap workshops are held according to four themes: market, product, technology and roadmapping. In the first three workshops, the necessary information is collected from the different perspectives and in the fourth workshop information is combined into a roadmap. The customised process will be determined according to the needs of each actor. The third roll-out phase involves putting the roadmap in place and integrating it into the business. Phaal et al. (2004) point out the importance of ensuring that after the first roadmap has been created, it is kept up to date and the process is repeated at intervals.

Gerdsri et al. (2007) also divide the process into three phases. The first phase is the initiation phase, where the purpose is to gather the necessary information for the later phases. In this phase, so-called core teams are set up to take charge of the process and discuss how the roadmap will fit into the strategic planning. An important part is also the sharing of information about the roadmapping process and the clarification of requirements. The second development phase focuses on data collection and analysis. In this phase, the guidelines set out in the first phase are used to guide the process. After data collection and analysis, this phase builds the roadmap. The third phase is the integration phase, where after the roadmap has been created, it is defined how the roadmap will be integrated into existing operations. The maintaining of the roadmap is also part of this phase.

Phaal & Muller (2009) present four phases to complete the process: ideation, divergence, convergence, and synthesis. According to Phaal and Muller (2009), the ideation phase involves planning the priorities for the roadmap content, preferably in a small process group. The ideation phase defines, among other things, the objectives, scope, and critical aspects. In the divergence phase, information and facts are sought. In this phase, a wide range of information is collected and explored through possibilities and different scenarios. In the third convergence phase, all the information from the previous phase is analysed. The purpose of the analysis is to bring together only the information that is relevant to the roadmap and to exclude unnecessary information. In the last phase, a synthesis, or roadmap, is created by the process team.

De Carolis et al. (2017) focus their study on creating a methodology that companies can use to develop a roadmap for digitalisation. The proposed methodology consists of four steps. The first step is a maturity assessment. In this step, the current level of digital readiness of the firm needs to be identified. This is a starting point, as the current level of digitalisation needs to be known to set realistic and sufficiently ambitious targets. The next step is to identify strengths and weaknesses. The purpose of this phase is to identify the strengths and weaknesses of the company using various tools, such as a SWOT analysis. The third step focuses on identifying the company's opportunities. The first three phases focus mainly on gathering information about the company and its potential. In the fourth phase, the roadmap itself is created based on the information gathered earlier.

Different researchers' guidelines for the roadmapping process follow much the same formula. In fact, the only difference is how precisely the different stages are described and which stage is focused on. Figure 10 summarises the views of the authors Phaal et al. (2004), Gerdsri et al. (2007), Phaal & Muller (2009) & De Carolis et al. (2017) on the process in a very simple format to make it clearer. Based on the literature, it can be observed that the roadmapping process most commonly consists of an initiation phase, the creation of the roadmap itself and finally a follow-up phase.

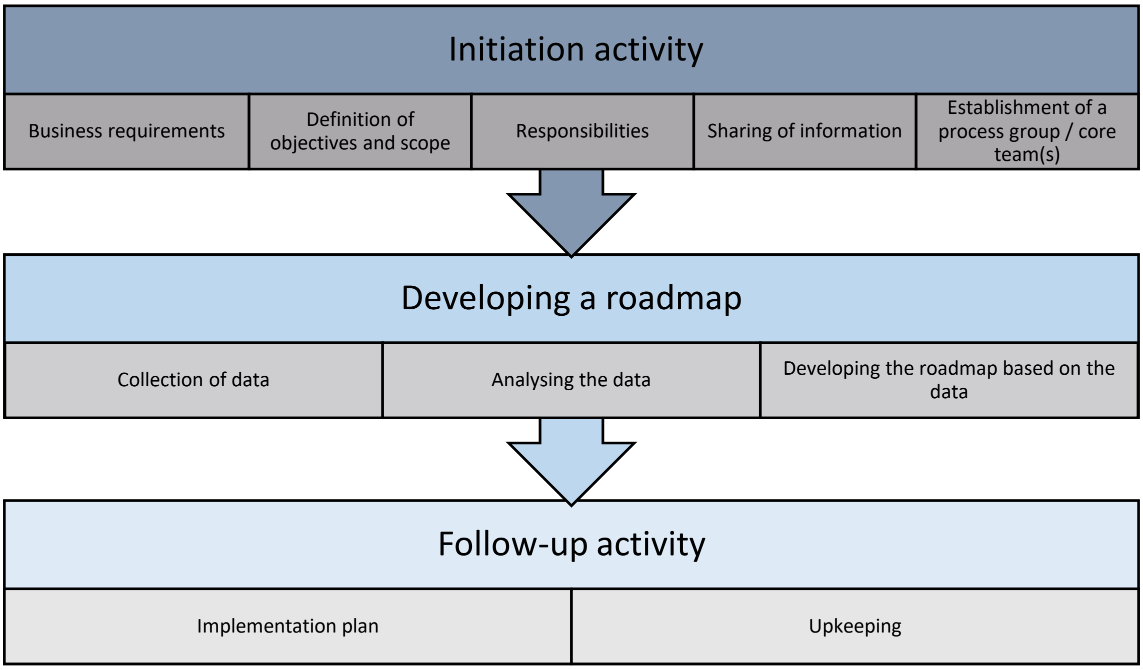

Figure 10. Roadmapping process steps in summary.

In summary, roadmapping processes vary widely depending on the company and the purpose, as there can be a wide range of differences between companies in terms of industry, markets, skills, technology, and budget. It should also be noted that the process of creating a roadmap is important, not just the roadmap itself. While creating a roadmap is a challenging task, implementing it is often even more challenging (Nimmo, 2013).

2.2.3 The benefits of roadmap

Roadmapping is a critical process for strategic planning, offering numerous benefits that enhance organisational alignment and future readiness. Schuh et al. (2013) emphasise its relevance in finding, analysing, and selecting strategic choices, allowing businesses to successfully achieve their goals. Cosner et al. (2007) point out, a roadmap can identify gaps and inconsistencies in the planning process, enabling a cohesive approach to manage risks and detect possible problems. This is especially significant for long-term strategic planning in industry since it identifies new technologies and processes and models their possible applications (Schuh et al., 2011).

Moreover, roadmapping promotes synergy across business units by identifying areas of similar effort, thus improving collaboration and efficiency (Cosner et al., 2007). A holistic approach also increases stakeholder engagement by considering cause and effect relationships and promoting shared understanding across departments (Cosner et al., 2007). It also prioritises investment proposals and business opportunities, clarifying the relationship between investments and their revenue potential. The core benefit of a roadmap is that it provides a tool for synchronising technology development with market objectives, clarifying future development paths and promoting continuous improvement by integrating technology investments into business strategies (Gindy et al., 2006; Schuh et al., 2013). Above all, a roadmap is a good tool to clarify structured processes to fully exploit technological opportunities (De Carolis et al., 2017). To conclude, the list of benefits of the roadmap is long and the benefits that can be gained from its adoption are significant.

3 Research methods

The choice of the appropriate research method depends on the specific aims and objectives of the study, as highlighted by Galletta et al. (2013). Thus, it is crucial to carefully select a method that is in line with the intended outcomes of the research project. This chapter explains the reason for using the Design Science Research Methodology (DSRM) in this study and highlights its applicability. Chapter also describes the qualitative data gathering method chosen, thus providing a comprehensive overview of the research framework.

3.1 Design Science Research

Design Science Research (DSR) is recognised as an effective problem-solving paradigm because it seeks to find solutions or improvements to real-world problems (Hevner et al., 2004). According to Hevner et al. (2004), the basis of design science research lies in addressing the research problem through the creation and evaluation of an artefact. Vom Brocke et al. (2020) succinctly summarise that DSR aims to provide insights into the creation of information systems, business processes and other entities to achieve desired goals. The artefact produced in DSR can be a construct, a model, an instantiation, or a method, if it facilitates the solution of the intended problem (Hevner et al., 2004).

Design research is characterised by the creation of new knowledge through artefacts that add to the knowledge base (Hevner et al., 2004). In DSR, researchers design and develop artefacts to solve specific problems or challenges in a particular field. These artefacts are not only practical solutions, but also sources of new knowledge that can enhance the existing knowledge base in the field (Gregor & Hevner, 2013).

Hevner et al. (2004) present a framework for how design science can be used in information systems research. Their aim is to provide clear guidelines for conducting and evaluating research. In practice, the framework is a seven-point list to help the researcher and reader understand the DSR requirements. All seven points are shown in Table 1, which also includes a column indicating whether the point in question has been implemented in this thesis.

Table 1. Design-Science Research Guidelines (Hevner et al., 2004, pp. 83).

Guideline	Description	Implementation in this thesis
1. Design as an Artefact	DSR should result in a sensible IT artefact that addresses the major organizational problems.	This thesis will create a roadmap.
2. Problem Relevance	The aim is to develop technology-based solutions to unsolved and critical problems. The relevance of the research will be determined by its ability to solve problems faced by professionals interacting with information technology.	The importance of the problem has been identified through literature and interviews with case company employees.
3. Design Evaluation	Evaluation methods should carefully demonstrate the utility, quality, and effectiveness of the design. Evaluation methods may vary according to, for example, the functionality and usability of the type of artefact.	The artefact is evaluated by professionals from the case company.
4. Research Contributions	Effective DSR must contribute to the creation of an artefact, to increasing knowledge about building and/or to increasing knowledge about the evaluation of an artefact. The contribution of research can be innovative artefacts that solve problems, or improvements in fundamental methods or evaluation metrics.	Artefact is a contribution, but also the process of creating it.
5. Research Rigor	Rigour means rigour in both the building and evaluation of the designed artefacts.	Reliable material used as literature and interviews conducted using appropriate method
6. Design as a Search Process	Research should be distinguished by seeking for the best answer that is well matched to the selected setting.	Literature is used to create the theory, but the artefact is created step by step by the company's employee to get the best possible result.
7. Communication of Research	The results of the research must be communicated to both the technology- and management-oriented public.	The construction and final version of the artefact of this work will be presented in this thesis, which will be published in Osuva. The artefact will also be presented in the case company.

3.2 Design Science Research Method

Peffers et al. (2007) establish a design science research methodology (DSRM) for conducting and presenting design science research in IS. They reviewed the existing literature to outline the characteristics of design science and key considerations for researchers conducting design science research. The method has proven to be a good one, as it is the most widely used DSR process in the field (vom Brocke et al., 2020).

The DSRM was chosen as the methodology for this study because of its scientifically proven effectiveness and its ability to generate artefacts. Since the aim of this thesis is to create a workable artefact, in this instance a roadmap, the DSRM in combination with a qualitative data gathering, is a viable research framework. The DSRM consists of six different activities, which are followed in this thesis. These six activities are shown graphically in figure 11 and explained in more detail below (Peffers et al., 2007).

The first activity is "Problem identification". In this first step, the research problem is defined in detail and the importance of the research is justified. This step is crucial, as effective problem identification and definition are essential for achieving the desired research outcomes. Second activity is "Define the objectives for a solution". The primary aim of this step is to determine study objectives closely aligned with the defined problem. The first two activities give direction to the research and are therefore important.

Activity three, "Design and development", involves the design of an artefact, which aims to outline its desired functionality and architecture while starting its creation. The transition from objectives to design and development is based on the use of theoretical knowledge applicable to the solution. The fourth activity, "Demonstration", means that the ability of the artefact to solve a real-world problem or problems must be demonstrated, for example through a case study, simulation, or other appropriate activity.

The fifth activity, "Evaluation", aims to assess how well the artefact generated solves the problem defined. Client feedback and satisfaction surveys are examples of relevant empirical evidence or logical proof that may be used in evaluation. The aim is to evaluate whether it is necessary to go back to activity three and continue development or whether it is possible to move on to the next step. The final activity six is "Communication". The last step is to make sure that the importance of the problem, its relevance and the solution provided by the artefact are clearly communicated in the relevant channels and to the relevant audience. Care must also be taken to ensure that the process is communicated in accordance with good scientific practice.

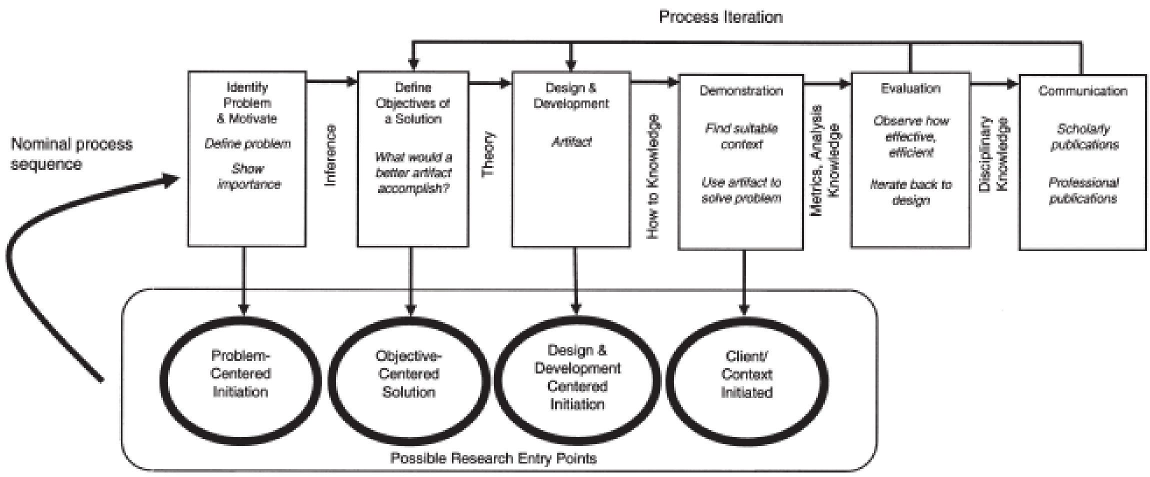

Figure 11. DSRM process model (Peffers et al., 2007, pp. 54).

As shown above, the process model presents a particular sequence of sequential activities, but it can start at any entry point (Peffer et al., 2007). Figure 11 presents "Possible Research Entry Points", the choice of which depends on why the research is being done and what it is intended to achieve. In this research, the entry point is the Problem-Centered solution.

3.3 Data gathering in Design Science research

Smuts and Van der Merve (2020) define four distinct areas of data collection for design science research, corresponding to the nature of the research. They have placed the four areas in the Information Systems research framework presented by Hevner et al. (2004). The framework is presented in Figure 12 and explained in the following in a brief way, as it helps to understand data collection in DSR and to select the best data gathering methods. The data collection areas of Smuts and Merve (2020) are then explained.

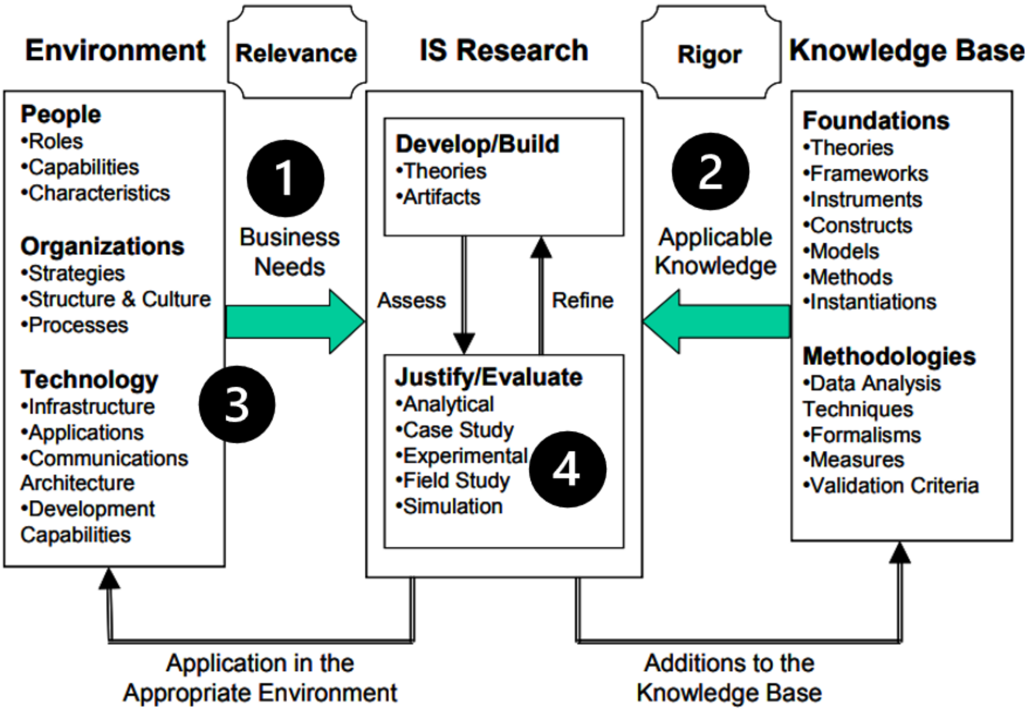

Figure 12. Information Systems Research Framework and data collection areas (adapted from Hevner et al., 2004).

Figure 12 shows the framework of Hevner et al. (2004), which can be divided into three sections. The Environment entity provides relevance and purpose of the research. The Environment is the set of people, organisation and technology that influence the definition of a business need or problem. The knowledge base consists of previous foundations and methodologies, thus providing information and possible models for research based on previous studies. In the middle, IS research consists of features of behavioural research, focusing on the development and justification of theories, and design science research, focusing on the building and evaluation of artefacts. Therefore, the environment and the knowledge base each play a significant role in IS research.

Numbers 1-4 have been added to Figure 12 to represent each of the data collection areas presented by Smuts & van der Merve (2020) in the DSR study. The first area is related to the identification of the relevance of the study, where the necessary information about the problem area must be acquired to create the artefact. The second area involves the collection of data from existing knowledge to facilitate the creation of the artefact. The third area is data collection, which should identify existing and established practices in the research environment that can help in the construction of the artefact. In the fourth data collection area, the artefact is evaluated in a laboratory or business environment to verify its usefulness.

Hevner (2007) presents a perspective in which Design Science Research (DSR) consists of three research cycles: the Relevance Cycle, the Rigor Cycle, and the Design Cycle. The Relevance Cycle connects the research project to its contextual environment, ensuring that the research addresses real-world problems. The Rigor Cycle links the research project to the existing knowledge base, which includes scientific foundations, experience, and expertise. In the Design Cycle, design artefacts and processes are built and evaluated within the research project. The aim is to iterate through these three cycles until the desired outcome is achieved.

A connection can be seen between the data collection areas identified by Smuts & van der Merven (2020) and Hevner's (2007) research cycles. Specifically, data collection areas 1 and 3 can be said to belong to the Relevance Cycle, while data collection area 2 directly relates to the Rigor Cycle. The third cycle occurs when the artefact is created, evaluated, and potentially further developed based on the evaluation. Thus, the data collection areas identified by Smuts & van der Merven (2020) can be considered well-suited for Design Science Research.

In this study, the first data collection will be conducted by interviewing the case company's employees relevant to digital transformation. These interviews will be open-ended and will aim to clearly define, through brainstorming, the objective of the study, the problem area, and other general questions. The second phase of data collection will involve a literature review to establish the theoretical framework. The third phase will consist of interviews with company experts to create an artefact. The final phase will involve interviewing the same individuals as in the first phase to assess the usefulness of the created artefact.

Interviews of the third data collections area in this thesis will be done in semi-structured form. The choice of semi-structured interviews as the data gathering method is due to several reasons. First, Smuts and Van der Merve (2020) consider it suitable for studies that follow the DSRM, while Tuomi and Sarajärvi (2018) state the advantage of interviews as flexibility and the possibility to self-select interviewees according to the needs of the study, for instance from specific departments. Galletta et al. (2013) add that semi-structured interviews help to create a so-called "story" in the interview, which allows to obtain qualitative and in-depth information from the interviewees.

Collecting and processing data from interviews is also an important part of the interview process (Galletta et al., 2013; Tuomi & Sarajärvi, 2018). Data is collected from the face-to-face interviews by recording and taking notes. The data analysis will follow Braun & Clarke's (2006) six-step framework, presented later. In general, the results of the interviews will be thematised to facilitate the creation of the final artefact. Because the interviews are interested in understanding phenomena and meanings in depth, just as qualitative research normally does, there is no need to collect how many times a certain thing has been said, but rather to understand why it is said (Tuomi & Sarajärvi, 2018).

4 Artefact development and the final artefact

This chapter describes how the research was carried out and the artefact was created according to the Desing Science research method of Peffers et al (2007). First, the problem identified, and the research objectives of the artefact are presented. Then, the artefact and its evaluation are presented.

4.1 Problem identification

In this thesis, the identification of the problem primarily originates from the case company. The business division of the case company is undergoing significant changes, both technically and in terms of business operations. The first meeting, held on 2.3.2024, openly discussed the problem and the thesis process. Attendees included the Processes and Tools Manager and the Business Development Manager of the case company. The digitalisation of production and related projects have been identified as important but challenging entities. Due to the challenges posed by technological development, clarifying the involved processes is considered a priority for the company. Investments in technology and the digitalisation of production are often very expensive, making it crucial to justify, prove their importance, and ensure their success.

The case company has defined "Smart digital goals" related to the digitalisation of production, intended to outline the various digital developments they aim to focus on. However, there is no plan for the digitalisation of production or for achieving the "Smart digital goals." This lack of a plan is perceived as a problem, necessitating a solution. It should also be noted that in today's competitive market, it is important for a firm to improve productivity and competitiveness, which is often possible in a manufacturing firm through technology (Schuh et al., 2013). This further justifies the importance of research.

4.2 Research objectives

After the problem had been explained and understood in detail, the next step was to define the study's objectives. It was important to define these objectives carefully and formulate them in a comprehensible manner, as they significantly impact the final study (Peffers et al., 2007). A dedicated meeting was held on 17.3.2024 to discuss the objectives with the IS Manager, the Business Development Manager, and the Processes and Tools Manager of the case company. These individuals formed the so-called "core team" for the duration of the study.

At the first meeting, it became clear that a roadmap for the digitalisation of production would be an effective solution to create a coherent and clear path. Therefore, the meeting on 17.3.2024 began with a brief PowerPoint presentation on the theory and benefits of the roadmap. The roadmap was selected as the artefact to be developed in the study. The following objectives were set for building the roadmap:

1. Create a roadmap to establish a strategic path that guides technology investments and improvements towards the company's future goals.
2. Involve people from different functions in the process to bring a broader perspective and knowledge to the roadmap.
3. Produce a roadmap relatively quickly, which can be easily modified and extended later.

In summary, the study aims to create a roadmap for the case company to help clarify future technological developments. For this reason, the meeting also decided that the roadmap should include only production-related elements linked to the digitalisation and continuous improvement of production. The aim is to use the roadmap to identify the development direction for each function and to identify potential technological gaps in achieving the goals. To do this, it is necessary to gather information from the most relevant functions by interviewing them about their future trends.

4.3 Design and development of artefact

The construction of the artefact starts with the defined problem and objectives (Peffers et al., 2007). Once the research problem and objectives were clear, the design of the artefact itself began. The meeting on 17.3.2024 also focused on the visual form and features of the roadmap that would best assist the case company. Several roadmap templates presented by Phaal et al. (2004) were reviewed, and their functionalities were discussed. Ultimately, the "Generalised Technology Roadmap Structure" presented by Phaal et al. (2013), as shown in Figure 9, was selected as the basis.

The top layer will be the "Strategy," which answers the question "Why?" This layer will be used to add the company's strategy, guiding all company activities. The next layer is called "Processes," which answers the question "What?" The content of this layer was discussed extensively with the core team to determine the appropriate level of detail for the roadmap. It was concluded that interviews would be used to collect the major elements related to the defined scope. For example, mentioning a desire for more "automation" in the interviews would be too broad. Conversely, specifying "automation of roller conveyors using technology X, connected to the network in a way Y, and using a roller conveyor from manufacturer Z" would be too specific. Collecting trends at a general level is desirable to identify possible similarities between objectives based on the collected data. For instance, if the future goal for logistics is automated forklifts and for maintenance is tracking and locating tools, the result may be to consider whether both could be achieved using ultra-wideband (UWB) technology. This approach aims to avoid numerous individual development projects and find entities that can benefit multiple areas.

The last two layers will be named "Technology" and "People & Skills." These layers answer the question "How?" The resources required by the objectives of the upper layer in terms of technology and skills will be added to these layers. Initially, it was considered to exclude the People & Skills layer, focusing strongly on the digitalisation aspect. However, it was ultimately decided that digitalisation is not useful if people do not have the skills to use the technology. This is strongly supported by the literature (see Nimmo, 2013; Cosner et al., 2007). It was therefore decided to build a very conventional roadmap, as usually technology roadmaps in companies are such that different layers are described along the y-axis and time is described along the x-axis (see Phaal et al., 2004; Gindy et al., 2006). The roadmap was defined to show five years ahead, meaning that visions for ten years ahead will not be considered.

At the same meeting, the second objective point was clarified. It was considered important to collect information from the most relevant departments and suitable persons for the digitisation of production. Table 2 lists the interviewees, of which there were 14 in total.

Table 2. Participants in the interviews.

Function	ID) Job title
Quality	1) Quality Development Manager 2) Quality Manager 3) Quality Control Manager 4) Supplier Quality Engineer
Production	5) Operations Manager 6) Production Manager
Maintenance	7) Maintenance Manager 8) Maintenance Supervisor
Logistics	9) Division Logistics Manager 10) Production Supervisor 11) Senior Customer Support Specialist
IS	12) IS Manager 13) Processes & Tools Manager 14) Business Development Manager

When the development of the artefact began, the process utilised guidelines from previous literature. The models investigated in the theoretical framework were used to clarify the essential steps involved in the roadmapping process to achieve optimal success (Phaal et al., 2004; Gerdsri et al., 2007; Phaal & Muller, 2009; De Carolis et al., 2017). Figure 10, presented earlier, summarises the roadmapping process using different sources. The roadmapping process can be generalised into three phases: initiation activity, developing a roadmap and follow-up activity. The purpose of this study is to follow the first two phases, as the third phase, creating a plan for integrating the entities added to the roadmap and updating the roadmap, was considered outside the scope of this study.

The aim of the first initiation activity phase is to define business needs and objectives, assign responsibilities, share information, and set up a core team for the duration of the project. The Design Science research methodology proved to be an excellent choice, as all the necessary definitions for the roadmapping process had already been made at this stage of the research. The following is a description of how the data collection for the Developing a roadmap phase of the study was carried out.

4.3.1 Interviews and analysis of findings

The data collection for the study was carried out by interviewing pre-defined employees from different functions of the case company. Fourteen people took part in the interviews, and people in the same function were interviewed at the same time. Thus, the number of interviewees per session varied from 2 to 4, depending on the function, for a total of five interviews. The order of the interviews was irrelevant, except that the interview with the IS function was scheduled last and conducted after data analysis. This decision was made as the aim was to first gather development needs from other functions, and then have the IS function assess these needs in terms of technological requirements.

Scheduling the interviews was challenging because the interviewees are very busy at their jobs. This was also the reason why no larger workshops were organised. It was found that, given the time available for the study, it was impossible to schedule a time that would suit employees from several functions at the same time. Overall, only one interview could be held at the time originally agreed and other interviews had to be rescheduled, some several times.

The interviews were held as semi-structured thematic interviews. The choice was influenced by the desire to gather informally the development needs of the departments, while remaining within certain themes. The interviews therefore had to be flexible, with a desire to select the people to be interviewed and to keep the interview process as free flowing as possible and to gain an in-depth understanding of the problem being studied. Semi-structured thematic interviews were found to be suitable for this purpose (see Galletta et al., 2013; Tuomi & Sarajärvi, 2018).

Initially, the interviews introduced the purpose of the study and briefly presented the roadmapping process in theory and the benefits it can achieve. The interviews were framed around themes:

1. The current state of digitalisation in the department.
2. The status/objectives to be achieved in the future?
3. How to achieve the objectives, i.e. what technologies and skills are needed.

In the interviews, the most important of the themes is the future state and developments, and therefore the most time is purposely reserved for this in the interviews. The interviews were each one hour in length. A very short four-question questionnaire was sent to the interviewees with the invitation to the interviews, to stimulate their thoughts on the themes of the interviews. The questionnaire is attached as Appendix 1. The interviews will be recorded for later transcription. The content of the interviews is opened at a very general level, as some of the issues discussed in the interviews are confidential.

The data are analysed using the six steps outlined by Braun and Clarke (2006). The first step is "familiarising yourself with your data," which in this study is done by transcribing the recorded interviews. The second stage is "generating initial codes," which involves marking clear entities related to the digitalisation of production in the transcribed text. The third and fourth stages, "searching for themes" and "reviewing themes," are carried out once all the interviews have been conducted. During these phases, the Mural platform is used to organise ideas on digital sticky notes. The fifth step is "defining and naming themes," also carried out on the Mural platform. The final, sixth step is "producing the report." After the interviews, the recordings were immediately reviewed, and clear production digitalisation entities were collected. Thus, steps one and two of the analysis were carried out immediately after the interviews.

The first interview was held with the Quality department on 2.5.2024. The interview included interviewees 1-4. The interviews identified a wide range of areas for improvement. The current situation of the department is that some projects related to digitalisation and automation have already been started, but there is still a lot of manual work that needs to be facilitated. One of the main topics discussed was traceability, which has been a big project in the department recently. A related project has encountered problems with data collection and lack of data structuring. For example, interviewee one stated, "(Current projects) required a huge amount of data structuring" and interviewee two, "There is actually a lot of data already available, such as humidity data, but it is challenging to draw conclusions and analyses from it."

The interview also raised concrete visions for the future, such as the use of machine vision for quality control. Figure 13 below presents the digitalisation of production related entities found after transcribing the interview. The entities are also defined in the table according to the criticality expressed by the department, with an indicative timeframe.

		Short-term	Medium	Long	Vision
Quality	Traceability (EX components)	x			
	Traceability (other components)	x			
	Data collection (must be made easier)	x			
	Old machines (data colllection methods)	x			
	Facilitating data processing		x		
	Data from tools to MES	x			
	Identification of parts at kitting phase				x
	FUD-report			x	
	The need for better reporting	x			
	Working instructions IMS migration	x			
	Machine Vision in Quality Control				x
	Leveraging machine learning for prediction				x

Figure 13. Digitalisation entities from the quality department interview.

A second interview was held with interviewees 5 and 6 on 7.5.2024, representing the production department. In production, there is currently a painting robot, several automated warehouses, and a MES for instance. A good amount of automation is already in use now, but both interviewees stated that the aim is to increase it in the future. Among other things, automation aims to make production more efficient and to make it easier for employees to carry out physically demanding tasks. Traceability, which was raised in the previous interview, was also seen as particularly important. In this context, data also generated a lot of discussion. Interviewees felt that nowadays the problems of automation and reporting are very much related to data. Interviewee 5 noted that an additional challenge to increasing automation and digitalising processes is posed by the products manufactured by the case company: ''We have to understand that there are a huge number of variant code combinations in the motors in this factory. It is often said that here, take digitalisation and use it, it will revolutionise everything. This is much easier said than done."

The interviews were varied, with both clear visions for the future, for example in terms of automation, and concrete developments to make the job of production workers easier.

Overall, the interview gave a comprehensive picture of the trends in digitalisation of production and of the needs. As in previous interviews, many of the developments were concerned about how data is collected and used, because in each area of development, data is the basis of functionality. In the interview, it was also emphasised that, although there are currently ongoing digitalisation projects, digitalisation is a continuous process and can never be fully completed. It is important to continue developing operations in the future also. This is exemplified by the red mark in Figure 14, which represents entities of the interview with the Production Department. This means that, even though the implementation of automated forklifts in production is already underway, there is a desire to make even greater use of them in the future.

		Short-term	Medium	Long	Vision
Production	Fully automatic painting robot(s)				x
	Assembly drawings for all motors			x	
	Machine Vision in Quality control				x
	Relevant and correct data used by production	x			
	Automatic flow in the confirmation of work steps (at the factory)	x			
	Digital HSE documents		x		
	Automation of stator and rotor disc stacking			x	
	More automated in-factory logistics	x		x	
	Traceability of motors/parts		x		
	Fully digitalised production workcard	x			
	Relevant and correct data used by production	x			
	Real-time reporting	x			
	Manageability of the order book		x		
	"Trade transfer" of scrapped motors				x
	Using AI in production planning and order book		x		

Figure 14. Digitalisation entities from the production department interview.

The third interview was held on 14.5.2024 with the maintenance department, attended by interviewees 7 and 8. The current situation in the maintenance department is that, for example, a lot of data is collected when measuring the energy consumption of machines. However, many documents are still in paper format. However, there is a strong desire to make extensive use of technology in the various processes of the department. The department considers it important to be able to collect more data from machines in the future in a harmonised way and to better analyse the data. The interviews also revealed that when purchasing new machines, it is essential to consider suppliers' requirements for connectivity. Overall, the interviews focused on data collectability, processing, and connectivity. The digitalisation entities of the maintenance department are shown in Figure 15.

		Short-term	Medium	Long	Vision
Maintenance	Automatic forklifts	x			
	Monitoring of machines	x			
	Faster connectivity for new machines (machine track)	x			
	A common, harmonised process on how to extract data from machines.	x			
	All maintenance documents in digital format		x		
	Predictive maintenance of machines			x	
	Facilitating the work permit process		x		

Figure 15. Digitalisation entities from the maintenance department interview.

An interview with the logistics department was held on 20.5.2024, with interviewees 9-11. The department uses automation, for example in the goods receiving area and in the shipping of motors. However, automation is only used in some cases and, for example not all goods are received automatically. There is also a lot of manual work, such as manual data searching, where the employees themselves use Excel functions to find information. The case company has a project underway to bring automated forklifts into factory. Various activities have already been carried out for this project in the background. During the interview, a particular amount of time was spent discussing the current biggest problem in logistics, which can be summarised as the lack of a well-defined demand for parts in production, which leads to most of the problems and where most improvement is wanted.

		Short-term	Medium	Long	Vision
Logistics	Visualisation (digital twin)		x		
	Specifying the actual schedule of parts needed (production start date accuracy)	x			
	Forecasting logistics-related scenarios			x	
	Receiving area automation		x		
	Development of reporting (e.g. "uncirculated goods")	x			
	Scrapping/redirection of parts due to trade changes		x		
	Automatic forklifts	x			
	Traceability of parts	x			

Figure 16. Digitalisation entities from the logistics department interview**.**

Once all interviews, except for the IS department, had been completed, the data analysis proceeded according to Braun and Clarke's (2006) six steps. Next, recurring themes were sought from the entities shown in Figures 13-16. The Mural platform was used to facilitate this process. Initially, all entities were added to sticky notes, which were then grouped.

The first finding was that it was easy to group the themes that emerged from the interviews, as similar themes recurred. Thus, right from the start of the analysis, it was evident that the needs for digitisation of production in the different departments were largely concentrated in very similar areas. Figure 17 shows the themes into which the sticky notes were divided. The themes are reporting, traceability, automation, and data and document management.

At this stage of the analysis, the original intention was not to consider how the entities that emerged from the interviews could be made technologically feasible. However, it became apparent during the analysis that many current problems and future objectives depend on similar entities. First, the importance of data is evident. Every department has a clear unified goal to collect more data, analyse it, and use it better for both decision-making and reporting. Additionally, several clear areas for automation improvement require well-managed master data. Facilitating connectivity is another entity that needs to be considered from a technological perspective, as it enables the collection of data from production machines and tools.

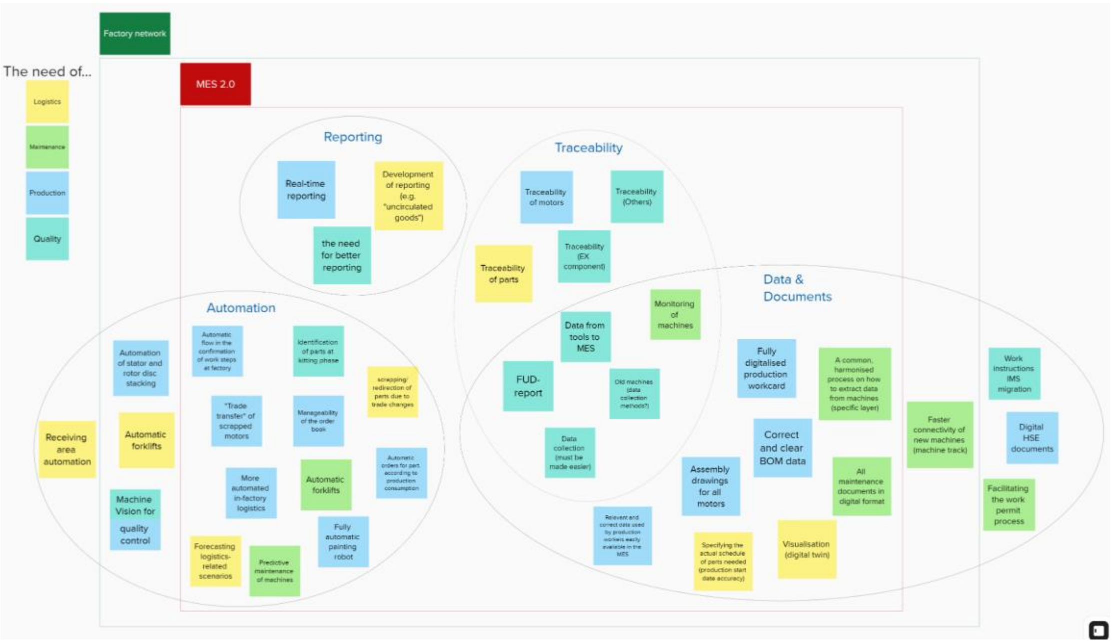

Figure 17. The results of the analysis.

In Figure 17, in addition to the four themes, two objects are shown: the factory network and MES “2.0”. The factory network is shown with a green box and the MES system with a red box. The entities inside the boxes are those that the factory network and the MES system could potentially solve. It is noteworthy that few of the digitalisation developments identified in the interviews are outside the two "technologies" presented. Although the company already has a MES system, the current system does not fully meet the needs of the departments. This is why the term MES “2.0" is used in Figure 17. "Factory network" refers to a unified architecture based on a specific protocol, allowing data to be collected from an increasing number of sensors and enabling maximum utilisation of the MES.

The case company already has a project underway to replace its current MES with a new one, but the project is still in its early stages. The project is known in different departments and therefore in each interview "new MES" came up. Interviewees commented, for instance: "Maybe the new MES will make this possible", "Hopefully the new MES will make this easier", "I wonder if this could be made easier with the new MES?"

After the analysis, the results were discussed with the IS department on 24.5.2024. Interviewees 12-14 attended this meeting. First, the results of the analysis were presented and discussed. It was noted that the analysis supports the need to pilot the new MES project as soon as possible to determine how effectively it can address development issues. The analysis was also critically assessed, as the entities requiring a new MES shown in Figure 17 can in some cases be implemented without a new MES. This led to a discussion on what can already be achieved with existing resources, as this information is crucial for the roadmap. Overall, it was concluded that improving data manageability is important.

As originally intended, the roadmap is not intended to define in detail the entities that emerged from the interviews, and nor the technologies, but to provide an overview of the situation. For this reason, the interviews with the IS department did not go much deeper into the discussion of technologies, as the analysis had actually reached a sufficient level. In terms of employee skills, it is worth noting that skills such as security, low code skills and equally data understanding and processing are skills that will be increasingly needed from employees in the future.

4.3.2 Final artefact

Peffers et al. (2007) state that the artifact of a DSR can be very broadly different once research input is included in its creation and design. In this study, the final artefact will be a roadmap created to facilitate the case company's path to digitalisation. The roadmap helps, among other things, to identify potential pitfalls and target technology investments wisely. The roadmap also helps you understand the big picture.

The structure of the roadmap is like the model presented by Phaal et al. (2013) but has been adapted in some parts to better meet the needs of the company. The roadmap is built based on the data collected and the timing of the different actions is done in such a way that the most critical processes and actions to be taken soon are shown on the left-hand side. The right-hand side is more focused on the vision and long-term goals to be achieved. The roadmap created for the case company is shown in Figure 18. The content of the roadmap is confidential.

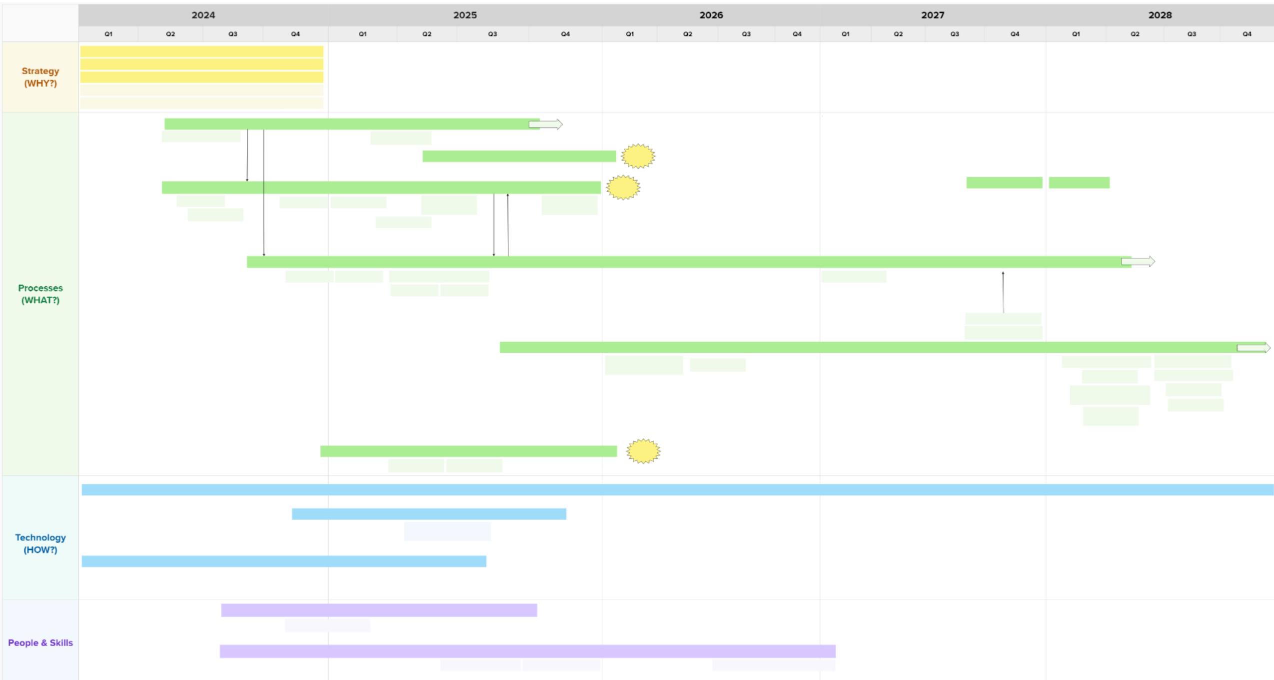

Figure 18. Final artefact: the roadmap.

Creating the final roadmap was not easy. As noted in the analysis, the future objectives of the departments are very similar. Based on the groupings from the analysis, the initial focus should be on data, followed by the development of reporting, traceability, and automation. However, simply categorising the roadmap at this high level does not provide a clear enough picture of the situation. Conversely, detailing all the necessary developments in terms of data collection and processing, traceability, reporting, and automation would result in hundreds of points and links in the roadmap, which is precisely what should be avoided (Blackwell et al., 2008).

The initial aim was not to describe any projects in detail, but rather to get an overview of needs so that the case company could prepare for future developments. With this in mind, the roadmap describes the entities in as much detail as they emerged from the interviews. The so-called backbone of the roadmap is the target company's "smart digital goals", the importance of which can be demonstrated by the future goals of the departments.

In summary, the roadmap shows the strong interconnectedness of the different entities and the overall picture. It is clear that following the entities presented in the roadmap will not automatically and unambiguously achieve a high level of digitalisation. It is worth noting that a roadmap is not an exact and absolute description of a process, but rather a tool for understanding and planning the big picture and predicting the future (Schuh et al., 2013; Cosner et al., 2007).

Hevner (2007) state that the outcomes of Design Science Research (DSR) can be diverse, including extensions to existing theories or methods, as well as entirely new artefacts, all of which contribute to the knowledge base. Consequently, after creating the final artefact, a description of the roadmapping process is developed, which can enhance the existing knowledge base on the subject (Gregor & Hevner, 2013). This process description also facilitates the achievement of the third objective set for the research, as it aids in the repeatability of the process in the future. Figure 19 depicts the various stages of the process.

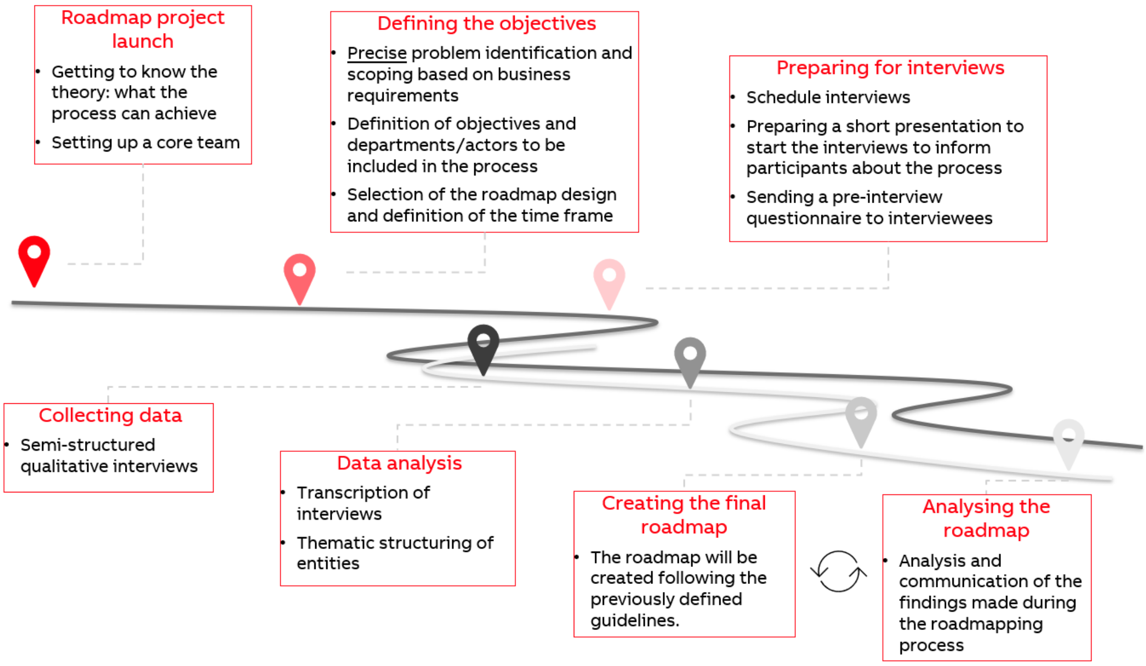

Figure 19. Description of the roadmapping process.

4.4 Demonstration, Evaluation and Communication

After the creation of the artefact, the next steps in the design science research methodology developed by Peffers et al. (2007) are demonstration, evaluation, and communication. The demonstration of the artefact in this research can be shown through a practical example in a business environment. Following data analysis and the creation of the artefact, a diagram of the data analysis and the final roadmap, as shown in Figures 17 and 18, has been created. As originally intended, the artefact can be used to clarify and communicate the evolution and current state of digitalisation, helping to focus on the right areas to achieve the objectives. Thus, the results obtained during the roadmap process can be used to define new requirements and justify the importance of implementing a new system, for example in an existing MES project.

The evaluation was conducted with the supervisor from the case company involved in this thesis. The aim was to assess whether the study's objectives had been met. In summary, the objectives were to create a roadmap to clarify future goals for the factory's digitalisation, involve employees from various functions in the roadmapping process, and develop a roadmap within a relatively short timeframe that could be updated later.

During the evaluation interview, it was discussed that the roadmapping process provided a good overall picture of the case company's digitalisation status. Firstly, it was clearly found that the digitalisation goals of different functions were well-aligned and there was a strong desire for digitalisation. The company recognises the significant benefits of digitalisation. Secondly, an understanding of the short and long-term goals of various functions was achieved, which will help guide operations in the right direction.

The evaluation indicated that the research clarified that the similarity in the future goals of the case company's functions enables projects that benefit multiple functions broadly. It was considered important that this finding highlights the possibility of achieving wide-ranging benefits through larger projects that support many functions, rather than focusing solely on projects that benefit specific functions.

The roadmap was created quickly in the thesis, and the Mural platform was used for the first time for this kind of purpose. This was seen as a positive aspect, as the company is now well-prepared to repeat the roadmapping process. However, the roadmap created does not unequivocally guide operations towards future goals. This is due to the initially defined scope of work and expectations being somewhat unclear or overly ambitious. Overall, the work was satisfactory and is considered a good informative start towards a more digitalised future, even though the roadmapping process produced more valuable information than the final roadmap itself.

As for communication, two actions will be carried out. First, the thesis will be presented to the case company, where the findings will be presented. It is desirable that, after the introduction of the results, the similarity of the long-term objectives of the departments is internalised, which will allow developments to be steered in a coherent way towards smarter manufacturing. The thesis will also be published in the University of Vaasa's open access repository Osuva.

5 Discussion

This master's thesis was conducted in collaboration with the case company, aiming to create a roadmap to illustrate and guide the direction of digitalisation development and to clarify the overall picture of the company's different departments' digitalisation priorities. By understanding these priorities, the company can better direct its operations, investments, and expertise towards areas needing development. The roadmap was created to first understand the needs of the departments and then, through analysis, identify potential gaps and areas for improvement. It was also designed to help communicate and guide future developments regarding the digitisation of production.

The research was conducted as Design Science research, which proved to be an excellent research method due to its ability to create artefact, in this case, a roadmap. The study also produced a step-by-step guide to the roadmapping process so that it could be easily repeated in the future. Two research questions were set at the start of the study to support the desired outcome. The first research question, " What is Industry 4.0 and how to benefit from it?" can be answered based on the theoretical framework. The second question, "What factors need to be considered and what gaps may arise during the digital transformation of the factory in the case company?" can be addressed through the Design Science Research.

To answer the first research question, Industry 4.0 refers to the present trend of automation and information sharing in manufacturing technologies. The essence of the concept is that it focuses on the seamless, real-time interconnection of people, machines, objects, and ICT systems, both horizontally and vertically. The aim is to enable dynamic control of complex systems (Trappey et al., 2016; Ahuett-Garza & Kurfess, 2018). Although Industry 4.0 is a concept that can be understood very differently by various companies, it is important to note that a deep understanding of it and the practical implementation of related technologies facilitate smart manufacturing which, in turn, increases production productivity.

To answer the second research question, a study was conducted in which an artefact was created. Data were collected through interviews, providing a comprehensive overview of the current state of digitalisation across departments and the major future needs for the development of production and operations. The study particularly focused on future goals that can be achieved by enhancing digitalisation. When analysing the interview results, the first finding was that the themes of development needs were very similar. Different departments emphasised slightly different development areas in terms of importance, which is understandable, but overall, the themes were similar. Based on the interviews, clear development themes include reporting, data and document management, traceability, and automation. It is important to note that there is interdependence within these development themes. For instance, many aspects of traceability cannot be achieved without organising the data first.

The purpose of the first research question was to explore the theory and potentially find new perspectives, such as new technologies, and learn about their usefulness and possible impact and implementation in business. This aimed to enable the addition of important development areas to the roadmap through theoretical insights, which might not otherwise emerge. However, the interview results were surprising as only a few issues raised were not connected to Industry 4.0. Overall, the knowledge of Industry 4.0-related technologies within the target company’s departments is already at a good level, and their added value and usability in various operations are clearly recognised. It is also noteworthy that the departments’ desire for development is strongly aligned with Industry 4.0.

After conducting the study and creating the roadmap, it is possible to answer the second research question. When adding development areas to the roadmap, the interconnections between them became even clearer. During the roadmap creation, it was observed that many projects cannot start or be implemented until another actions, such as data collection or organisation, is completed. This posed a challenge in creating the roadmap, as placing the development areas was not straightforward due to the many interdependencies. However, the roadmap indicates that many projects cannot commence until the data is organised or collected. Conversely, the desired data cannot be collected without several preliminary actions. Therefore, the roadmap does not detail everything precisely but provides a general overview.

Factors to consider based on the study include the similarity and interdependence of the departments' development areas. With the right projects and investments, it is possible to simultaneously benefit multiple development areas. A long-term perspective would be beneficial, although some departmental development areas can already be implemented with current resources. For example, the quality department has started collecting data from certain devices and built the necessary infrastructure to upload this data to the cloud. This solution serves only one department and one purpose. However, the data still needs to be manually retrieved from the cloud and processed as needed. Alternatively, the process could involve a ready IT infrastructure in the company that allows data collection in one place, such as collecting desired values directly from the production tools into the MES.

The study identified two technological solutions that could address several development needs across different departments. These two improvements are the factory network and a more advanced MES. It is clear from the various departments' development that connectivity is increasing, and there is a desire to collect and process data better and more extensively. Investing in a factory network that meets the requirements and an advanced MES would standardise and, above all, enable future and long-term development areas. This would prevent departments from having to carry out separate data collection projects. A MES project is already underway in the company, and the study supports the significance of its completion and implementation.

Previous literature strongly supports these findings. Frank et al. (2019) emphasise that vertical integration is the first component that must function to achieve smart manufacturing. Wang et al. (2016a) also describe, in a previously presented figure 5, the layers required for a smart factory. This description also aligns well with the high-level needs of the case company. Bauernhansl et al. (2016) stress that the goal of the Industry 4.0 concept is not to implement a vast amount of digitalisation in the factory but to focus on the potential enabled by the real-time networking of technical systems. Therefore, attention should be given to basic aspects such as data quality and its uniform collection and connectivity, to further develop operations later.

Overall, the company is undoubtedly on the right track, but the shortcomings identified are significant and will not be implemented in a large company in an instant. In particular, the potential of the factory network should be carefully considered, and preparatory measures should be started as soon as possible. The roadmapping process also resulted in a roadmap and a comprehensive overview of the future needs of the departments, which should also be considered. Overall, in this study, the knowledge gained through the roadmapping process is even more important than the roadmap itself, as often noted in previous literature (see Phaal & Muller, 2009; Nimmo, 2013; Cosner et al., 2007).

A limitation of the study is that the evaluation cycle typical of DSR research was performed only once due to time constraints. Although the results of the study were satisfactory on the first attempt, evaluation could have also been done by department. This would have provided a more detailed roadmap. However, it is impossible to create a roadmap that ensures seamless and fully guaranteed success in digitalisation. Digitalisation and related aspects are so vast that it is difficult to determine the level of detail for the roadmap. For this reason, the final roadmap includes items with varying levels of detail.

In the future, the process conducted in this study should be repeated to further evaluate its effectiveness and achieve a more precise result. The roadmapping process should also be performed in a different unit or company to verify the applicability of this study in other environments. It would be interesting to explore whether a more detailed and information-rich roadmap could be created if each department initially created its own roadmap, which would then be combined into one. Additionally, an essential aspect from a business perspective, the financial viewpoint, should be explored to determine how it could be easily integrated into the roadmapping process.

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Appendices

Appendix 1. Preliminary Survey.

Towards a smarter factory - Roadmapping

About the questions:

The questions in the questionnaire are formulated in a very open-ended way on purpose. There are no right and wrong answers, but answers to questions are allowed to be pure "thought flow". I ask you to answer the questions from the point of view of your job role, i.e. if you work in a quality department, for example, the answers should be related to the development of quality processes.

1. **What is the current state of digitalisation in your department?** (e.g. do you feel that you are in the early stages of digitalisation: is there still a lot of manual "pen and paper" work in your department. Or is automation and digitalisation already widely used in different processes?) *

   Enter your answer

2. **What is the situation you would like to achieve/be in in the future?** (you can answer this with very concrete and also ambitious specific things for your department, such as: "operational reporting accurate and real-time", "all forklifts automated", "use of AI in predictive maintenance of production equipment." etc.) *

   Enter your answer

3. **What skills/knowledge are required from employees to achieve the objectives?** (For example, is it assumed that better office365, programming, PowerBI skills are necessarily required?) *

   Enter your answer

4. **How will management and reporting change as digitalisation progresses?** (Do you see opportunities/eases in management with digitalisation? For example, could it be easier for a supervisor to inform employees, could AI take care of machine maintenance scheduling, how could reporting evolve to better meet the needs of your department?) *

   Enter your answer