A roadmap design for implementing digital production technology

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TABLE OF CONTENTS

1. Introduction

1.1 Research gap

“Innovate or die”, is a saying that most firms tend to follow closely. That is why in recent years, digital transformation has been a subject of attention and exploration for many manufacturing firms (Matt et al., 2015). Digital transformation encompasses a process that aims to improve an entity through the implementation of information, computing, communication, and connectivity technologies (Vial, 2021). The process is often linked to industrial improvement, due to its great potential for production technologies; all measures and facilities for the industrial production of goods (Liere-Netheler et al., 2018). Digitally transforming production technology, by integrating the above-mentioned technologies, enables organizations to improve their production efficiency, flexibility, and resilience (Matt et al., 2015; Tortorella et al., 2022). Therefore, it is believed that the successful implementation of digital production technology (the production technology that possesses the digital technologies) should play a vital role in improving an organization's performance and maintaining or even gaining a competitive advantage (Buer et al., 2021). However, the innovative and changing characteristics of the digital technologies that are integrated within the implemented production technology remain a challenge to organizations and people (Liere-Netheler et al., 2018).

The innovative and changing characteristics of the digital technologies that are integrated within the implemented production technology cause companies often to encounter barriers during the implementation process. Such barriers can occur in numerous areas. Most often, companies stumble upon the fact that their organizations (and their employees) misses the skills and knowledge to operate and control the new technology (Vogelsang et al., 2019). For that reason, or for individual reasons such as for instance a fear of loss of a job, employees might act resistant to the digital transformation plan (Vogelsang et al., 2019). Other organizations find out that their current physical or digital infrastructure is not suitable for the new technology or that they have insufficient time and financial resources to complete the implementation process (Vogelsang et al., 2019). The barriers cause investments in (new) digital production technology often to be criticized for not meeting expectations at all, or within the desired period of time (Garrido-Vega et al., 2015). Vogelsang et al. (2019) even stress how barriers can entirely terminate a digital transformation process within an organization. It has thus become increasingly important for firms to develop a well-defined digital transformation strategy that ensures the successful implementation of digital production technology (Albukhitan, 2020).

According to the digital transformation strategy development guideline of Albukhitan (2020), it is crucial for organizations to create an implementation roadmap. The implementation roadmap that he mentioned would function as a plan with a timeline that visualizes how the company seeks to reach its goal; implementing digital production technology. The roadmap would consist of sequential process steps, actions within the process steps, and a division of responsibilities for those actions. Such an implementation roadmap would enable organizations to easily manage and communicate plans and expectations throughout the organization. Also, it enables the organizations to identify and plan the actions that need to be undertaken, Lastly, it enables organizations to identify what human and capital resources need to be present during the various process steps to undertake the actions and realize a successful implementation of the production technology. Thus, it would also help them to plan if, when, and how these human and capital resources need to be acquired or prepared to have them present at the required moment in time. For example, by using the implementation roadmap, Company X identifies that it needs 10 employees that are able to operate the production technology at moment Y in time. As a result, they are now able to plan which actions they need to undertake to make sure that the human resources are in place at moment Y; are they going to train or educate current employees or are they going to hire new employees, when does this need to happen and who in the organization do they make responsible for this task? Consequently, the implementation roadmap can be used by all stakeholders throughout the entire transformative process and it enables organizations to provide required support and minimize disturbances.

Approaches to implement new production technology exist in literature. For instance, the approaches of Goodman and Griffith (1991) and Harrison (2004) indicate the various processes through which an organization can adapt itself to integrate/implement the new technology. However, from their approaches does not become clear when the actions within each process should be undertaken which causes unclarity. Moreover, the approaches focus on the implementation of new production technology and do not necessarily specify how digital characteristics of a production technology potentially influence the approach. Contrary, the approach of Plinta and Radwan (2023) gives process steps through which an organization can implement a new technology. Yet, their model does not include specific actions that need to be undertaken during those process steps nor does it imply the changes that need to be made so that the technology can be implemented. From the shortcomings of both approaches can be stated that they don’t function as a plan with a timeline that visualizes how the company seeks to reach its goal; ‘a roadmap’, as described by Albukhitan (2020).

Contrarily, existing research on digital transformation has focused on exploring the concept of ‘digital transformation’ rather than on developing a roadmap for implementing digital production technology to achieve digital transformation. For instance, in his developed framework, Matt et al. (2015) propose the basic foundation of digital transformation which consists of four transformational dimensions of digital transformation; financial aspects, structural changes, changes in value creation, and the use of technologies. Other research identified how integrating digital leaders within an organization is one of the most important best practices for managing the dimensions of transformation and achieving a successful digital transformation (Romero et al., 2019; Fernandez-Vidal et al., 2022; Van Veldhoven & Vanthienen, 2022; Cichosz et al., 2023). It could be even argued that a digital transformation process, or the implementation of digital production technology, is a management challenge (Hess et al., 2016). They are able to initiate, organize, and fulfill many other success factors of digital transformation, such as creating an urge for and promoting change throughout the organization, fostering open communication, developing employee and partner engagement, aligning business strategies, setting up employee training and skills development, creating an organizational culture that is open for change/innovation and willing to learn, leveraging internal and external knowledge, and standardizing processes and data integration (Romero et al., 2019; Kraus et al., 2021; Van Veldhoven & Vanthienen, 2022; Cichosz et al., 2023). Despite the importance of managerial roles in digital transformation, there is a lack of guidance on how they can integrate the best practices into a digital transformation strategy or implementation roadmap. This can lead to difficulties in identifying necessary actions, allocating resources, and dividing responsibilities.

Based on the findings, it becomes evident that digital leaders and/or managers play a crucial role in the success of a digital transformation. However, there is a lack of knowledge on how these digital leaders can integrate the identified best practices into existing implementation approaches to develop a comprehensive digital transformation strategy; their roadmap for implementing the new digital production technology (Albukhitan, 2020). As a result, managers may face challenges in identifying necessary actions or resources, and/or dividing responsibilities. This lack of clarity can negatively affect the overall quality of the digital transformation strategy and can potentially cause an unsuccessful outcome of the transformation. To address this issue, it can thus be concluded that there is a managerial need for an implementation roadmap that visualizes both the steps of the process as well as the actions and best practices through which an organization can acquire a new digital production technology and adapt itself to integrate/implement it. This is supported by Mellor et al. (2014) who indicated in their paper that project managers of new and disruptive digital technology should have an implementation framework to guide their adoption efforts. Matt et al. (2015) add to this by stating that it is also important to identify the role of external parties during the implementation process as it can potentially be beneficial to the result. The roadmap should enable organizations and their managers to plan and incorporate best practices and actions, allocate responsibilities, and identify and allocate the required resources to ensure a smooth and successful transformation. It must function as a plan with a timeline that visualizes how the company seeks to reach its goal and it should contribute to an organization's ability to innovate, to ensure they won't die.

Based on the collected information, it can be stated that there is a research gap in the existing literature. The identified research gap can be formulated as:

There is no defined roadmap for implementing digital production technology, consisting of sequential process steps, actions within the process steps, and a division of responsibilities for those actions, that organizations can use to successfully manage the digital transformation of their production technology

1.2 Research goal

As discussed in Section 1.1, a defined roadmap for implementing digital production technology, consisting of sequential process steps, actions within the process steps, and a division of responsibilities for those actions, that organizations can use to successfully manage the digital transformation of their production technology, has not yet been developed. This created the research gap that this research aims to fill. Thus, the goal of this research is to:

Map out how organizations can successfully manage the digital transformation of their production technology by using a roadmap for implementing digital production technology that consists of sequential process steps, actions within the process steps, and a division of responsibilities for those actions

A research question should be a precise indication of the insights that must be obtained to achieve the research goal. Therefore, the research question is formulated as:

How can organizations successfully manage the digital transformation of their production technology, using a roadmap for implementing digital production technology that consists of sequential process steps, actions within the process steps, and a division of responsibilities for those actions?

The answer to the main research question would be a 'general roadmap for implementing digital production technology' that consists of sequential process steps, actions within the process steps, and a division of responsibilities for those actions. Such an implementation roadmap must enable digital leaders to manage and communicate plans and expectations throughout the organization. Also, it must enable the digital leaders to identify which actions need to be undertaken and what human and capital resources need to be present during the various process steps to undertake the actions and realize a successful implementation of the production technology. Thus, the roadmap would function as a tool that digital leaders can use to implement digital production technology in their organization. It will confirm existing literature and build upon it by combining the loose components that have previously been identified with new information from this research to ultimately develop the roadmap for implementing digital production technology.

An answer to the formulated research question is intended to be found by analyzing the processes through which end-users of production technology have implemented new digital production technology within their organization. The main research question is divided into several sub-questions to create structure in the research. Each sub-question aims to answer a specific part of the main research question which is further discussed in the following section.

1.2.1 Sub-research questions

The formulated sub-research questions form the backbone of this research. The combined answers to the sub-research questions will help formulate an answer to the main research question. The sub-research questions are discussed below combined with a brief elaboration on how the questions will be answered.

1. *How can a digital transformation of production technology be defined?*

To be able to develop a roadmap for implementing digital production technology, it is first important to understand how a digital transformation of production technology can be defined. Therefore, a literature review will be conducted to outline and define a digital transformation of production technology. In doing so, the core of the transformation process, the actual change that is happening/implemented, is identified and given a scope. The collected literature findings from this sub-research question will function as the basis for the following sub-research questions.

2. *When can a digital transformation of production technology be considered successful?*

Assessing if a digital transformation of production technology is successful can be difficult. For that reason, a framework will be created with which the performance of a production technology can be assessed. By analyzing the performance of the production technology, it can be assessed whether or not the objectives (or planned performance for the production technology) of a company are reached. However, it is also interesting to identify how the implementation of the production technology has affected the work environment of involved employees and the organizational performance (both operational and financial). Thus, the assessment framework will be developed through a literature review that enables the identification of key performance indicators (KPIs) for (digital) production technologies, people, and organizations. The developed framework of KPIs will function as a tool for answering sub-research question 5.

3. *What are known best practices for implementing digital production technology within an organization?*

Once the assessment framework is developed, it is interesting to understand what is currently known about approaches and best practices that are used to successfully implement digital production technology and/or achieve a digital transformation. A literature review is conducted to identify best practices (or key activities) for implementing digital production technology in the existing literature. The findings will function as input for the implementation roadmap. Also, findings from the literature review can be confirmed during the case studies.

4. *Which actions have been undertaken by whom and at what moment in time during the implementation process of the digital production technology?*

Before the performance of the production technology, involved employees, and organization can be assessed, a glance must be cast at how the companies have implemented the digital production technology within their organization. More specifically, a deeper understanding must be created of how the organizations have implemented the digital production technology within their organization through which they aimed to achieve the objectives and/or digital transformation. A qualitative research method will be used to collect data from end-users of production technology on [1] the process steps that they used during the implementation process, [2] the actions that were carried within the process steps, and [3] the people who were responsible for/carried out these actions. An analysis of the collected data, and a comparison between cases, will give a better understanding of similarities and differences.

5. *What are key activities and barriers that impact the performance of the implemented production technology, involved employees, and organization?*

It is important to understand which (key) activities and barriers impact the performance of the production technology, involved employees, and organization. To do so, an insight must be created at what performance level the companies had planned for the production technology, involved people, and organization and how this differs from the actual performance after implementation. This performance assessment is done using the previously developed framework. By using the assessment framework, potential over- and underperformances of the production technology, involved employees, and/or organization on specific KPIs can be identified. The identification of over- or underperformances enables a root-cause-analysis (RCA) through which key activities and/or barriers potentially can be identified that caused these differences in performance.

6. *What changes to the implementation process could have improved the eventual performance of the implemented production technology, involved employees, and organization?*

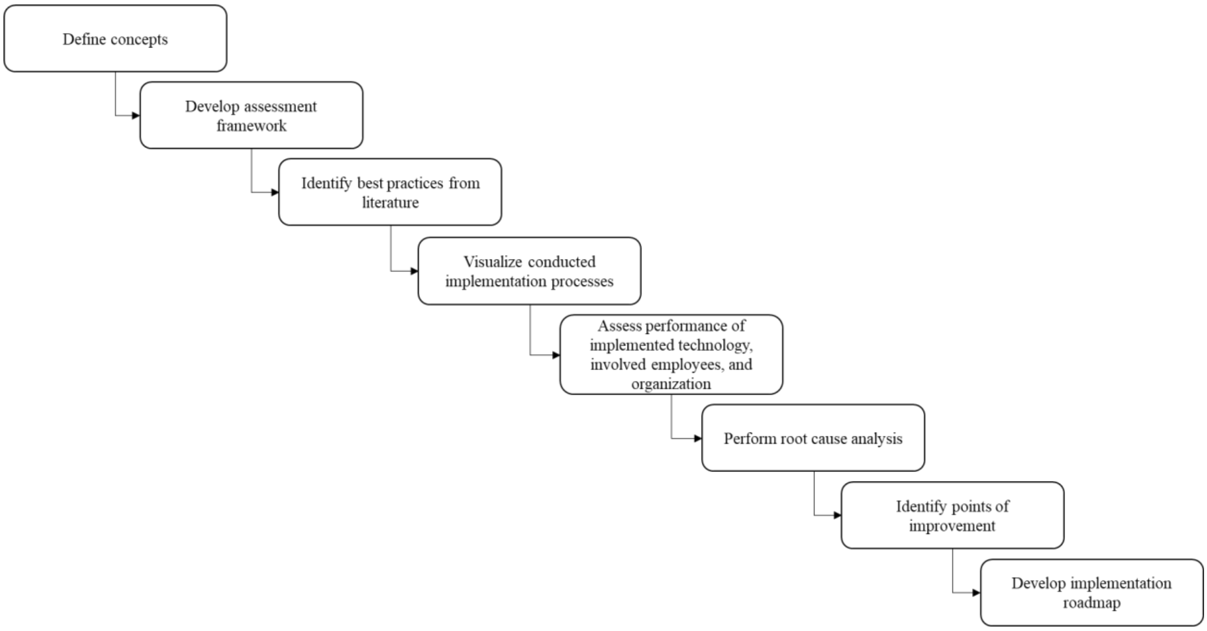
Answering sub-research questions 4 and 5 provides insight into past processes and their ultimate impact on the performance of the production technology, involved employees, and organization. A better understanding must be created about which changes to the implementation process the end-users of the production technology believe would have improved the success of their technological investment. This includes changes to the process steps, actions that need to be undertaken during the process steps, and the involved actors who carry out the actions. A comparison between cases will give a better understanding of potential similarities and differences.

A combination of successful processes and key activities from the past (information retrieved to answer sub-research questions 3, 4, and 5) and points of improvement (information retrieved to answer sub-research question 6) will be used to develop a roadmap for implementing digital production technology within an organization that consists of sequential process steps, actions within the process steps, and a division of responsibilities for those actions. The developed framework will function as an answer to the main research question.

The sub-research questions and main research question are answered sequentially. The research steps can be seen in Figure 1 on page number 9.

Figure 1.

Research Steps of Research Questions



1.3 Methodology

1.3.1 Business case

This research is performed at Demcon Industrial Systems Enschede BV (DIS), located in Enschede, the Netherlands. The company is an independent part of Demcon Group, a technology provider with about 1000 employees and a wide range of technical expertise. DIS develops, creates, and supports technical solutions for the production industry, and wants to be a "Partner for production technology". The technical solutions are mostly accompanied by internally developed (PLC) software. They can provide customers with smaller custom semi-automatic modules or even with complete full automatic turnkey production machines. At DIS, the customer is closely involved in the development of a solution to create a perfect fit.

The research is performed at DIS because they are a supplier of production technology. Consequently, they are in contact with companies that have implemented digital production technology within their organization. Additionally, DIS is interested to identify if its role and contribution as a manufacturer and supplier of production technology in the implementation process can be improved. By studying the experiences of end-users, DIS can analyze and identify areas where they can improve their support and assistance to organizations adopting a production technology. This aligns with the perspective put forth by Matt et al. (2015) that highlights the potential benefits of an external actor during the implementation process of digital production technology/ digital transformation.

1.3.2 Company selection

As discussed in Section 1.2, the goal of this research is to map out how organizations can successfully implement digital production technology to achieve a digital transformation by using a roadmap that consists of a schedule of actions and a division of responsibilities. Consequently, the participating companies need to be production companies that have implemented digital production technology within their organization. No other requirements were imposed on the participating companies as it is interesting to analyze what other factors might be of influence during the implementation process of production technology. At first, companies were selected solely from the customer pool of DIS. However, it was chosen to also select companies outside of their customer pool to increase the sample size. These companies were found via the internet using the same selection criteria as discussed above.

1.3.3 Data collection method

Two data collection methods will be used throughout this research; literature review and semi-structured interviewing.

A literature review is conducted to form a knowledge base. The knowledge base is necessary to create an understanding of the subject and answer sub-research questions 1, 2, and 3. A first literature review is conducted to define the digital transformation of production technologies and answer sub-research question 1. Additionally, a second literature review is conducted to develop a framework with which the performance of the implemented production technology, involved people, and organization can be assessed. This ultimately answers sub-research question 2. As discussed in Section 1.2.1, the literature review that is used for the development of an assessment framework consists of exploring scientific journals, papers, and books. A combination of these sources enables the development of a broad yet also specific framework of KPIs. Lastly, a third literature review is conducted to form a knowledge base on best practices for implementing digital production technology. The knowledge base that is created during that literature review is used to answer sub-research question 3 and formulate specific questions for the RCA and follow-up questions during the RCA.

The primary goal of sub-research questions 4, 5, and 6 is to collect data on the processes through which the interviewed companies have implemented their digital production technology. Another goal is to identify key activities and barriers that have had an impact on the performance of the implemented production technology, involved people and organization. Such understanding can be created through interviewing; a qualitative research method (Fossey et al., 2002; Patton, 2005; Jackson et al., 2007; DiCicco-Bloom & Crabtree, 2007). Qualitative interviews can either be structured, semi-structured, or unstructured. Similar to this research, structured or semi-structured interviews aim to grasp a deep understanding of one or more pre-determined topics, using an interview guide (Fossey et al., 2002; DiCicco-Bloom & Crabtree, 2007). The interview guide is used to formulate open-ended interview questions so that the flexibility and responsiveness from the interviewer as well as from the interviewee are increased (Jackson et al., 2007). Semi-structured interviewing, compared to structured interviewing, allows for follow-up questions to the answers to the open-ended interview questions that might differ between interviewees. For that reason, semi-structured interviewing using open-ended interview questions is chosen as the data collection method for answering sub-research questions 4, 5, and 6.

The framework of Kallio et al. (2016) will be used to develop an interview guide for the semi-structured interviews. A structured process for the development of an interview guide has been chosen because it contributes to the objective and trustworthiness of the research which makes the results more plausible (Kallio et al., 2016). Five steps to the development of an interview guide for semi-structured interviews can be identified in the framework:

1. Identifying the prerequisites for using semi-structured interviews
2. Retrieving and using previous knowledge
3. Formulating the preliminary semi-structured interview guide

4. Pilot testing of the interview guide
5. Presenting the complete semi-structured interview guide

The identification of the prerequisites for using semi-structured interviews has previously been discussed in this section. Previous knowledge will be retrieved and used throughout Section 2 of this research. The scope of the literature reviews was to gather an overview of previous knowledge. Retrieved knowledge is used to develop a KPI framework with which the performance of the production technologies can be assessed and to formulate open-ended interview questions. Both will be integrated into the preliminary semi-structured interview guide. Due to the limited number of companies that can be interviewed for this research, it has been decided to conduct the pilot test of the interview internally at DIS. The complete semi-structured interview guide will be used during the interviews and can be seen in Appendix A. An overview of the results of the interviews is given in Section 3.

1.3.4 Data analysis method

A qualitative data analysis method consists of segmenting and reassembling the collected data to transform the data into findings (Boeije, 2010). Because the data is transformed, careful considerations should be made on the actions taken so that transparency and validity of the findings are ensured (Linneberg & Korsgaard, 2019).

Analysing qualitative data is done through two fundamental approaches; the inductive and deductive approaches (Burnard et al., 2008). A deductive data analysis approach involves using a structure or predetermined framework to analyse the data whereas the inductive approach uses the data itself to create a structure of analysis. This research relies on an inductive data analysis approach as no developed frameworks are used to analyse the collected data. The most commonly used inductive method of analysis is that of thematic content analysis (Burnard et al., 2008). The method rose from grounded theory methodology in which a theory is developed from the data rather than imposed upon it (Burnard et al., 2008; Blair, 2015). Three stages of coding can be identified in the method: 1) open coding, 2) axial coding, and 3) selective coding (Blair, 2015).

First, a summary statement will be developed for each subject that is discussed in the interview transcript. Then, similarities between the open codes are identified so that overlapping categories can be formulated. A final step in the process is selective coding. Finally, a grounded theory is developed from the identified axial codes.

This research aims to explore a process that outlines how manufacturing companies can successfully implement digital production technology and manage a digital transformation. In doing so, a new, grounded theory is formed. For that reason, thematic content analysis, or grounded theory methodology, is used as the data analysis method in this paper.

2. Theory

First, the digital transformation of production technology is defined and put into the context of Industry 4.0. By defining the digital transformation of production technology, and placing it into the context of Industry 4.0, it is clear 'what' the subject at hand is. This is beneficial for the clarity of the research. It also answers the first research question: *"How can a digital transformation of production technology be defined?"*. Another literature review was performed to understand the organizational reasoning behind the choice to implement a digital transformation of production technology. The literature review is limited to the scope of this research; e.g., only literature that concerns digital transformation in general or within production/manufacturing is included.

Second, an assessment matrix is developed with which the performance of the implemented production technology, involved employees, and organization can be assessed. It was developed through a literature review on key performance indicators for production technology, employees, and organizations. The literature review is supplemented with the organizational objectives to implement a digital transformation that were identified in sub-section 2.1.3. By developing the matrix, an answer can be formed to sub-research question 2: *"When can a digital transformation of production technology be considered successful?"*. The outcome of the assessment will enable the identification of differences between the planned and actual performance values for each of the three categories mentioned above, which will contribute to the root-cause-analysis

Third, once it is understood how the success of the implementation of production technology can be assessed, a focus can be put on 'how' the organizations believe they can achieve their objectives. Thus, a knowledge base was formed on the methods and key activities to implement new and digital production technology through a literature review. The literature review is limited to the scope of this research; e.g., only literature that concerns the implementation of new and digital production technology or digital transformation within production/manufacturing is included. The developed knowledge base will be used to [1] test existing literature on its accuracy and completeness during the open-ended interviews and [2] supplement the information retrieved from the interviewees during the development of the implementation roadmap, and [3] answer sub-research question 3: "*What are known best practices for implementing digital production technology within an organization"*.

2.1 Defining digital transformation

Digital transformation is continuously undergoing rapid changes due to the ongoing adoption of new and innovative, yet disruptive, technologies (Ebert, 2018). The changing nature of digital transformation has caused definitions to differ between and within industries. In his literature review, Vial (2021) analyzed existing definitions of digital transformation intending to formulate one overarching definition. During this literature review, he made three important observations. First, he identified how some definitions refer to digital transformation as being an organizational change while other definitions assign the transformation to individual or societal changes. For that reason, Vial chose to refer to digital transformation as the transformation of an entity, being all of the above and more. Second, he identified how almost all definitions refer to digital transformation as a process of improvement. Lastly, he identified how most definitions referred to the term 'digital technologies'. Therefore, Vial (2021) chose to integrate the definition of Bharadwaj et al. (2013) of digital technologies, to improve conceptual clarity in the definition of digital transformation. Based on these three observations, Vial (2021) defines digital transformation as:

"A process that aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies."

A closer look must be taken at definitions of digital transformation that were not included in the literature review to identify if the definition of Vial (2021) is valid. The definitions that were not included in the literature review of Vial (2021) and that were reviewed during this research can be seen in Table 1 on page number 14. All reviewed definitions describe a process of change. However, differences and similarities can be identified between the definitions based on the type of change they describe, the type of technology they mention, and the goal of the transformation.

First, many definitions refer to it as a transformation of an entire business, including activities, processes, competencies, and models (Majdalahwieh, 2019; Romero et al., 2019; Ghobakhloo & Iranmanesh, 2021). This does, however, somewhat imply that a digital transformation always affects an entire business. This is not the case since a digital transformation can be implemented on different levels; organizational, departmental, and individual (Matt et al., 2015). This is recognized by Gong and Ribiere (2021) who refer to digital transformation as a fundamental change that aims to improve an entity.

Second, most definitions refer to digital transformation as the integration of digital technologies. Interpretations of digital technologies can, however, differ, which influences the conceptual clarity of the term. It is for that reason important that digital technologies are further specified. Bharadwaj et al. (2013) define digital technologies as a combination of information, computing, communication, and connectivity technologies. These specific technologies are also mentioned in the definition of Romero et al. (2019) and Ghobakhloo and Iranmanesh (2021); confirming that the definition of digital technologies by Bharadwaj et al. (2013) is overarching.

Third, whereas some definitions didn't assign a goal to digital transformation, other definitions agree that digital transformation is implemented to improve; whether it is an organization's competitive advantage, leveraging opportunities, or just improving. The 'improvement of an entity', as described by Gong and Riebiere (2021) would serve as an overarching goal that would include all definitions.

In conclusion, recent definitions still have likewise differences and similarities to the ones observed by Vial (2021) which makes his definition valid. The researched 'properties that are being changed', are for this study, as mentioned in Section 1.2, the digital production technologies that end-users of the production technology have implemented within their organization Thus, altering the definition of Vial (2019), the digital transformation of production technologies will be defined in this research as:

"A process that aims to improve an entity by triggering significant changes to its production technology through combinations of information, computing, communication, and connectivity technologies."

Table 1.

Recent Definitions of Digital Transformation

Source	Definition
Romero et al. (2019)	Digital transformation is a specialized type of business transformation, in the pursuit of innovative digital or hybrid business and/or operating models, where the adoption and integration of information, communication and operational technologies play a dominant role in the corporate strategy to create new competitive advantages.
Majdalahwieh (2019)	Digital transformation is the profound transformation of business and organizational activities, processes, competencies and models to fully leverage the changes and opportunities of a mix of digital technologies and their accelerating impact across society in a strategic and prioritized way, with present and future shifts in mind.
Ghobakhloo and Iranmanesh (2021)	The digital transformation under Industry 4.0 is a strategic business transformation that relies on the institutionalization and integration of various combinations of modern information and digital technologies (IDT) such as AI, data analytics, digital twins, industrial robots and blockchain.
Abdallah et al. (2021)	Digital transformation is about technology and creating a dynamic framework of all aspects of the organization, including structure, workforce, and culture, to cope with these changes.
Gong and Ribiere (2021)	Digital transformation is a fundamental change process, enabled by the innovative use of digital technologies accompanied by the strategic leverage of key resources and capabilities, aiming to radically improve an entity and redefine its value proposition for its stakeholders.

2.1.1 Digital transformation in context of Industry 4.0

Manufacturing organizations have been going through numerous transformations in the past decades, including four industrial revolutions. The fourth industrial revolution; Industry 4.0, was introduced by the German government at the Hannover fair in 2011 (Rojko, 2017). It encompasses the introduction of advanced technologies to improve smart manufacturing and uphold, or even gain competitive advantage. The eventual goal of Industry 4.0 is clearly described in the definition given by Dalenogare et al. (2018):

"A merge of the physical and digital worlds through cyber-physical systems and autonomous machine-to-machine communication"

Important Industry 4.0 technologies are the Internet of Things (IoT), Cloud Computing, Blockchain, and Big Data Analytics (Frank et al., 2019; Bai et al., 2020). These technologies can also be used by manufacturing firms to implement a digital transformation (Ghobakhloo & Iranmanesh, 2021; Ghosh et al., 2022). As a result, digital transformation is often closely linked to Industry 4.0 (Lola & Bakeev, 2020; Ghobakhloo & Iranmanesh, 2021), confusing some people that it is a similar concept.

As discussed in Section 2.1, digital transformation aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies (Vial, 2019). These digital technologies could be Industry 4.0 technologies, but don’t necessarily have to be. The aim of digital transformation is also not to merge the physical and digital worlds but merely an improvement of the entity. Furthermore, the improvement of an entity does not specifically refer to smart manufacturing as it could mean any sort of improvement (Lola & Bakeev, 2020). However, the implementation of digital production technologies is often motivated by the opportunities that Industry 4.0 technologies opportunities offer, being; increased quality, increased productivity, increased flexibility, increased efficiency, and decreased operating costs (Dalenogare et al., 2018; Frank et al., 2019). The organizational motivation to implement a digital production technology, and consequently achieve a digital transformation, is further discussed in Section 2.1.2.

For the above-mentioned reasons, it can be stated that Industry 4.0 and digital transformation are closely linked, yet varying concepts. Instead, pursuing digital transformation should be viewed as an underlying, enabling, concept of Industry 4.0 (Ghobakhloo & Iranmanesh, 2021). By initiating a digital transformation, manufacturing organizations could get closer to achieving Industry 4.0 (Dalenogare et al., 2018).

2.1.2 Organizational motivation to implement digital production technology in their organization and pursue a digital transformation

Similar to any other change process, implementing a digital production technology, and consequently pursuing digital transformation, is motivated by organizational objectives to improve an entity (Vial, 2019). The objectives can be broad and can also differ between organizations and organizational departments. A literature review was conducted to identify objectives to implement digital production technology and form a knowledge base. Appendix B visualizes all identified objectives. An interesting finding is that the identified objectives are closely linked, some even similar, to the opportunities that are offered by Industry 4.0 technologies, as discussed in Section 2.1.1. Once again proving that digital transformation is closely linked to Industry 4.0 and its technologies. The objectives were identified in three main categories, namely [1] operational objectives, [2] financial objectives, and [3] human objectives. These categories, and the objectives, are discussed below.

Organizations are motivated to integrate information, computing, communication, and connectivity technologies (such as the Industry 4.0 technologies discussed in Section 2.1.1) in their production technology because they believe that it will have a positive effect on the operational performance of the technology as well as on their organizational process(es). The positive effect on operational performance can be traced back to improved employability and output of the production technology. For instance, by integrating (a combination of) the various digital technologies, the production technology can be more autonomous, causing it to be more flexible and resilient; its employability (Albukhitan., 2021; Fernandez-Vidal et al., 2022). Also, digital technologies enable production technology to produce (more) automated which causes the production to be at a higher rate and at a higher quality (Matt et al., 2015; Ghobakhloo and Iranmanesh, 2021; Kraus et al., 2021; Favoretto et al., 2022).

Integrating information, computing, communication, and connectivity technologies in production technology also has potential economic benefits (Mugge et al., 2020; Vial, 2021. For instance, by integrating (a combination of) digital technology, the production technology could be able to work more automated and autonomously, reducing the need for operators which consequently reduces overall operating costs. The potential autonomous characteristic of the production technology also allows for self-optimization of the production technology. This causes the production technology to be more efficient and the waste to be reduced. Thus, once again reducing the costs of production.

The human benefits of digital transformation of production technology are caused by its improved operability. Digitalization of the production technology (integrating digital technologies) causes it to produce more data. Once the data is translated into visual and useable information, operators are able to perform their job faster and with fewer mistakes as there are more aware of the situation and potential problems (Lierre-Netheler et al., 2018). The autonomous aspect of integrating digital technologies in production technology, together with the improved ability of operators to detect problems, also cause improved safety levels as accidents are less likely to occur (Abdallah et al., 2021).

A final motivational reason why organizations decide to implement digital production technology in their organization is that they believe it initiates an innovative push for their products and processes; an improvement of the way in which value is created within and by the organization (Matt et al., 2015; Lierre-Netheler et al., 2018; Ghobakhloo and Iranmanesh, 2021). The push for innovation can potentially have an impact on all categories. For that reason, it is not assigned to one category but rather stands alone.

2.2 Assessment framework to analyze the performance of digital production technology and its effect on the work of involved employees and the organization

As discussed in Section 1.2, this research aims to develop a roadmap for implementing digital production technology. However, it is not only the performance of the production technology that is potentially affected by the implementation process. Rather, the performance of the production technology, the work and environment of involved employees, the organizational processes, and the organization as a whole can be affected by the implementation (process) of new digital production technology (Jones et al., 2021). The outcome of the implementation process; the ultimate performance of the production technology, and its potential impact on the rest of the organization will, for that reason, be assessed on three different levels: [1] the performance of the production technology, [2] the impact the new production technology might have on the work (environment) of individuals/employees, and [3] the impact the new production technology might have on the organizational processes and the organization in whole. Throughout this section, an assessment framework will be developed for each of those levels of analysis. Afterward, the frameworks will be combined in Section 2.2.4.

2.2.1 Assessment framework for the performance of digital production technology

Implementing digital production technology within an organization mostly impacts the production technology/process in its operational performance. When assessing the operational performance of production technology, managers often use the overall equipment effectiveness (OEE) measurement tool (Muchiri & Pintelon, 2008). The tool consists of three key performance indicators: [1] productivity rate, [2] availability rate, and [3] quality of the output. It is used to measure the total equipment performance. The three components were also identified in the literature as motivation for organizations to implement digital production technology within their organization and pursue digital transformation. However, in many cases, production technology is required to produce at/above a specific rate. Therefore, there is no added value to include the productivity rate in the assessment framework, as there will not be a large approximate difference between the planned and actual value.

In addition to the OEE, the performance of production technology can also be assessed on the changes in total operating costs which were also identified as motivation for organizations to implement digital transformation of production technology (Slack et al., 2016; Moeuf et al., 2018). The total operating costs consist of multiple components. In this research, the production technologies will be assessed on the following components of total operating costs: the raw materials used, energy consumed, required personnel, and repair and maintenance costs. In order to evaluate the sustainability of the production technology, we analyze the amount of residual material generated, taking into account that the required raw materials to produce one unit will remain relatively stable, and the energy consumed. The energy consumed can be divided into two categories: the (electric) energy consumed (consumed kWh) and the personnel required (required man-hours).

A final performance indicator of production technologies that will be included in the KPI assessment framework is lead time (Moeuf et al., 2018). Similar to the total operating costs, lead time will be included in the category 'production efficiency'. The assessment framework for production technology performance is visualized in Table 2 below.

Table 2.

Assessment Framework for Production Technology Performance

Key Performance Indicators		**Unit of metrics**	**Value**		
Category	**Indicator**		**Planned**	**Actual**	**Difference**
OEE	Availability rate	Run time / planned production time (%)			
	Quality of the output	Good count / total count (%)			
Production efficiency	Raw materials used	Residual material (%)			
	Energy consumed	kWh (%)			
	Personnel required	Required man-hours (%)			
	Repair and maintenance costs	Total number of repair and maintenance actions (%)			
	Lead time	Production time single unit (%)			

2.2.2 Assessment framework for the work of involved individuals/employees

It is difficult to assess how the implementation of a (new) digital production technology impacts the involved individuals within an organization; the employees. The difficulty is that, compared to machines, change within an organization not only potentially affects the ability of an employee to fulfill their tasks/job (e.g. the performance), but also how they might think and feel about, and act within the change/new situation; their attitude towards the job and company. Behavior and emotion are, compared to data that is linked to a performance/job (e.g., productivity rate), difficult to measure. However, they can directly influence job performance and are therefore important values to measure during and after a process of change (Dugguh & Dennis, 2014). For that reason, the impact of digital transformation of production technology on individuals/employees should be assessed based on their performance, behavior, and emotion.

To assess how the implementation of a (new) digital production technology within an organization affects the performance/job of an individual, managers often look at the productivity rate, quality of work they produced, and the number of issues, compliances, and errors they filed (Koopmans et al., 2014;). These are also directly linked to the digital transformation of production technology as improved production rate, improved produced quality, and machine/process resilience were also identified in the literature as motivation for organizations to implement a (new) digital production technology. Produced quality, however, is already tested in the production technology assessment. Therefore, it is left out of the individual/assessment matrix. Furthermore, the 'productivity rate of an individual/employee' refers to the time in which an employee is able to fulfill his tasks. By analyzing the actual operating time of the employee with the planned operating time, a better understanding can be created about the level of control an employee has over the production technology.

More difficult to assess, yet still important, are job satisfaction and employee engagement. Job satisfaction is the collection of feelings and beliefs that people have about their job and the perception that the job enables their material and psychological needs (Aziri, 2011). Employee engagement is the degree to which employees are associated with their work and coworkers; the degree to which employees are involved in their job (Kahn, 1990). The concepts can both influence employee performance but also be influenced by employee performance

(Aziri, 2011; Dugguh & Dennis, 2014). For instance, the inability to successfully perform a task or job can cause the psychological needs of an employee to not be fulfilled, negatively influencing the employee's job satisfaction and/or engagement. Thus, job satisfaction and employee engagement are influenced by working conditions which might be impacted by digital transformation (Aziri, 2011).

The assessment framework for individuals/employees can be seen in Table 3 below. Note: the framework is used to assess the individuals/employees whose work is directly affected by the acquired production technology.

Table 3.

Assessment Framework for Individuals/Employees

Key Performance Indicators		Unit of metrics	Value		
Category	**Indicator**		**Planned**	**Actual**	**Difference**
Performance	Productivity rate	Operating time / planned operating time (%)			
	Issues, compliance, and error logs	Total number of issues, compliance, and error logs (%)			
Emotion and behavior	Job satisfaction	Rate 1-10			
	Employee engagement	Rate 1-10			

2.2.3 Assessment framework for the organization

The impact the implementation of a (new) digital production technology might have on an entire organization highly depends on the employability/performance of the technology as well as the individuals who operate it. Still, by implementing a (new) digital production technology, not only the technology or the operators are affected, but also the organizational processes in which the production technology fulfills a role, and the organization as a whole (Matt et al., 2015). For instance, digitally transforming a production technology can improve its production efficiency; reduced lead time, labor costs, and material costs (Dalenogare et al., 2018). The improved lead time of one machine not only affects the lead time of that specific machine but potentially the entire organizational process it functions in. Moreover, decreased labor and material costs have a monetary impact on the organization. The contribution one production technology has to the total costs of an organization is easily, and accurately, measurable as it is the sum of the total operating costs for that specific technology. The contribution one production technology has on the total revenue of an organization is more difficult to measure. This is because one would have to assign a monetary value to the action the production technology fulfilled to the product which might not always be accurate. Therefore, the contribution to the total revenue of an organization is not included in the assessment matrix.

Thus, measures with which the impact of implementing a digital production technology might have on an organization are the throughput time of the process in which the production technology fulfills a role, and the direct contribution the production technology has to the total costs of an organization. The organizational assessment framework can be seen in Table 4 below.

Table 4.

Assessment Framework for the Organization

Key Performance Indicators		**Unit of metrics**	**Value**		
Category	**Indicator**		**Planned**	**Actual**	**Difference**
Operational performance	Throughput time	Total process time (%)			
Financial performance	Contribution to total costs	Total operating costs (%)			

2.2.4 Combined assessment framework to analyze the performance of the implemented digital production technology and its effect on the work of involved employees and the organization

The previously developed frameworks are combined into one framework with which the performance of the implemented digital production technology, involved employees, and organization can be assessed. The framework can be seen in Table 5 on page number 20. From the framework can be stated that it includes every motivational reason to implement a digital transformation, as discussed in Section 2.1.3. Therefore, the framework can be seen as an accurate tool to the assess performance of the implemented digital production technology, involved employees, and organization.

Table 5.

Matrix to Assess how implementing Digital Production Technology within an Organization impacts the Performance of the Production technology, People, and Organization

Key Performance Indicators			Unit of metrics	Value ***		
Area of analysis	**Category**	**Indicator**		**Planned**	**Actual**	**Difference**
Production technology	OEE	Availability rate	Run time / planned production time (%)			
		Quality of the output	Good count / total count (%)			
	Production efficiency	Raw materials used	Residual material (%)			
		Energy consumed	kWh (%)			
		Personnel required	Required man-hours (%)			
		Repair and maintenance costs	Total number of repair and maintenance actions (%)			
		Lead time	Production time single unit (%)			
Individuals/employees *	Performance	Productivity rate	Operating time / planned operating time (%)			
		Issues, compliance, and error logs	Total number of issues, compliance, and error logs (%)			
	Emotion and behavior	Job satisfaction	Rate 1-10			
		Employee engagement	Rate 1-10			
Organization **	Operational performance	Throughput time	Total process time (%)			
	Financial performance	Contribution to total costs	Total operating costs (%)			

* This includes individuals/employees whose work is directly affected by the implemented production technology.
** This is about the impact the implemented production technology has on the organizational processes it functions in and on the financial performance of the organization.
*** The values within this column are compared with the situation before the implementation of the production technology (e.g., 'planned' change compared to previous situation and 'actual' change compared to previous situation).

2.3 Approaches to implement new production technology

The previous sections aimed to define and explore the concept digital transformation of production technology. Furthermore, a framework was developed through which the performance of the implemented digital production technology and its effect on the work of involved employees and the organization can be assessed. This section delves deeper into the various approaches to successfully implement a new production technology. In Section 2.3.1, a focus is put on the best practices to implement new digital production technology and achieve a digital transformation.

In Section 2.1, it was discussed how the digital transformation of production technology can be achieved by triggering significant changes to its production technology through combinations of information, computing, communication, and connectivity technologies (Vial, 2021). Often, this is done by integrating digital technologies into existing production technology or by implementing entirely new production technology within an organization. Various approaches exist to how new technology should be implemented within an organization. For instance, Goodman and Griffith (1991) view the implementation of new technology as a process approach. Their approach indicates that the implementation of a new technology is driven by numerous processes that often run simultaneously. The processes include [1] socialization, [2] commitment, [3] reward allocation, [4] feedback and redesign, and [5] diffusion. Socialization refers to the processes through which individuals/employees collect knowledge and skills on the new technology and orient themselves with it. In doing so, they create a social construction for the new technology. Through commitment processes, individuals are bound to specific behavioral acts that are relevant to the new technology. It increases the probability of consistent performance behavior, stimulates the development of positive behavior, and influences how individuals process discrepant information about the technology. Reward allocation consists of the allocation of different types of rewards that are relevant to the implementation of the new technology. Allocating rewards positively influences the behavior of individuals during the entire implementation process. Feedback and redesign refers to the process by which data is collected about the new technology and redesign activities are initiated to improve the operation of the new technology. This is mostly done to enhance the 'fit' of the technology within the organization; improve its performance and decrease its costs. Finally, during the diffusion, the new technology is extended to other parts of the company. Thus, truly integrating the new technology within an organization. In later research, Griffith (1996) dives further into the importance of communication and negotiation during the implementation processes. He identified how negotiating with participants can uncover information regarding the participants' expectancies, interests, and motivations. Uncovering such information can contribute to the creation of integrative solutions that result in agreement with participants that result in an improved commitment to the process and the use of the new technology.

Harrison (2004) agrees with the view of Goodman and Griffith (1991) that the implementation of new technology is driven by various processes. Harrison (2004) defines these processes as integration mechanisms that each include actions or interventions. Four integration mechanisms were identified [1] structures, [2] processes, [3] resources, and [4] culture. In the context of structures, examples of interventions include modifications to job roles, such as implementing job rotation, refining procedures, establishing reward systems that incorporate non-financial and symbolic incentives, and efficiently allocating tasks. Processes-oriented interventions encompass actions directed at the development and management of systems and procedures related to the integration of technology. These interventions might take the form of processes tailored for decision-making, leadership, communication, or action planning. Taking a resources-based approach, interventions encompass actions related to internal human resources, which might involve activities like recruiting, selecting, training, and designating technology project champions. Moreover, these interventions could extend to the identification, management, and nurturing of relationships with external resources. Within the realm of culture, interventions pertain to mechanisms that induce and regulate changes in corporate culture, encompassing aspects such as attitudes, values, norms, beliefs, and reactions to shifts and transformations.

A more recent approach is given by Plinta and Radwan (2023). They view the implementation of a new technology as a process of steps. The process starts with an analysis of the current condition and the recognition of the organizational needs. Once the awareness of the needs is developed, innovation concepts are created for the desired new technology that functions as a solution to the needs. Then, the innovation concepts must be managed. This indicates that a business model/business case must be formulated for each of the previously developed innovation concepts. In the next step, these business models/cases are evaluated and the optimal solution is selected. Finally, the technological innovation is developed and implemented.

2.3.1 Best practices to implement new digital production technology and achieve a digital transformation

The process approaches that were discussed in Section 2.3 focus on implementing new technology and do not necessarily specify how digital characteristics of a technology might influence the approaches. Thus, they do not specify how digital technology should be implemented. Furthermore, the discussed process-flow approach has a strong focus on the development and acquisition of an innovative concept. Yet, that approach does not indicate the actions that need to be undertaken during the steps of the process flow nor do they discuss the changes that need to be made within and to an organization so that the technology can be implemented. Thus, a glance must be taken at the various approaches through which a digital technology could be implemented.

Matt et al. (2015) propose that the implementation of new digital technology (digital transformation) is a process of change that is built out of four dimensions; [1] the use of technologies, [2] changes in value creation, [3] structural changes, and [4] the financial aspects. Matt et al. (2015) explain that the use/adoption of new technologies (in the case of this research the adoption/implementation of digital production technology) often leads to shifts in how a company's value is generated. This pertains to how digital transformation strategies impact a company's value chains, wherein the extent of deviation from traditional, often more analog, core business activities is measured. Since different technologies and value-creation approaches are involved, substantial structural adjustments are frequently necessary to establish a suitable foundation for these new operations. These structural changes primarily concern the organization of a company, particularly the integration of new digital activities into its corporate framework. Sometimes, organizations find that their digital transformation is limited by an organizational infrastructure (both physical and digital) that is not suitable for the implementation of new technology (Vogelsang et al., 2019). However, it is crucial to address financial aspects before undertaking any transformation. These include evaluating a company's urgency to act due to a decline in its core business and assessing its financial capacity to embark on a digital transformation journey. Financial considerations act as both a driving force and a limiting factor in the transformation process (Kraus et al., 2021; Mugge et al., 2020). This also accounts for human considerations. Companies need to address the human resources that are needed to fulfill the process. The resources include the skills, knowledge, and employee support and engagement that are necessary to fulfill the transformation process or implement a digital production technology (Vogelsang et al., 2019). Matt et al. (2015) implicate that managerial roles are needed to coordinate and manage the four dimensions and resolve any limiting factors within them.

During their research, Fernandez-Vidal et al. (2022) identified that digital leaders were expected to fulfill this need. Roles that are included in the digital leaders are the chief technology officer, chief digital officer, chief transformation officer, digital innovation officer, and head of digital strategy. They are expected to fulfill a strategic role within the organization that is responsible for the effective integration and collaboration of all business areas within the digital transformation process. IDL's are expected to secure the commitment and engagement of the employees to minimize or resolve any resistance to the change process. In doing so, they secure the use of the production technology by coordinating/managing the required changes in value creation through changes in the organizational structure (both physical and digital structure). However, to do so, digital leaders should understand the financial implications of technological decisions and the resources that are needed to fulfill the process. Resources include both capital and human resources. Capital resources include the physical and digital assets that are needed for digital transformation. For instance, an adaptation of the physical and digital infrastructure is needed to be able to integrate a new production technology within the organization. Human resources can be further divided into skills, capabilities, and knowledge. To acquire these resources, digital leaders are expected to develop a learning culture and make training a strategic priority.

Integrating digital leaders within an organization is identified as one of the most important best practices for achieving a successful digital transformation (Romero et al., 2019; Fernandez-Vidal et al., 2022; Van Veldhoven & Vanthienen, 2022; Cichosz et al., 2023). It could be even argued that a digital transformation process, or the implementation of digital production technology, is a management challenge (Hess et al., 2016). They can initiate, organize, and fulfill best practices for many other success factors of digital transformation, such as creating an urge for and promoting change throughout the organization, fostering open communication, developing employee and partner engagement, aligning business strategies, setting up employee training and skills development (Romero et al., 2019; Kraus et al., 2021; Colli, 2022; Ghosh et al., 2022; Van Veldhoven & Vanthienen, 2022; Cichosz et al., 2023). Other important success factors that managers can contribute to are the creation of an organizational culture that is open to change/innovation and willing to learn, the leveraging of internal and external knowledge, and the standardization of processes and data integration (Osmundsen et al., 2018, Ghobakhloo and Iranmanesh, 2021; Van Veldhoven & Vanthienen, 2022; Cichosz et al., 2023). Examples of best practices for these success factors setting up a program that stimulates collaboration with technological suppliers, and/or organizing workshops to build digital awareness and enhance digital skills Another best practice is setting up bottom-up initiatives to proactively improve processes and services. That best practices contribute to creating a supportive organizational culture (Chichosz et al., 2023) An organizational culture that is open to and willing to innovate makes other success factors easier. For instance, it is easier to leverage internal and external knowledge in an organization that is open to change and willing to participate. Through leveraging internal and external knowledge, barriers can be identified, and know-how for the desired innovation can be exploited. Thus, if carried out, these best practices can resolve the above-mentioned limiting factors.

The process approaches of Goodman and Griffith (1991) and Harrison (2004) that were discussed in the previous section indicate the various processes through which an organization can adapt itself, and more importantly the individuals, to integrate/implement the new technology. However, from the approaches does not become clear when the actions within each process should be undertaken which causes unclarity. Also, it does not become clear which actions need to be undertaken to actually implement the technology. Contrary, the implementation approach of Plinta and Radwan (2023) gives a clear idea of the process steps through which an organization can implement a new technology. Yet, their model does not include specific actions that need to be undertaken during those process steps nor does it imply the changes that need to be made so that the technology can be implemented. Furthermore, from the key factors and best practices that were discussed above can be stated that the role of managers is believed to be highly important during a digital transformation. However, there is little to find out about how these managers can integrate the above-mentioned key factors and best practices into a digital transformation strategy or in the implementation approaches (Albukhitan, 2021). Consequently, managers can experience trouble identifying which actions need to (still) be undertaken, allocating necessary resources, and/or dividing responsibilities for all tasks. This negatively influences the quality of the overall digital transformation strategy that they can formulate and might also potentially impact the success of the outcome of the digital transformation.

Based on the findings, it can be concluded that there is a need for an implementation roadmap that visualizes both the steps of the process as well as the actions and best practices through which an organization can acquire a new digital production technology and adapt itself to integrate/implement it. This is supported by Mellor et al. (2014) who indicated in their paper that project managers of new and disruptive digital technology should have an implementation framework to guide their adoption efforts. Such an implementation roadmap should enable managers to plan best practices and actions, divide responsibilities for them, and identify and allocate the necessary resources to fulfill them.

3. Designing a draft version of an implementation roadmap for digital production technology

Throughout this section, a draft version of a roadmap for implementing digital production technology will be developed. Creating a draft version is done by researching existing models for change and/or models for implementing new technology. The section is divided into three subsections. The first subsection is used to establish the 'phases of change' whereas the second subsection is used to establish the 'areas of change'. Both subsections are then combined within the third subsection to create the base roadmap for implementing digital production technology within an organization to pursue digital transformation.

3.1 Phases of change

In Section 2.3.1 was discussed how the process approaches of Goodman and Griffith (1991) and Harrison (2004) do not specify when the actions within each process should be undertaken which causes unclarity. Also, it was discussed how the approach of Plinta and Radwan (2023) does not include specific actions that need to be undertaken during those process-steps nor does it imply the changes that need to be made so that the technology can be implemented. Lastly, it was discussed how all approaches focus on implementing new technology and do not necessarily specify how digital characteristics of a technology might influence the approaches. Therefore, a glance will be taken at existing change management models to develop a draft version of a roadmap for implementing digital production technology.

One of the first, well-respected, views of change management was developed by Kurt Lewin (1947). Even though Lewin's (1947) three-phase model was originally developed as a metatheory for resolving social conflict (from which other/new theories or models could be drawn), it has often been viewed as the foundation for organizational change management. Lewin's (1947) model for change consists of three phases/steps: [1] unfreezing, [2] moving, and [3] refreezing. The first phase of the model encompasses the unfreezing of the present level; identifying and addressing the 'things' that hinder the change. It can involve creating a sense of urgency or dissatisfaction with the status quo; at the present level. The second phase encompasses the moving/changing of the present level; implementing the desired changes. This phase may include developing new policies or procedures, altering organizational structures, or, in the case of this research, introducing new technologies. The final phase of the model encompasses the refreezing of the new level; reinforcing the changes and making them a permanent part of the organization and its culture. This phase can include developing new norms and values or providing training and support to employees to ensure the changes are understood and adopted.

Another approach to organizational change management was later developed by Kotter (1996) in his book; "Leading Change". In this approach, Kotter (1996) builds on the theory of Lewin (1947) by expanding the three original phases to a change process consisting of eight stages. Each of the eight stages of Kotter offers a solution to the eight key problems of why most change efforts fail. The stages are as follows:

1. Establish a sense of urgency
2. Create the guiding coalition
3. Create a vision to direct the change effort and develop strategies to achieve that vision
4. Communicate the change vision using every vehicle possible

5. Empower broad-based action
6. Generate short-term wins
7. Consolidate gains and produce more change
8. Anchor new approaches in the organization’s culture.

Figure 2 on page number 24 visualizes how the eight stages of Kotter (1996) are divided among the three phases of Lewin (1947).

Figure 2.

Lewin’s Three-Phase Model (1947) combined with Kotter’s Eight-Stage Approach (1996)

Lewin’s (1947) three-phase model	Phase 1: Unfreeze	Phase 2: Moving	Phase 3: Refreeze
Kotter’s (1996) eight-stages approach to change management	Step 1: Establish a sense of urgency Step 2: Create the guiding coalition Step 3: Create a vision to direct the change effort and develop strategies to achieve that vision Step 4: Communicate the change vision using every vehicle possible	Step 5: Empower broad-based action Step 6: Generate short-term wins Step 7: Consolidate gains and produce more change	Step 8: Anchor new approaches in the organization’s culture

A more recent approach to managing change was developed by Anderson and Anderson (2010). They translated their vision for managing change into the ‘Change Leader’s Roadmap’. The roadmap embeds the essential human dynamics of transformation within the concrete tasks of changing structures, systems, processes, or technology. It discusses nine sequential phases for transformational change, each including activities and actions. Although the phases are discussed sequentially, they do not have to be followed in that way. Rather, the phases can happen simultaneously or the work of phases can be done in parallel. The nine phases of their approach are:

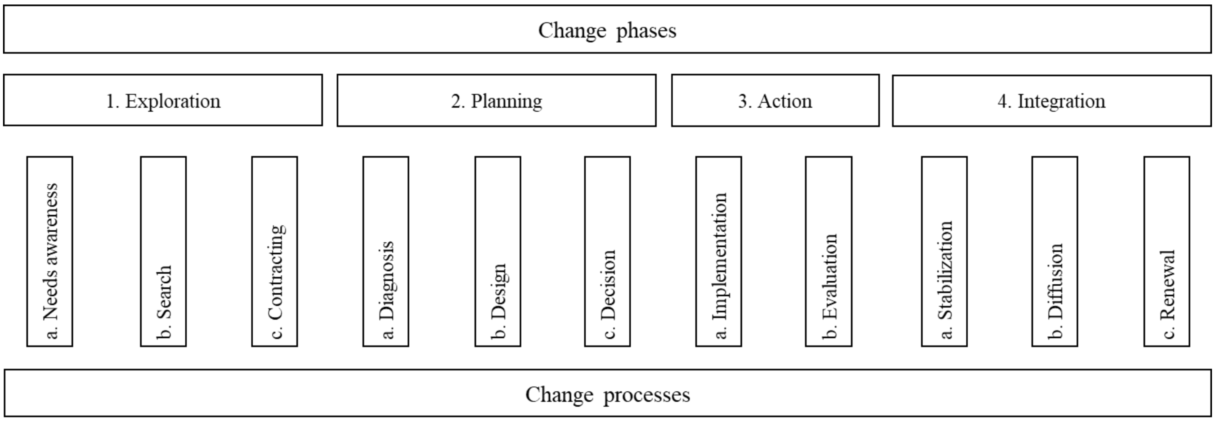
1. Prepare to lead the change
2. Create an organizational vision, commitment, and capability
3. Assess the situation to determine design requirements
4. Design the desired state
5. Analyze the impact
6. Plan and organize for implementation
7. Implement the change
8. Celebrate and integrate the new state
9. Learn and course correct

The phases discussed in the approach of Anderson and Anderson (2010) have strong similarities with the stages that are discussed in the approach of Kotter (1996). Yet, whereas Kotter (2012) developed a model for organizational change, the approach of Anderson and Anderson (2010) can be adapted so that it is more suitable for smaller changes within an organization.

Another approach to change management is the change management model of Bullock and Batten (1985). Their approach is derived from theories of project management and is based on an analysis of over 30 change management models. Differing from the previous models, the model of Bullock and Batten (1985) contains both organizational phases and processes. The phases refer to the states in which an organization can be in whereas the processes refer to the mechanisms an organization needs to move from one state to another. Their analysis showed four overarching phases amongst the observed models; [1] exploration, [2] planning, [3] action, and [4] integration. According to Bullock and Batten (1985), the process of change initiates with the recognition of needs, often leading to a search for assistance and support, as well as the development of both physical and emotional arrangements/contracts. Once goals and preferences have been established, action plans and integration strategies are formulated, requiring approval from decision-makers. Once the action plan is implemented and integrated within the organization, individuals responsible for implementing the change must be present within the organization. Furthermore, the change must be institutionalized, signifying that the organization transitions from a change initiative to a state of continuous improvement (Bullock & Batten, 1985). An overview of the model can be seen in Figure 3.

Figure 3.

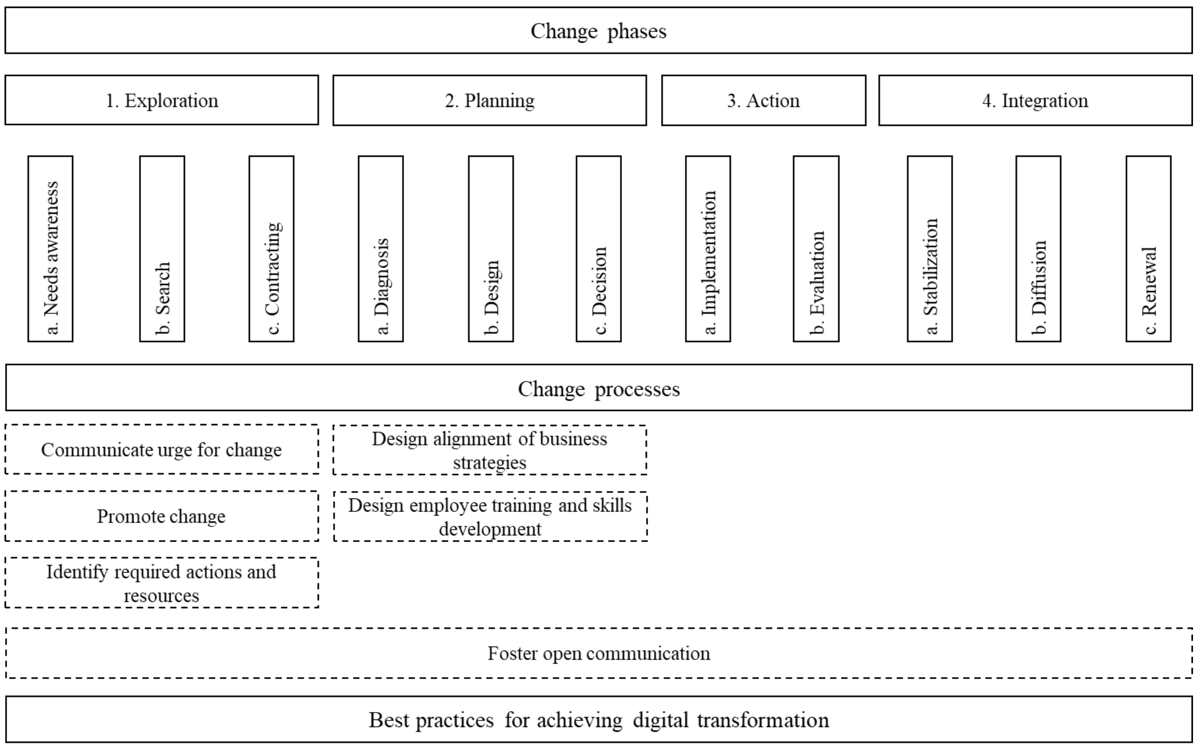
Change Management Model Bullock and Batten (1985)



As shown in Figure 3, the Bullock and Batten (1985) model contains similar steps/processes as the models from Kotter (1996) and Anderson and Anderson (2010). Also, it shows similarity to the implementation approach of Plinta and Radwan (2023), which was discussed in Section 2.3. However, compared to the other models, the model of Bullock and Batten has a clear distinction between the various organizational phases an organization can go through when transforming and the mechanisms an organization needs to move through the phases. Such distinction improves the structure and consequently clarity of a change management model. Furthermore, the model of Bullock and Batten (1985) is built on project management theories and models and is therefore very suitable for change projects, such as the digital transformation of production technology. Some of the key factors for success to achieve digital transformation, that were discussed in Section 2.3, could be placed within the change phases of the model of Bullock and Batten (1985). For instance, during the exploration phase, companies can communicate their urge for change and promote the change throughout the organization. During the exploration phase, companies also identify the changes that need to be made and the resources that are required to make them. These identified changes and required resources can also be communicated to make employees further aware of the situation. In doing so, they foster open communication for their plans. Such communication should be held throughout the entire process. As a result, the open communication might lead to an improved employee and partner engagement, creating an organizational culture that is open for change/innovation and willing to learn. Plans on how to align all business areas and strategies, or how to set up necessary employee training and skills development, is done throughout the planning phase. These plans are then executed and evaluated during the ‘action phase’. Figure 4 visualizes how the best practices for achieving digital transformation could be placed within the model of Bullock and Batten (1985).

Figure 4.

Change Management Model Bullock and Batten (1985) and Best Practices for Achieving Digital Transformation



The process steps of the model from Bullock and Batten (1985) that are used for the draft version of the roadmap are defined quite generally. As a result, it is still a bit unclear which exact actions need to be undertaken during each process step and how the responsibilities for these actions should be divided. Furthermore, it is still unclear how the success factors for digital transformation that were discussed in Section 2.3 should be precisely taken care of or placed within the model of Bullock and Batten (1985). These components should all be further researched during the in-depth open-ended interviews. Although the developed model in Figure 4 contains unclarity, it does give us an idea of how the roadmap for implementing digital production technology could ultimately be. Therefore, the change management model of Bullock and Batten (1985) is used to develop the draft version of an implementation roadmap for the digital transformation of production technology

3.2 Areas of change

Section 1.2 discussed how the roadmap for implementing digital production technology must enable organizations to easily manage and communicate plans and expectations throughout the organization. Also, it must enable the organizations to identify which actions need to be undertaken and what human and capital resources need to be present during the various process steps to undertake the actions.

Including areas of change within the roadmap can contribute to this. Actions and required resources can be assigned to specific areas, making the visual roadmap more structured. An improved structure increases clarity which makes it easier to communicate plans and expectations. This has a potential benefit for the openness of communication which might positively impact employee engagement and support. The areas of change are further discussed below.

Within their research, Verina and Titko (2019) developed a conceptual framework for digital transformation. They analyzed existing research on digital transformation to develop a deep understanding of the subject, specifying its key elements, components, and categories. Similar to the extensive literature review of Vial (2019), their research identified that many scholars include differing elements in their definitions of digital transformation. However, Verina and Titko (2019) identified that the varying elements can be summarized in three overarching concepts. These concepts are [1] technologies, [2], management/processes, and [3] people. An overview of the conceptual framework of digital transformation can be seen in Appendix C.

Differing from the other approaches discussed in Section 3.1, the Change Leader's Roadmap of Anderson and Anderson (2010) includes three areas of change: [1] content, [2] people, and [3] process. Content describes the organizational and technical areas that must change. People describe the mindset, behavioral, and cultural changes required to deliver and sustain changes. Process describes the actions required to plan, design, and implement all of the changes in an integrated and unified manner.

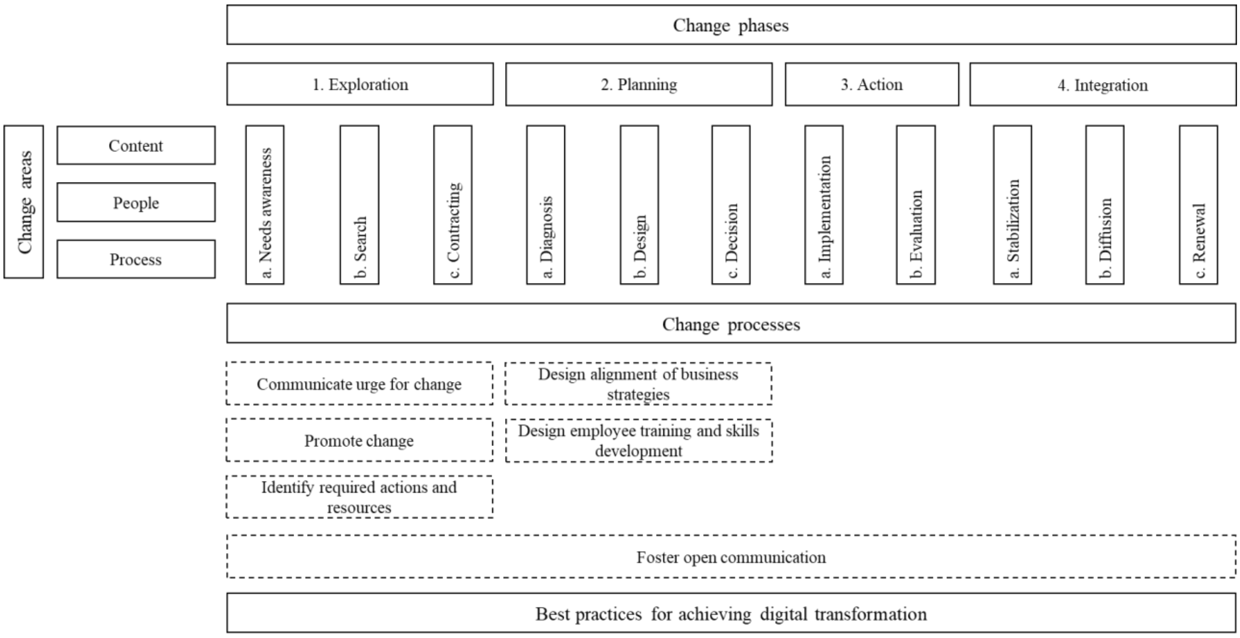
The concepts that were identified in the research of Verina and Titko (2019) are similar to the areas of change that are included in the Change Leader's Roadmap of Anderson and Anderson (2010). Yet, the areas of change from the roadmap of Anderson and Anderson (2010) are broader and more inclusive. This is not surprising because the research of Verina and Titko (2019) aimed to develop a conceptual framework solely for digital transformation. However, this research aims to identify every action or change that needs to be undertaken within (or outside of) an organization so that a digital transformation of production technology can successfully be managed. For that reason, the areas of change that are included in the Change Leader's Roadmap of Anderson and Anderson (2010) will be used in the development of the base roadmap for implementing a digital transformation of production technology in Section 3.3.

3.3 A draft version of a roadmap for implementing digital production technology through which a digital transformation can be achieved

As discussed prior, the previously identified change phases, change processes, and areas of change are combined within this section to develop a draft version of a roadmap for implementing digital production technology within an organization to pursue digital transformation. The combined model can be seen in Figure 5. The draft version will function as the base roadmap for implementing a digital production technology that is further modified throughout the following sections of this research. The potential modifications are based on the information collected during the open-ended interviews. The draft version can be seen in Figure 5 on page number 29.

Figure 5.

Draft Version of a Roadmap for Implementing Digital Production Technology Through Which a Digital Transformation can be achieved



4. Results

Throughout this section, an overview is given of the results from the semi-structured open-ended interviews. First, an overview is provided of the participating companies in Section 4.1. Then, a general overview is given of the various implementation processes that the participating companies have conducted in Section 4.2. Finally, Section 4.3 offers a specific yet comprehensive portrayal of the implementation processes the interviewed companies carried out for their digital production technology together with the impact it had on the performance of the production technology, people, and organization.

4.1 Overview of the participating companies and the production technology they implemented

In total, 7 companies have been interviewed. General information about these companies is given in an overview in Table 6 on page number 32. The overview consists of various components. First, it includes information about the company's level of maturity. The maturity is divided into three categories; start up, scale up, and mature. Second, the overview provides information about the production technology the interviewed companies have implemented. That information encompasses the name of the production technology, whether it's a standardized or unique technology, the generation of the production technology within the company, the digital components it possesses, and the type of software it runs on and uses. Finally, the overview gives information about whether the production technology is internally built or externally bought.

Table 6.

General Overview of the Interview Companies

	Company 1	Company 2	Company 3	Company 4	Company 5	Company 6	Company 7
Company maturity	Mature	Mature	Mature	Scale up	Startup	Scale up	Mature
Implemented technology	Metal injection molding technology	Metal straightening technology	Metal folding technology	Additive manufacturing, 3D-printing of metal	Fiber blow spinning technology	Enhancer of silicon solar cells	Metal turn and milling technology
Bought / build	Bought	Build	Bought	Bought	Bought	Bought	Bought
Standardized / unique production technology	Standardized production technology	Standardized production technology	Standardized production technology	Standardized production technology	Unique production technology	Unique production technology	Standardized production technology
Generation of the production technology within company	2nd	5th	At least 8th	1st	1st	2nd	1st
Digital components in production technology	Digital human machine interface Cloud-connection Data generation Data storage	Digital human machine interface Data generation Data storage	Digital human machine interface Cyber-physical systems Cloud-connection Data generation Data storage (Big) data analytics	Digital human machine interface Cloud-connection Data generation Data storage	Digital human machine interface Data generation Data storage	Digital human machine interface Analytical measuring equipment Cloud connection Data generation Data storage	Digital human machine interface Analytical measuring equipment Data generation Data storage
Type of software in production technology	Operational software Informative software Computing software	Operational software Informative software	Operational software Computing software Communicative software Informative software	Operational software Informative software	Operational software Informative software	Operational software Informative software	Operational software Informative software Computing software
Bought / developed internally	Developed internally	Developed internally	Bought and developed internally	Bought	Bought	Bought	Bought

4.2 General overview of the various implementation processes

This section provides a general overview of the implementation processes that each interviewed company carried out for their production technology. The overview consists of the various process steps that were included in each individual implementation process. Each process step is defined in the table exactly as they were mentioned during the open-ended interview and describes the (set of) action(s) that were conducted during that part of the process. All processes and their process steps are visualized in the order they were conducted and should be read in a chronological way (from top to bottom). The overview can be seen in Table 7 below. Each implementation process is discussed in detail in the next subsection.

Table 7.

Overview of the Process steps used by the Companies during the Implementation of their Production Technology

Process step	Company 1	Company 2	Company 3	Company 4	Company 5	Company 6	Company 7
1.	Idea generation	Idea generation	Idea generation	Idea generation	Idea generation	Idea generation	Idea generation
2.	Formulate machine specifications	Research and design	Design / specifications	General machine test	Feasibility testing	Formulate functional specifications	Formulate minimum functional specifications
3.	Search for and approach supplier	Search for and approach supplier	Search for and approach supplier	Design / specifications	Formulate functional specifications	Search for and approach supplier	Search for and approach supplier
4.	Formulate detailed machine specifications	machine components	Construction of the machine	Construction of machine	Search for and approach supplier	Formulate detailed machine specifications	Reference research
5.	Construction of the machine	Construction of the machine	Testing	Training externally	Formulate design and engineering specifications machine	Engineering phase	Formulate detailed specifications
6.	Testing / Factory Acceptance Test	Testing	Installation / placement of machine	Factory acceptance test	Construction of the machine	Construction of the machine	Construction of the machine
7.	Training externally	Factory Acceptance Test	Machine put into use	Installation / placement of machine	Factory acceptance test	Factory Acceptance Test	Installation machine
8.	Digital layout factory	Installation / placement of machine	Optimization of machine	Site Acceptance Test	Installation / placement of machine	Installation machine	Internal training operators
9.	Installation / placement of machine	Internal training operators		Internal training operators	Site Acceptance Test	Site Acceptance Test	Machine put into use
10.	Safety check / Site Acceptance Test	Machine put into use		Machine put into use	Optimization of machine	Recipe Development	Optimization of machine
11.	Internal training operators	Optimization of machine				Internal training operators	
12.	0 series / test internally					Integration of machine into production process	
13.	Safety check/test						
14.	Machine put into use						
15.	Optimization of machine						

4.3 Detailed overview of individual cases and their implementation process

This subsection provides a detailed overview of the implementation process that each company undertook for their specific production technology. Each overview consists of two tables. The first table shows the steps/mechanisms of the process, along with people who were involved in that step of the process and the actions those people took during that step of the process. The actions that were undertaken during each process step are summarized in short statements, based on the data that was gathered during the interview. In addition, a second table is included that shows the impact of the implementation process that each company has carried out on the performance of their production technology, people, and organization.

4.3.1 Company 1

Company 1 is a mature company that implemented a metal injection molding machine within their organization. The technology within the implemented machine can be viewed as a second-generation technology within the organization as it was also present within the machine that got replaced. The reason behind the implementation of the machine was to improve the quality of the output, decrease the lead time, improve the level of automation, and therefore decrease the required 'man-hours', and improve the safety situation around the machine for and work (environment) of the employees. During the implementation process, Company 1 did not experience any noticeable barriers. However, they did identify key actions within the process that they believe contributed greatly to the success of the process and reaching the set objectives. These key activities were the step-by-step configuration and installation of the machine, the development and use of a quality system, the external and internal training of employees, and the integration of safety procedures and analyses within the various process steps. According to the interviewee, these key activities enabled the company to deeply understand and control the machine. As a result, they were very able to adjust the performance of the machine to the desired level and maintain that it. In future projects, Company 1 wishes to have a more prominent role for its supplier. They believe that the knowledge transfer between a customer and supplier improves the level of knowledge and skills within both organizations which contributes to the level of independence of both firms. Also, they believe that it would be beneficial to the implementation process if there would be a 'specialist' role. The specialist would have extensive knowledge of the production technology that is implemented. Consequently, they believe that such a specialist would be better able to coordinate the process and gain maximum performance from the machine. The process steps, involved actors, and undertaken actions of the implementation process that they carried out are visualized in Table 8 on page numbers 34 and 35.

Table 8.

Implementation Process of Company 1

Process step / mechanisms	Responsible actor	Action
1. Idea generation	Project manager	Coordinate process step
2. Formulate machine specifications	Health, Safety and Environmental (HSE) team	Integrate safety into machine specifications
	Project manager	Coordinating project; monitoring scope, planning, budget and quality
	Programmer / IT-specialist	Drafting digital specifications / software machine
	Quality engineer	Drawing up quality requirements for output

3. Search for and approach supplier	Project manager	Coordinating project; monitoring scope, planning, budget and quality
4. Formulate detailed machine specifications	Researcher	Configure and set up machine architecture
	Supplier	Communicate configuration machine
	Project manager	Coordinating project; monitoring scope, planning, budget and quality
5. Construction of the machine	Supplier	Construction of machine
6. Factory acceptance test	Quality engineer	Preparation and testing of process parameters / quality system
	Programmer / IT-specialist	Analysis functionality and development software
	Supplier	Assist test phase
	Project manager	Coordinating project; monitoring scope, planning, budget and quality
7. Training externally	Supplier	Giving digital training / programming training
	Project manager	Coordinating project; monitoring scope, planning, budget and quality
8. Digital layout factory	Programmer / IT-specialist	Developing digital layout of factory
	Project manager	Coordinating project; monitoring scope, planning, budget and quality
9. Installation / placement of machine	Technical service	Physical installation machine
	Supplier	Physical and digital installation machine
	Production engineer	Specific machine configuration in factory
	Programmer / IT-specialist	Digital installation machine
	Health, Safety and Environmental (HSE) team	Set security measures
	Quality engineer	Adjustment and control of process parameters
	Project manager	Coordinating project; monitoring scope, planning, budget and quality
10. Safety check/SAT	Health, Safety and Environmental (HSE) team	Test security measures
	Project manager	Coordinate process step
11. Internal training operators	Supplier	Provide operational training
	Operator	Follow operational training
	Project manager	Coordinating project; monitoring scope, planning, budget and quality
12. 0-series / Internal testing	Health, Safety and Environmental (HSE) team	Test security measures
	Quality engineer	Analyzing quality of the output based on parameters
	Production engineer	Analyze and improve machine configuration in factory
	Programmer / IT-specialist	Analysis functionality software
	Project manager	Coordinating project; monitoring scope, planning, budget and quality
13. Safety check/test	Health, Safety and Environmental (HSE) team	Test security measures
	Project manager	Coordinating project; monitoring scope, planning, budget and quality
14. Machine put into use	Project manager	Coordinating project; monitoring scope, planning, budget and quality
	Supplier	Assisting first production rounds
15. Optimization of machine	Quality engineer	Analyzing the quality of the output based on parameters
	Production engineer	Analyze and improve operational performance of machine

Company 1 was asked what performance level they had planned for the machine and how it currently performs. Also, they were asked how they expected the new production technology to affect the work and environment of the involved employees and the organizational processes and financial results, and how it affected these areas. An overview of the values for the planned and actual performance can be seen in Table 9 on page number 37. Company 1 did not have all the required information to fill in the table. Therefore, some data is missing from the table.

The objectives Company 1 had for implementing the production technology can be most traced back to the following KPIs from the table: quality of the output, lead time, personnel required, issues, compliances, and error logs, productivity rate of the employees, job satisfaction, and employee engagement. From the table can be stated that, after carrying out the implementation process, the production technology has a higher quality of output than planned, fewer personnel was required, and the lead time decreased more than expected. Moreover, the number of repair and maintenance actions decreased which positively influenced the availability rate of the machine. Lastly, the productivity rate of the employees improved and the employee engagement was at a higher level than planned. According to the interviewee of Company 1, the differences between the planned and actual performance can be traced back to the key activities they identified: the step-by-step configuration and installation of the machine, the development and use of a quality system, the external and internal training of employees, and the integration of safety procedures and analyses within the various process steps.

Table 9.

Assessment of the Impact the Implementation Process of Company 1 had on the Performance of the Production Technology, People, and Organization

Key Performance Indicators			**Unit of Metrics**	**Value**		
Area of analysis	**Category**	**Indicator**		**Planned**	**Actual**	**Difference**
Production technology	OEE	Availability rate	Run time / planned production time (%)	80%	90%	10%
		Quality of the output	Good count / total count (%)	92%	97%	5%
	Production efficiency	Raw materials used	Residual material (%)	n.a.	n.a.	-
		Energy consumed	kWh (%)	-	-	- 10%
		Personnel required	Required man-hours (%)	100%	50%	-50%
		Repair and maintenance	Total number of repair and maintenance actions (%)	10%	1%	-9%
		Lead time	Production time single unit (%)	40 sec	30 sec	- 10 sec / - 25%
Individuals/employees	Performance	Productivity rate	Operating time / planned operating time (%)	1000	1300	30%
		Issues, compliance, and error logs	Total number of issues, compliance, and error logs (%)	-	-	-
	Emotion and behavior	Job satisfaction	Rate 1-10	8	8	0
		Employee engagement	Rate 1-10	7	9	2
Organization	Operational performance	Throughput time of process	Total process time (%)			- 30%
	Financial performance	Contribution to total costs	Total operating costs (%)			-27%

4.3.2 Company 2

Company 2 is a mature company that implemented a metal straightening machine within their organization. They have experience with the technology in the machine because it already is the 5th generation of the technology within their organization. Differing from all other interviewed companies, Company 2 built/constructed the machine themselves. They did, however, use subcontractors to develop the various components of the machine. While developing the new machine, Company 2 mostly focused on improving the functional and operational performance of the machine. The company wanted the machine to be able to produce at least the same output quality as the employees /existing machines. Also, they wanted the machine to produce at the same speed, or preferably faster, than the employees and previous machines. To do so, the company relied heavily on the experience and expertise of one head operator and his team. They were asked to formulate technical and functional specifications for the machine. However, this did cause a barrier within the implementation process. As it turned out, the chosen technique that was integrated within the machine was not the best fit for the company. They had relied too much on the knowledge and expertise of the head operator which resulted in a machine that was unable to perform at the required level. A second barrier within the implementation process is the lack of financial resources. Because the company was short on financial resources, it chose to already put the machine into use. However, at that point, the machine was only 70-80% finished in its construction. This also affected the machine's ability to perform at the required level. Because of the main barriers, the interviewee stated that he could not really identify any key actions within the implementation process that contributed to its success. Contrarily, the interviewee could identify points of improvement for the implementation process. The interviewee stated that, for future projects, he would include more operators during all steps of the process. This is so that the engineers who develop the concept of the machine can rely on a broader knowledge base which will positively affect the accuracy the functional performance of the machine. Another point of improvement has to do with the training of the employees. In future projects, or when a machine is bought externally, the interviewee wishes that the employees are trained earlier in the process; during or right after the construction of the machine (or during/right after the factory acceptance test when the machine is bought externally). This point of improvement correlates with the next point of improvement; an extended period of performance testing and analysis. An extended period of testing and analysis lets the employees practice their operational skills and it also enables engineers to analyze (more) production data before the machine is actually put into use. As a result, the machine is more adjusted to the required performance level and the operators are more experienced with the machine. Both will contribute to the operational performance of the machine. The process steps, involved actors, and undertaken actions of the implementation process that Company 2 carried out are visualized in Table 10 on page number 39.

Table 10.

Implementation Process of Company 2

Process step / mechanisms	Responsible actor	Action
1. Idea generation	Chief operations	Coordinating the start process
	Software developer / programmer	Brainstorm desired digital aspects machine
	Technical designer	Brainstorm about the desired machine architecture/functionality
	Head operator / operators	Brainstorm about desired practical aspects / functionality of the machine
2. Research / design	Chief operations	Approve design
	Maintenance manager	Choose a hardware machine
	Head-operator	Provide advice on desired technology
	Technical designer	Assemble/configure hardware machine
	Software developer / programmer	Design/Development software
	Operators	Check design and landmarks for areas for improvement
3. Search for and approach supplier	-	-
4. Develop machine components	External supplier	Development and delivery of components
5. Assembly components / construction of the machine	External supplier	Delivery components
	Maintenance manager	Assembly hardware machine
	Technical designer	Check technical drawing
	Software developer / programmer	Integration software in machine
6. Testing / Factory Acceptance Test	Maintenance manager	Analysis functionality hardware
	Software developer / programmer	Analysis functionality software
	Head-operator	Analysis functionality production
7. Installation / placement of machine	Maintenance manager	Installation / placement of machine
	Software developer / programmer	Machine integration software in digital environment
	Head-operator	Installation / placement of machine
8. Internal training operators	Software developer / programmer	Providing operational training machine
	Operators	Take machine operational training
9. Machine put into use	Head-operator	Production
	Operators	Production
	Chief operations	Check whether the process has been completed successful
10. Optimization of machine	Technology analyst	Analysis of generated production data and functional performance of machine

Company 2 was asked what performance level they had planned for the machine and how it currently performs. Also, they were asked how they expected the new production technology to affect the work and environment of the involved employees and the organizational processes and financial results, and how it actually affected these areas. An overview of the values for the planned and actual performance can be seen in Table 11 on page number 40. Company 2 did not have all the required information to fill in the table. Therefore, some data is missing from the table.

As discussed above, Company 2 wanted the machine to be able to produce at least the same output quality as the employees /existing machines. Also, they wanted the machine to produce at the same speed, or preferably faster, than the employees and previous machines. These objectives can be traced back to the KPIs of the production technology; quality of the output and lead time. From the table can be stated that Company did not manage to reach any of the planned performance values for their objectives nor did they manage to get the performance of the production technology at the planned level on any of the other KPIs. The interviewee indicated that this difference was caused by the barriers that were discussed above. The interviewee also stated that the barriers had their effect on job satisfaction and employee engagement which is supported by the values from the table.

Table 11.

Assessment of the Impact the Implementation Process of Company 2 had on the Performance of the Production Technology, People, and Organization

Key Performance Indicators			Unit of Metrics	Value		
Area of analysis	**Category**	**Indicator**		**Planned**	**Actual**	**Difference**
Production technology	OEE	Availability rate	Run time / planned production time (%)	>=80%	+/- 60%	- 20%
		Quality of the output	Good count / total count (%)	Hammering average 5	Hammering average 16	11 more attempts
	Production efficiency	Raw materials used	Residual material (%)	N/A	N/A	N/A
		Energy consumed	kWh (%)	N/A	N/A	N/A
		Personnel required	Required man-hours (%)	MTBA 24hrs	MTBA 4hrs	-600%
		Repair and maintenance	Total number of repair and maintenance actions (%)	N/A	N/A	N/A
		Lead time	Production time single unit (%)	Average 6 blades p/h	Average 4 blades p/h	- 2 blades p/h
Individuals/employees	Performance	Productivity rate	Operating time / planned operating time (%)	MTBA 24hrs	MTBA 4hrs	600%
		Issues, compliance, and error logs	Total number of issues, compliance, and error logs (%)	N/A	N/A	N/A
	Emotion and behavior	Job satisfaction	Rate 1-10	9	6	- 3
		Employee engagement	Rate 1-10	9	7	- 2
Organization	Operational performance	Throughput time of process	Total process time (%)	10%****	15%	5%
	Financial performance	Contribution to total costs	Total operating costs (%)	N/A	N/A	N/A

4.3.3 Company 3

Company 3 is a mature company that implemented a metal folding machine within their organization. The company has a lot of experience with the implemented machine as it is at least the 8th generation metal folding machine within their company. Compared to the other companies, the production process of Company 3 is very digitalized and highly automated. That is why, differing from most of the other companies, Company 3 chose to implement the machine to improve its production process based on the level of digitalization and automation; an improvement of the digital environment. An important aspect of their implementation process is their continuous and extensive search for and analysis of new opportunities that allow them to improve the level of digitalization and automation within their company. As a result, Company 3 was highly capable of formulating what type of machine they would like, and what the specifications of the machine must be; making that a key activity within the implementation process. Other key activities within their implementation process are the analysis of the digital capabilities of a machine together with the integration of the machine into the digital environment of the company. These activities are vital for the machine to be able to operate in the highly digitalized and automated production process of the company. However, because their production process differs from other end-users of a similar machine, they have trouble finding a suitable supplier that can manufacture a machine that can operate at the required level of automation. Consequently, finding a suitable supplier is the barrier that they identified during the implementation process. To resolve this barrier, Company 3 believes that is important to include the supplier more in the implementation process. A higher degree of knowledge sharing between Company 3 and the supplier, especially with the technical employees of the supplier, is believed to have a positive impact on the ability of a supplier to deliver a machine that can operate at the required level of digitalization and automation. The process steps, involved actors, and undertaken actions of the implementation process that they carried out are visualized in Table 12 on page number 42.

Table 12.

Implementation Process of Company 3

Process step / mechanisms	Responsible actor	Action
1. Idea generation	Manufacturing engineer	Prepare business case
2. Design / specifications	Operators	Formulation of practical machine specifications
	Manufacturing engineer	Formulation of functional, practical, and digital machine specifications
3. Search for and approach supplier	Manufacturing engineer	Communicating specifications with supplier
	Procurement employee	Approach the supplier and go through the purchasing process
4. Construction of the machine	Supplier	Construction machine
5. Testing	ICT team	Testing whether the machine can be integrated in a digital environment
	Supplier	Provide assistance during testing period
	Operators	Operational training internally
	Manufacturing engineer	Analysis test production series
6. Machine placement	ICT Team	Integration machine in digital environmental company
	Supplier	Physical integration / placement of machines
7. Machine commissioned	Supplier	Provide commissioning assistance
	Operators	Operate machine
8. Optimization	Manufacturing engineer	Analysis production and optimization machine
	Supplier	Provide assistance during optimization

Company 3 was asked what performance level they had planned for the machine and how it currently performs. Also, they were asked if and how they expected the new production technology to affect the work and environment of the involved employees and the organizational processes and financial results and how it affected these areas. An overview of the values for the planned and actual performance can be seen in Table 13 on page number 43. Company 3 did not have all the required information to fill in the table. Therefore, some data is missing from the table.

The objectives that Company 3 had for implementing the production technology; an improvement of the digital environment, can't be analyzed using the KPIs from the table. However, it is important to state that Company 3 wishes for the machines to do the work and let the employees interfere with the automated production process as little as possible. Therefore, it is interesting to look at the productivity rate of the employees; do they have to do more work than planned? From the table can be stated that the planned and actual productivity rate is similar. This means that the company was successful in keeping the actual operating time of the employees similar to the planned operating time. It is also noticeable to say that the actual availability rate of the machine was lower than the planned availability rate. The interviewee indicates that this difference in performance value can be traced back to various errors in the codes of their production program. Overall, the interviewee stated that their structured implementation process ("what do we precisely want and how are we going to achieve that") causes the actual performance of the production technology to be almost always highly similar to the planned performance. Thus, once again proving that the development of a well-defined business case is a key activity within their process.

Table 13.

Assessment of the Impact the Implementation Process of Company 3 had on the Performance of the Production Technology, People, and Organization

Key Performance Indicators			Unit of Metrics	Value		
Area of analysis	**Category**	**Indicator**		**Planned**	**Actual**	**Difference**
Production technology	OEE	Availability rate	Run time / planned production time (%)	65%	58%	-7%
		Quality of the output	Good count / total count (%)	99.80%	99.80%	0
	Production efficiency	Raw materials used	Residual material (%)	Average ~30%	Average ~30%	Depending strong on order and material type
		Energy consumed	kWh (%)	40	40	Depending on production program
		Personnel required	Required man-hours (%)	100%	100%	0
		Repair and maintenance	Total number of repair and maintenance actions (%)	3%	2,75%	-0.25%
		Lead time	Production time single unit (%)	Dependent on production program	Dependent on production program	-
Individuals/employees	Performance	Productivity rate	Operating time / planned operating time (%)	100%	100%	0
		Issues, compliance, and error logs	Total number of issues, compliance, and error logs (%)	3 minutes per crash	3 minutes per crash	0
	Emotion and behavior	Job satisfaction	Rate 1-10	-	-	No information available
		Employee engagement	Rate 1-10	-	-	No information available
Organization	Operational performance	Throughput time of process	Total process time (%)	48 hours from order to delivery	48 hours from order to delivery	Delivery performance 98%
	Financial performance	Contribution to total costs	Total operating costs (%)	~ 70%	~ 70%	0

4.3.4 Company 4

Company 4 is a new branch of a company that implemented a 3D printer for metal within their organization to set up an additive manufacturing process. The main objective for implementing the machine was to set up a well-working production process that is ready for an industrial scale (scaling up). Therefore, Company 4 focused on controlling the machine and getting its performance consistent and on the required level. This branch of the company did not have any previous experience with the implemented machine but they were able to do some research on a 3D-metal-printer at another branch of the company that already used a previous version/generation of it. However, according to the interviewee, the machine at the other branch was quite outdated and used another technique than that they wanted to use. Although they did external internal (at the other branch) and external research on what type of machine to buy, Company 4 experienced various barriers during and after the implementation of their machine. As it turned out when the machine was installed, the employees of the company were still [1] unaware of some of its characteristics, [2] inexperienced with operating the machine, and [3] missing tools for the machines that were needed for the production process. According to the interviewee, these barriers were caused by ignorance from the employees of the machine and a training period that was too short. According to the interviewee, the barriers have harmed the operational performance of the machine and the production process. Consequently, the financial performance of the organization was negatively impacted. To resolve these barriers in future projects, the interviewee believes that it is important to do extensive research and gain more information, early in the implementation process. This would enable Company 4 to develop a business case or formulate technical specifications for the machine in much more detail which consequently improves a supplier's ability to develop a machine that fits expectations. The interviewee also believes that it is important that the training period is extended to enlarge the knowledge base and skills of the involved employees. Important to note is that the points of improvement show similarities with the key activities that were carried out and identified during the implementation process. According to the interviewee, a key factor within the process was that the supplier was easy to reach and had a high degree of proactivity in solving problems. Simultaneously, the application engineer from the supplier fulfilled an advising role during the process through which employees of the Company received a lot of information and expertise. Together with the application engineer, Company 4 learned a lot about the machine in a short period which helped them close the knowledge and skill gap and improve the performance of the machine. The steep learning curve of Company 4 caused the machine to now perform above expectations. Thus, the interviewee from Company 4 believes that it is important to extend the current key factors and enlarge the role of the supplier in future implementation processes. In doing so, it is believed that Company 4 will possess more knowledge, skill, and expertise of the machine earlier in the implementation process which eventually will improve the operational performance of the machine and organization. The process steps, involved actors, and undertaken actions of the implementation process that they carried out are visualized in Table 14 on page number 45.

Table 14.

Implementation Process of Company 4

Process step / mechanisms	Responsible	Action
1. Idea generation	-	-
2. Test phase of the machine	Production/design engineers	Analyzing basic machine functionality
	Application engineer (supplier)	Analyzing whether the machine can meet the functional requirements
3. Design / Specifications	Production/design engineers	Drawing up functional specifications of the machine
	Procurement employee	Discuss design/specifications with supplier
	Procurement employee	Discuss terms of delivery with supplier
	Account manager (supplier)	Internally discussing design/specifications with engineers
	Account manager (supplier)	Discuss the terms of delivery with the customer
4. Construction of the machine	Supplier	Construction machine
5. External training	Application engineer (supplier)	Transferring operational knowledge and skills
	Application engineer (supplier)	Transferring programming knowledge and skills
	Production/design engineers	Attend training
6. Factory Acceptance Test	Production/design engineers	Analyzing machine functionality
	Service engineer (supplier)	Analysis operational functionality machine
	Application engineer (supplier)	Analysis digital functionality machine
7. Machine placement	Application engineer (supplier)	Digital integration machine
	Service engineer (supplier)	Physical Integration Machine
8. Site Acceptance Test	Production/design engineers	Analyzing machine functionality
	Service engineer (supplier)	Analysis operational functionality machine
	Application engineer (supplier)	Analysis digital functionality machine
9. Internal training operators	Operators	Undergo operational training
	Service technician (supplier)	Provide operational training
	Service technician (supplier)	Explain preventive maintenance
10. Machine commissioned	Operators	Operate machine
	Application engineer (supplier)	Assisting with first production rounds
	Service technician (supplier)	Assisting with first production rounds

Company 4 was asked what performance level they had planned for the machine and how it currently performs. Also, they were asked if and how they expected the new production technology to affect the work and environment of the involved employees and the organizational processes and financial results and how it affected these areas. The value in the column 'planned' is the improvement in performance that they had planned for the new machine compared to the existing machine that was currently operating within their branch. An overview of the values for the planned and actual performance can be seen in Table 15 on page number 47.

As discussed prior in this subsection, Company 4 aimed to control the machine and get its operational performance consistent and on the required level. From Table 15 can be stated that the actual operational performance of the machine is better than the planned operational performance on numerous KPIs; availability rate, quality of the output, raw materials used, personnel required, and lead time. This means that they reached their goal of implementing the technology. According to the interviewee, the positive differences in value are a result of the steep learning curve that they experienced with the help of (employees of) the supplier and their training process. However, from the table can also be stated that the gap in knowledge and skills, before the start of the learning curve, has harmed other KPIs, including the number of repair and maintenance actions, job satisfaction of employees, and the total amount of operating costs. According to the interviewee, these negative differences could have been prevented if the transfer of knowledge and skills between buyer and supplier would have been more extensive and sooner in the implementation process (starting during the construction of the machine).

Table 15.

Assessment of the Impact the Implementation Process of Company 4 had on the Performance of the Production Technology, People, and Organization

Key Performance Indicators			**Unit of Metrics**	**Value**		
Area of analysis	**Category**	**Indicator**		**Planned**	**Actual**	**Difference**
Production technology	OEE	Availability rate	Run time / planned production time (%)	20%	30%	10%
		Quality of the output	Good count / total count (%)	50%	60%	10%
	Production efficiency	Raw materials used	Residual material (%)	30%	20%	10%
		Energy consumed	kWh (%)	5%	5%	0%
		Personnel required	Required man-hours (%)	-20%	-30%	-10%
		Repair and maintenance	Total number of repair and maintenance actions (%)	20%	40%	20%
		Lead time	Production time single unit (%)	50%	40%	- 10%
Individuals/employees	Performance	Productivity rate	Operating time / planned operating time (%)	10%	20%	10%
		Issues, compliance, and error logs	Total number of issues, compliance, and error logs (%)	-10%	-10%	0%
	Emotion and behavior	Job satisfaction	Rate 1-10	9	8	- 1
		Employee engagement	Rate 1-10	9	9	0
Organization	Operational performance	Throughput time of process	Total process time (%)	-20%	-10%	10%
	Financial performance	Contribution to total costs	Total operating costs (%)	-40%	-30%	10%

4.3.5 Company 5

Company 5 is a startup company that implemented a first-generation fiber blow spinning machine within its organization. Together with Company 6, they differ from the other interviewed companies in the fact that the implemented technology is unique within their respective industry. Therefore, their objective was to develop a well-working machine that is capable of producing consistently at a required performance level and can be further developed on an industrial scale. To reach that objective Company 5 invested heavily in market research, feasibility testing of other technologies, and continuous contact with (the engineers from) their supplier. The market research and feasibility testing were important to identify if the technology was feasible for production and to formulate any minimal functional and operational specifications for the machine. These specifications were then given to the supplier after which a joint-development process between Company 5 and their supplier began; consisting of engineering and designing all specifications of the machine in detail. Once the construction of the machine had begun, their implementation process showed strong similarities with those of the other companies; factory acceptance test, installation of the machine, site acceptance test, and optimizing the machine internally. However, differing from the other companies, Company 5 did not yet put the machine into productional use since they do not have a working production process. The main barriers during the implementation process had to do with the communication between the supplier and their subcontractors. Due to a bad degree of communication and project management, components of the machine were delivered late or not according to their requirements. As a result, the duration of the implementation increased by more than a year and employees got frustrated. Key activities within the process were the extensive rounds of research and multiple rounds of testing and analyzing the machine. Because of these activities, the employees of the company were highly educated on the subject and that, together with the rounds of testing and analyzing, helped them to quickly identify and solve problems with the machine. To improve the future implementation processes, the interviewee believes that it is important to increase collaboration with the supplier even further. A higher degree of knowledge would enable both parties (buyer and supplier) to understand the case, and expectations, in more detail and come to the desired result. Another point of improvement is extending the rounds of testing and analyzing once the machine has been constructed. According to the interviewee, the production data that is generated during those rounds is highly valuable for analyzing and optimizing the performance of the machine. The data can also be used as input for new machines. Lastly, once Company 5 starts with the construction of a machine for industrial scale, they tend to include the operators within and during the entire implementation process. This allows the operator to understand the machine from the inside-out and control it. The process steps, involved actors, and undertaken actions of the implementation process that Company 5 carried out are visualized in Table 16 on pages 48-50.

Table 16.

Implementation Process of Company 5

Process step / mechanisms	**Responsible**	**Action**
1. Idea generation	Project manager	Research into the productivity of various processes and machines, machine builders and suppliers
	Chief Operations	Research on the production process, the productivity of different machines, machine builders, supplier
	Senior R&D Engineer	Research on the production process, the productivity of different machines, machine builders, supplier
2. Feasibility testing	Project manager	Research into the feasibility of the chosen production process
	Chief Operations	Research into the feasibility of the chosen production process
	Senior R&D Engineer	Research into the feasibility of the chosen production process

6. Formulate functional specifications	Senior R&D Engineer	Formulating functional specifications machine
	Project manager	Coordinating project; monitoring scope, planning, budget and quality
	Chief Operations	Check planning and budget, solve major problems
7. Search for and approach supplier	Project manager	Approach supplier
	Sales manager (supplier)	Conduct sales calls and negotiations
	Senior R&D Engineer	Communicate functional specifications of machine to supplier
	Project manager	Coordinating project; monitoring scope, planning, budget and quality
	Chief Operations	Check planning and budget, solve major problems
	Project manager (supplier)	Coordinating project; monitoring scope, planning, budget and quality
8. Design and engineering specifications machine	Engineers (supplier)	Translate functional requirements into machine design
	Technical director (supplier)	Translate functional requirements into machine design
	Project manager	Coordinating project; monitoring scope, planning, budget and quality
	Chief Operations	Check planning and budget, solve major problems
	Project manager (supplier)	Coordinating project; monitoring scope, planning, budget and quality
9. Construction of the machine	Engineers (supplier)	Develop the machine
	Project manager	Coordinating project; monitoring scope, planning, budget and quality
	Chief Operations	Check planning and budget, solve major problems
	Project manager (supplier)	Coordinating project; monitoring scope, planning, budget and quality
	Technical director (supplier)	Coordinating project; solving big problems; transfer knowledge and experience
10. Factory acceptance test	Engineers (supplier)	Perform test and analyze machine functional performance
	Senior R&D Engineer	Analyzing functional machine performance
	Project manager	Coordinating project; monitoring scope, planning, budget and quality
	Chief Operations	Check planning and budget, solve major problems
	Project manager (supplier)	Coordinating project; monitoring scope, planning, budget and quality
	Technical director (supplier)	Coordinating project; solving big problems; transfer knowledge and experience
11. Installation / placement of machine	Project manager	Coordinating project; monitoring scope, planning, budget and quality
	Chief Operations	Check planning and budget, solve major problems
	Project manager (supplier)	Coordinating project; monitoring scope, planning, budget and quality
	Technical director (supplier)	Coordinating project; solving big problems; transfer knowledge and experience
12. Site Acceptance Test	Engineers (supplier)	Perform test and analyze machine functional performance
	Senior R&D Engineer	Analyzing functional machine performance
	R&D technicians	Analyzing functional machine performance
	Project manager	Coordinating project; monitoring scope, planning, budget and quality

	Chief Operations	Check planning and budget, solve major problems
	Project manager (supplier)	Coordinating project; monitoring scope, planning, budget and quality
	Technical director (supplier)	Coordinating project; solving big problems; transfer knowledge and experience
13. Optimization	R&D technicians	Operate machine
	R&D technicians	Run analytics to optimize machine performance
	Senior R&D Engineer	Run analytics to optimize machine performance
	Project manager	Coordinating project; monitoring scope, planning, budget and quality
	Chief Operations	Check planning and budget, solve major problems
	Project manager (supplier)	Coordinating project; monitoring scope, planning, budget and quality
	Technical director (supplier)	Coordinating project; solving big problems; transfer knowledge and experience

Company 5 was asked what performance level they had planned for the machine and how it currently performs. Also, they were asked if and how they expected the new production technology to affect the work and environment of the involved employees and the organizational processes and financial results and how it actually affected these areas. An overview of the values for the planned and actual performance can be seen in Table 17 on page number 51. Company 5 did not have all the required information to fill in the table. Therefore, some data is missing from the table.

As discussed, Company 5 aimed to implement a well-working machine that is capable of producing consistently at a required performance level and can be further developed on an industrial scale. To do so, Company 5 mostly focused on operational performance KPIs of the production technology. In the table, these can be seen under the OEE and production efficiency. From the table can be stated that the actual performance of the production technology is worse than the planned performance, based on all KPIs. According to the interviewee, these differences were mostly caused by the previously mentioned hardware problems. The hardware problems caused an inaccurate production process that had to be put to a stop on many occasions. Also, it made it difficult for Company 5 to adjust the performance to the desired level. At the time of the interview, Company 5 was still optimizing the machine to get it at the desired performance level. According to the interviewee, this could have been prevented if the communication between all involved organizations is improved; sharing more information that is highly accurate.

Table 17.

Assessment of the Impact the Implementation Process of Company 5 had on the Performance of the Production Technology, People, and Organization

Key Performance Indicators			Unit of Metrics	Value		
Area of analysis	**Category**	**Indicator**		**Planned**	**Actual**	**Difference**
Production technology	OEE	Availability rate	Run time / planned production time (%)	60%	40%	-20%
		Quality of the output	Good count / total count (%)	50%	30%	-20%
	Production efficiency	Raw materials used	Residual material (%)	10%	50%	40%
		Energy consumed	kWh (%)	n.a.	n.a.	n.a.
		Personnel required	Required man-hours (%)	2 FTE	2 FTE	0
		Repair and maintenance	Total number of repair and maintenance actions (%)	n.a.	n.a.	n.a.
		Lead time	Production time single unit (%)	50%	75%	25%
Individuals/employees	Performance	Productivity rate	Operating time / planned operating time (%)	60%	40%	-20%
		Issues, compliance, and error logs	Total number of issues, compliance, and error logs (%)	n.a.	n.a.	n.a.
	Emotion and behavior	Job satisfaction	Rate 1-10	8	8	0
		Employee engagement	Rate 1-10	8	9	1
Organization	Operational performance	Throughput time of process	Total process time (%)	X	X*3	-
	Financial performance	Contribution to total costs	Total operating costs (%)	n.a.	n.a.	n.a.

4.3.6 Company 6

Company 6 is a scale-up company that implemented a machine that enhances silicon solar cells within their organization. Together with Company 5, they differ from the other interviewed companies in the fact that the implemented technology is unique within their respective industry. Similar to the maturity of the company, the reason behind the implementation of the new machine/technology was to scale up an existing machine to make it faster, wider, and better than the existing version in several functional and operational aspects. To do so, Company 6 invested heavily in conducting fundamental, technological, and functional research on the machine that was desired/described in the business case. The research was first conducted internally to understand the fundamental parts of the machine and to formulate the first minimal functional specifications. However, this already caused a barrier within their process. The interviewee stated that they had difficulty with translating a theoretical concept to functional specifications of a physical machine. This is because the technology was so unique and they did not have any reference material that they could learn from. Once they succeeded in that part of the process, a new barrier occurred; finding a suitable supplier for a machine that is as unique as theirs. Yet again, they succeeded and found a supplier and the process became more of a joint-development program in which Company 6 developed the desired machine in collaboration with the supplier. However, the first barrier that occurred during the process; formulating minimal functional specifications for the machine, consequently caused a new barrier later in the process. See, during the development of the machine (e.g. during the formulation of specific machine specifications and the engineering phase), Company 6 had different expectations than their supplier. Company 6 was on a budget, both monetary and timewise, and therefore wanted to start with the construction of the machine and work towards a simple version of it that could be tested. However, the supplier first wanted to work out the concept of the machine in detail. This resulted in miscommunication about expectations. This was initially caused by the fact that Company 6 had only formulated bare minimal functional specifications for the machine; with too little information for a supplier to work with. Thus, as a result, the interviewee believes that an important part of improvement for future implementation processes would be to invest more time and effort in formulating an understandable and (more) specific concept for a supplier. This in turn prevents unforeseen costs and loss of time in later steps of the process, as happened now. As the interviewee stated, you pay for any vagueness that ends up with the supplier with time and money. The process steps, involved actors, and undertaken actions of the implementation process that Company 6 carried out are visualized in Table 18 on page number 52 and 53.

Table 18.

Implementation Process of Company 6

Process step / mechanisms	Responsible	Action
1. Idea generation	Chief Technology Officer	Formulating the business case and initial operational specifications
2. Formulate functional specifications	Tech team	Analyzing and advising on the fundamental aspects of the process
	Mechanical engineer	Analyzing and advising on the mechanical aspects of the process/machine
	Electrical engineer	Analyzing and advising on the electrical aspects of the process/machine
	Software engineer	Analyzing and advising on the software aspects of the process/machine
	Process engineer	Analyzing all practical matters concerning the machine
	Chief Technology Officer	Formulate initial operational specifications
3. Search for and approach supplier	Upscaling team	To approach
	Chief Technology Officer	Coordinating process and assisting during problems
4. Formulate specified machine specifications	Tech team	Analyzing and advising on the fundamental aspects of the process
	Mechanical engineer	Analyzing and advising on the mechanical aspects of the process/machine

	Electrical engineer	Analyzing and advising on the electrical aspects of the process/machine
	Software engineer	Analyzing and advising on the software aspects of the process/machine
	Chief Technology Officer	Coordinating process and assisting during problems
5. Engineering phase	Supplier	Dividing the machine into components and formulating a construction plan
6. Construction of the machine	Supplier	Construction machine
7. Factory Acceptance Test	Tech team	Quality control
	Mechanical engineer	Analyzing the functional performance of the process/machine
	Electrical engineer	Analyzing the functional performance of the process/machine
	Software engineer	Analyzing the functional performance of the process/machine
	Process engineer	Documenting the control and functional properties of the machine
	Chief Technology Officer	Coordinating process and assisting during problems
8. Installation / placement of machine	Installation manager	Organizing the necessary aspects to be able to install the machine
	Facility manager	Preparing the physical environment to install the machine
	Process engineer	Documenting the control and functional properties of the machine
	Chief Technology Officer	Coordinating process and assisting during problems
9. Site Acceptance Test	Tech team	Quality control
	Mechanical engineer	Analyzing the functional performance of the process/machine
	Electrical engineer	Analyzing the functional performance of the process/machine
	Software engineer	Analyzing the functional performance of the process/machine
	Process engineer	Documenting the control and functional properties of the machine
	Operators	Learning to understand the machine
	Chief Technology Officer	Coordinating process and assisting during problems
10. Recipe Development	Tech team	Entering material to examine how the machine is set up
	Process engineer	Documenting the control and functional properties of the machine
	Operators	Learning to understand the machine
	Chief Technology Officer	Coordinating process and assisting during problems
11. Internal training	Supplier	Providing internal training
	Operators	Following internal training
	Chief Technology Officer	Coordinating process and assisting during problems
12. Integration of machine into production process	Process engineer	Checking physical and digital integration of the machine in the factory
	Process engineer	Testing of functional specifications and machine safety
	Process engineer	Release machine to production

Assessment matrix Company 6:

The interviewee of Company 6 explained that they are currently unable to fill in the assessment matrix. When asked about it during the interview, the interviewee stated:

"Well, we actually have no data for this at all because the machine is not running yet. It's really too early for this. We do know that the machine is not yet performing at the level we want and therefore the machine has not yet been taken into production. It is such a new process that we have not actually been able to set any expectations. We are still figuring everything out."

4.3.7 Company 7

Company 7 is a mature company that implemented a metal turn and milling machine within their organization. The machine is the first multi-task machine within their organization. However, the various tasks within the machine were already present within the organization. The objective to implement the machine was to expand their overall production capacity and to increase the variety of production technology that is present within their company. Consequently, they had a great sense of what kind of machine they wanted to implement. This turned out during the initial process steps, in which the technology advisor of Company 6 developed a well-defined business case for the machine. The business case was then discussed with, analyzed, and complemented by the involved operators to eventually end up with a precise plan (consisting of functional for their machine. These activities (the preparation for, development, and analysis of a well-defined business case that included functional specifications) were identified by the interviewee as key activities within their implementation process that contributed greatly to its ultimate success. A result of the well-defined business case and specifications was that Company 7 did not need an additional process step in which they had to define and develop detailed specifications for the machine together with the supplier. Rather, they were only occupied with choosing optional aspects of the machine. This shows great similarity with Company 3 who was also well aware of the type of machine they truly wanted. Another aspect that contributed to the success of the implementation process of Company 7 was the preparation and education of the organization and its employees. This included the involvement of the operators throughout most of the implementation process and the operational education the operators received during their involvement. The involvement of the operators caused them to be well-informed, prepared for, and in control of the machine when it arrived. Once the machine was installed at the company, the operators were given time to get familiar with the new machine and train with it. However, these operators were also responsible for operating other machines. Consequently, to be prepared for the new machine, Company 7 chose to put the other machines out of use. This harmed the availability rate of those machines and the financial performance of the organization. Thus, the interviewee stated that the main barrier they encountered during the implementation process was the lack of resources (both human resources and time) to implement the new machine as well as keep the production process running. However, according to the interviewee, this barrier was well-considered and foreseen. Therefore, the consequences were accepted and limited where possible. Another barrier they encountered was that the supplier had a shortage of parts to finish the construction of the machine. The barrier was caused by the global pandemic and underperforming subcontractors of the suppliers. The barrier was unforeseen and caused the implementation process to take longer than planned. However, this barrier did not have any other negative impact as Company 7 was not reliant on the arrival of the new machine. The process steps, involved actors, and undertaken actions of the implementation process that Company 7 carried out are visualized in Table 19 on page number 55.

Table 19.

Implementation Process of Company 7

Process step / mechanisms	Responsible	Action
1. Idea generation	Technology advisor	Formulating business case
	Director	Business case approval
2. Formulate minimum functional specifications	Technology advisor	Formulate minimum specifications
	Director	Analyzing and approving minimum specifications
	Operators	Analyzing and approving minimum specifications
3. Search for and approach supplier	Project Manager	Approach supplier and coordinate process
4. Reference research	Project Manager	Visually inspect machine and analyze business case
	Director	Visually inspect machine and analyze business case
	Operators	Analyzing functional aspects of machine
5. Formulate detailed machine specifications	Technology advisor	Formulate detailed specifications
	Director	Analyzing and approving detailed specifications
	Operators	Analyzing and approving detailed specifications
	Project Manager	Coordinating process and assisting during problems
6. Construction of the machine	Supplier	Construction machine
	ICT manager	Digital integration of machine in organization
	Project Manager	Coordinating process and assisting during problems
7. Installation / placement of machine	Supplier	Installation machine
	Technical service	Facility preparation of factory for installation of machine
	Operators	Analyzing and advising on physical placement of machine in factory and process flow
	Project Manager	Coordinating process and assisting during problems
8. Internal operator training	Supplier	Provide machine operational training
	Operators	Follow machine operational training
	Project Manager	Coordinating process and assisting during problems
9. Machine put into use	Operators	Operate machine
	Project Manager	Coordinating process and assisting during problems
10. Optimization of machine	ICT manager	Alignment of control program with machine functionality
	Project Manager	Coordinating process and assisting during problems

Company 7 was asked what performance level they had planned for the machine and how it currently performs. Also, they were asked if and how they expected the new production technology to affect the work and environment of the involved employees and the organizational processes and financial results and how it affected these areas. An overview of the values for the planned and actual performance can be seen in Table 20 on page number 57.

Based on the table, it is impossible to say if Company 7 managed to achieve their objectives to implement the machine; an expansion of their overall production capacity, and an increase of the variety of production technology that are present within their company. However, from the table can be stated that Company 7 managed to get the actual operational performance of the machine and their employees to be higher than planned. According to the interviewee, this positive difference was caused by the preparation and education of the organization and its employees. Because the employees were given the time and opportunities to train with the machine throughout the process, they are now more in control of it than planned. This also positively affected job satisfaction and employee engagement. This, even though some involved employees were initially opposed to the innovative idea.

Table 20.

Assessment of the Impact the Implementation Process of Company 7 had on the Performance of the Production Technology, People, and Organization

Key Performance Indicators			Unit of Metrics	Value		
Area of analysis	**Category**	**Indicator**		**Planned**	**Actual**	**Difference**
Production technology	OEE	Availability rate	Run time / planned production time (%)	15%	20%	5%
		Quality of the output	Good count / total count (%)	95%	98%	3%
	Production efficiency	Raw materials used	Residual material (%)	75%	75%	-
		Energy consumed	kWh (%)	2%	3%	1%
		Personnel required	Required man-hours (%)	20%	40%	20%
		Repair and maintenance	Total number of repair and maintenance actions (%)	3%	5%	2%
		Lead time	Production time single unit (%)	10%	20%	10%
Individuals/employees	Performance	Productivity rate	Operating time / planned operating time (%)	30%	40%	10%
		Issues, compliance, and error logs	Total number of issues, compliance, and error logs (%)	1%	15%	14%
	Emotion and behavior	Job satisfaction	Rate 1-10	6	7	1
		Employee engagement	Rate 1-10	6	7	1
Organization	Operational performance	Throughput time of process	Total process time (%)	40%	30%	-10%
	Financial performance	Contribution to total costs	Total operating costs (%)	25%	15%	-10%

5. Analysis

Throughout this section, the implementation processes that the interviewed companies have carried out will be analyzed. First, a common structure of the process, consisting of process steps, will be identified in Section 5.1. Then, undertaken actions and best practices within the process steps will be discussed in Section 5.2. Afterwards, barriers that occurred during the processes and points of improvement for future projects will be discussed in Section 5.3 and 5.4, respectively. Finally, the identified process steps and identified best practices will be combined in Section 5.5 to ultimately develop a roadmap for implementing digital production technology.

5.1 Identification of a common structure of the process consisting of process steps and overarching ‘phases of the process’

To identify potential similarities between cases, based on the steps within their process, a statistical analysis was conducted. Within the analysis, it was presumed that a process step could be labeled ‘common’ if it was present in more than 50% percent of the implementation processes (at least 4 out of 7). An overview of the statistical analysis can be seen in Appendix D. Based on the statistical analysis, it can be stated that the implementation process of the researched cases is alike at various moments of the process. The similarities lie in the type of steps they included as well as the timing of those steps within the process. The common process steps can be summarized as:

1. Idea capture and generation
2. Formulation of functional specifications for production technology
3. Search for and approach supplier
4. Formulate detailed specifications for production technology
5. Construction of the production technology
6. Factory Acceptance Test
7. Installation / placement of production technology
8. Site Acceptance Test
9. Internal training for employees
10. Machine put into use
11. Optimization of production technology

The companies have conducted various actions within each of the above-mentioned process steps. These actions were summarized in an overview that can be seen in Appendix E. The overview shows one summary statement for the set of actions a company carried out during the process step the summary statement is assigned to. Based on an analysis of the summary statements for the set of actions each company carried out during their implementation process, it can be stated that there are four overarching themes/phases. These overarching phases are:

1. Orientation and exploration
2. Design and decide
3. Preparation and integration
4. Execution and advancements

The next section will go deeper into each phase and its process steps. The actions that companies conduct during those phases and steps will be discussed. Moreover, potential best practices are identified and discussed. A visual representation of the identified process phases and process steps can be seen in Figure 5 below.

Figure 5.

Overview of the Identified Process phases and Process steps

Process-phase	**Process-step**
1. Orientation and exploration	a. Idea capture and generation
	b. Formulation of core specifications for the production technology
	c. Search for and approach supplier
2. Design and decide	a. Formulation of detailed specifications for production technology
	b. Construction of machine
3. Preparation and integration	a. Factory Acceptance Test
	b. Installation / placement of production technology
	c. Site Acceptance Test
	d. Internal training for employees
4. Execution and advancements	a. Production technology put into use
	b. Optimization of production technology

5.2 A dive into the phases of the process; discussing the process steps, actions taken, best practices and impacting factors

Section 5.2 is intended to identify and discuss the actions and most effective best practices that were undertaken during the previously identified process phases and process steps. The section is divided into five subsections. The initial four subsections dive into the actions that should be conducted within each process phase, highlighting the activities occurring at each stage/step in a chronological way. Subsequently, within each of these subsections, the best practices observed within that phase are thoroughly analyzed and discussed in more detail. An overview of the best practices highlighted during the interview, along with their positive impacts, can be seen in Appendix F.

The fifth subsection in Section 5.2 aims to discuss the company's characteristics and/or the implemented production technology. This discussion explores their potential impact on the process's structure, necessary actions, and/or recommended best practices.

5.2.1 Phase 1: Orientation and exploration

In general, throughout this phase, the companies orient themselves with their innovative idea by developing a first version of a business case. The business case needs to answer a few questions, for instance, ‘what do we need to be improved?’, ‘why do we need/want it improved?’, ‘What do we believe is a feasible solution?’, ‘How can the solution be integrated within our organization?’, and ‘How do we realize the plan?’. An answer to the first and second question is commonly an objective/reason to improve the production process; improved lead time, quality, and/or availability rate. In the scope of this research, an answer to the third question would be to implement a new digital production technology. To give a precise answer to the question, and built the business case, (minimal) functional (physical and digital) specifications need to be formulated for the production technology that a company would like to implement. Afterward, the companies explore the market to search for and approach a suitable supplier together with that business case. Best practices during those process steps are discussed below.

5.2.1.1 Phase 1 - Best Practice 1: Assign a technology expert who is highly informed about the production process and is responsible for pushing the innovative idea through the organization connecting all actors

The process starts with an idea that is quickly translated to a first version of a business case that has answered the first two questions, as discussed above. An important part of this step is the presence of a technology advisor who continuously searches for innovation and is able to identify opportunities within the market. Some companies, such as Company 6, use a top-down approach in which a chief technology officer (CTO) identifies the opportunity for innovation and pushes it down the organization. However, in such situations, as indicated by the interviewee of Company 6, recipients of the idea might end up with little information. An example of this is given in Statement 1 below.

> Statement 1:
>
> Interviewee Company 6: *“Internally I was first instructed to do this. That was actually the assignment: ‘here are a few documents that give an idea of how the machine could be scaled up, look further into that’. So this wasn't much to begin with.”*

This can create misunderstandings which potentially negatively influences the duration of the process. The interviewee of Company 6 confirmed this by stating that their process took a lot longer than expected. According to the interviewee, this was caused by an ill-developed business case that contained too little information to work with in the following steps of their process. As a result, Company 6 had to go through numerous discussions with the eventual supplier to develop a concept of a machine that was ready for production. The top-down approach in which a senior executive hands a business case down to the organization can thus cause a lengthy and vague start of the process. This also accounted for two of the other interviewed companies that used the top-down approach in their process.

Contrary to the top-down approach discussed above, the interviewee from Company 3 indicated that they use a different approach in which their manufacturing engineer comes up with the idea for improvement. The manufacturing engineer has a central place within the organization (in-between operators and senior executives). That person is, together with the operators, also responsible for the development of a business case. According to the interviewee, the manufacturing engineer is highly informed about the possibilities for improvement that exist within the market and also what option is most suitable for their needs. This is because they are well-informed about the process that they want to improve and are in close contact with operators who operate it. As a result, they are able to develop a more defined business case that also answers how the machine needs to be designed so it can be integrated within the organization and what practical aspects need to be considered so that it is well-operatable. Furthermore, they are in direct contact with the supplier which gives an opportunity for a direct transfer of information from the business case between both companies. Thus, compared to a CFO, the manufacturing engineer is more able to develop and push innovative solutions through the organization.

In this first process step, it is thus a best practice if the person who pushes the idea through the organization is in close contact with all actors and is highly informed about the production process; they have a central place within the organization that is closely linked to the production process and they can push the innovation form inside the organization out. In doing so, direct awareness is created within all levels of the organization and most knowledge can be leveraged to come up with a feasible idea. Also, it makes sure that the people who are required for the next step in the process are already informed about the idea which positively influences the duration of the process. Lastly, it ensures that feasible expectations are set for the performance of the machine that is communicated within the organization and to the supplier(s). According to the interviewee of Company 3, the detailed business case and formulation of expectations cause the actual performance level of the machine to always be highly similar to the planned performance. This statement is supported by the values within the assessment framework in Table 13. Thus, although the idea for innovation can be grasped by a CTO, it should be pushed through the organization by an employee who is in the center of the organization.

5.2.1.2 Phase 1 - Best Practice 2: Set specifications and expectations that are precise and communicate these with all involved parties

Once the innovative idea is pushed through the organizations, companies go deeper into the question ‘What do we believe is a feasible solution?’. An answer to this question is a business case that contains functional and practical specifications of the production technology and steps to realize the idea. During this process step, it is a best practice to develop functional and practical specifications that are as precise as possible. Developing such precise specifications enables an organization to identify key factors and potential bottlenecks within the solution. Accordingly, an action plan can be set up to conduct in following process steps in order to ensure the identified key factors and to take care of the bottlenecks/barriers. This action plan can then be communicated with the involved parties. An example of this is given in Statement 2.

> <u>Statement 2:</u>
>
> Interviewee Company 7: *“First we encountered resistance and then together we look for a way to realize progress. We all have to move forward to keep up with the market.”*
>
> Interviewer: *“Is it perhaps another key activity that you put down a very precise business case in the first phases in which you also sketched a clear picture internally of the impact that the machine would have within the company?”*
>
> Interviewee Company 7: *“Yes, yes.”*

Interviewer: *"That you not only clearly mapped out what you wanted in terms of technology, but also how you were going to integrate it, what it takes to realize this."*

Interviewee Company 7: *"Yes, absolutely. Then we already knew where it would all end. We then made a plan for that."*

According to the interviewee from Company 7, the development of a precise business case enabled them to identify the actions needed to realize the plan. Ultimately, it improved their knowledge and control over the machine which caused the actual performance of the technology, involved employees, and organization to be better than the planned performance. This can be seen in Table 20.

A business case that contains precise information also contributes to the level of expectation management within and between organizations. Internally, involved employees are informed about the change that is happening and what is expected from them to realize that change. Externally, suppliers are informed about expectations; what do we want/expect you to make and can you do this? An example of the external communication of expectations is given in statement 3.

Statement 3:

Interviewee Company 3: *"We often run into that. Companies come to us that they want to and can help because they have helped metal companies before. When we ask for references, it turns out that these are machines for mass production companies. A lot of machines are therefore not suitable for our varied production. Based on our business case, we can continuously test whether both parties understand each other well and whether all wishes can be met."*

According to the interviewee from Company 3, having clear communication about expectations with a supplier ensures that the delivered production technology can perform at the required level. Only small adjustments need to be made to get it at the planned performance level. This has a positive impact on the duration of the process as well as on its outcome; the ultimate performance of the production technology.

5.2.1.3 Phase 1 - Best Practice 3: Search for a supplier that is willing and able to deliver the desired production technology and level of service

As discussed in the previous sub-section, the search for a supplier starts with a good understanding of the business case and an answer to the question: what do we want? The answer to that question is mostly concerning the desired production technology. Thus, often, a supplier must be searched for that can manufacture and deliver the desired production technology. But besides that, it is also important that a supplier can deliver the desired level of service throughout the process. Such service includes for example the advice that is given during the formulation of the detailed specifications, training that is given to employees, and/or assistance that is provided during the initial rounds of testing/production. The supplying organization should thus be less viewed as solely a supplier of the production technology and more as a partner in the process that is able and willing to advise and assist. The importance of having a partner throughout the process is emphasized by the interviewee from Company 4. This can be seen in statement 4 below.

Statement 4:

Interviewer: *"What factor or action would you identify as having contributed greatly during the implementation process?"*

Interviewee Company 4: *"Those are two points that both concern the supplier. The supplier really has a great accessible service. You can reach them day and night and they are proactive in solving problems.*

This almost always happens right away. In addition, the advisory role of the application engineer has been very important. We have collected so much information from the beginning because of it. As a result, we really had a steep learning curve based on knowledge and production."

The steep learning curve that Company 4 experienced ensured that the production technology quickly performed at the planned level. Furthermore, the knowledge and expertise that the (employees of the) supplying organization provided to Company 4 enabled them to better understand and optimize the functionality of the production technology. As a result, the production technology now performs at a higher level than planned, as can be seen in Table 14. Company 1 also experienced how the collaboration with and support of their supplier during the process contributed to the process. Similarly, their production technology also performs at a higher level than planned. These examples emphasize the importance of finding a supplier who is able to manufacture the desired production technology and who is able and willing to provide the desired level of service. Consequently, it is a best practice to search for a supplier that is willing and able to be a partner during the process

5.2.2 Phase 2: Design and decide

Within the second phase, the company and its supplier collaboratively formulate detailed specifications for the desired production technology and decide on a final concept which is then constructed. None of the interviewed companies have indicated any specific actions or best practices during the construction of the machine. This is because the supplier was responsible for the construction of the production technology and the interviewed companies were watching on the sideline. Therefore, there is only a sub-section that discusses the best practices during the formulation of detailed specifications for the production technology.

5.2.2.1 Phase 2 – Best Practice 1: Analyze the standard version of the desired production technology to adjust and optimize your initial concept

In many cases, the detailed specifications for the desired production technology concern the exterior of the production technology, practical characteristics, and any optional tools it must possess. However, in some cases, this process step is used to further develop any functional or technological specifications for the machine. This has to do with whether or not the production technology is unique or standardized which is further discussed in Section 5.2.5.2; Characteristics of the production technology that influence the core structure of the process. The companies that have implemented a standardized production technology are discussed in this sub-section. A best practice that is used by many of the interviewed companies during this process step is to do a round of research. During that round, the 'catalog' production technology (the basic version) is analyzed during production; how it can produce various production programs. During the analysis, buying companies can get a hands-on experience with the machine. This enables buying organizations to identify if and how specifications and options of the machine need to be adjusted, added, or removed from the initial concept to optimize its capabilities. An example of the analysis and configuration of the production technology that Company 7 conducted is given in statement 5 below.

<u>Statement 5:</u>

Interviewer: *"So you have the business case that includes the functional specifications for the machine and then look for a supplier. What's the next step for the company?"*

Interviewee Company 7: *"Then you sit down with the supplier to discuss all options, but also to further specify the machine in terms of the options that will all be on the machine. In addition, you will also conduct reference research by the supplier's customers to investigate how the machine works for them. Then you really get an idea of what you are going to buy. The machine is fairly new, so the reference research was not with customers but we visited the manufacturer instead to analyze and examine the machine there. Truly examine how the machine works and how we can adjust it to fit our desire. Then we check internally with the operators whether they also agree with the concept."*

Thus, the analysis of the production rounds enables organizations to identify how the initial concept of the production technology can be improved. Choosing how to improve the production technology can happen collaboratively, according to the interviewee from Company 4. The interviewee indicated that they relied on the expertise and knowledge of the supplier during the configuration and improvement of the production technology. The dependency of Company 4 on the knowledge and expertise of the supplier during this process step can be seen in statement 6.

Statement 6:

Interviewee Company 4: *"The next step is to personalize the machine. What kind of machine do we want. You start thinking about the systems you want, the materials you want to print."*

Interviewer: *"And when you have established this knowledge, will it then be passed on to the supplier?"*

Interviewee Company 4: "*Well, you actually do this in collaboration with the supplier. After all, they are the specialists who know what is possible and what options they have."*

The examples from the statements show that the formulation of detailed specifications for the machine is supported by analyzing production rounds of the standard production technology. According to the interviewees, the test rounds and configuration ultimately led to the actual performance of the production technology to be better than the planned performance of the production technology. This is also confirmed by the interviewee from Company 1 who stated that the continuous testing and configuration of the machine ultimately contributed to the higher-than-planned performance of their production technology.

Thus, the best practice that is identified during this process step is: to test the basic production technology to adjust and optimize the initial concept. However, this also shows how having a suitable partner that can assist and advise you can have a beneficial role. Therefore, it also further emphasizes the importance of establishing a suitable relationship with the supplier during the previous process step and finding a process partner.

5.2.3 Phase 3: Preparation and integration

Once the production technology is constructed, the companies move toward the third phase. In the third phase, the companies first analyze whether the production technology is ready for use through a factory acceptance test (FAT). During that test, the companies analyze whether or not the constructed production technology is able to produce at the agreed-upon performance level. Then, the companies prepare the physical and digital environment of the company for the production technology and install/integrate the production technology within them. After installing the production technology, a site-accepted test is carried out. The site acceptance test is used to analyze whether the production technology is able to perform at the required performance level on site. Also, to understand how it must be adjusted to optimize its fit within the production process. Best practices during the process steps of this phase are discussed below.

5.2.3.1 Phase 3 – Best Practice 1: Develop a quality control system and optimize it during the following rounds of testing and production

During the factory acceptance test, employees of the interviewed companies analyzed their performance to understand if the agreed-upon performance levels are met. However, the interviewee from Company 1 indicated that they also use the factory acceptance test and the initial rounds of testing to gather data from the production technology. By using that data, and data they gather during later rounds of testing, they developed and further improved a quality control system, as can be read in statement 7.

Statement 7:

Interviewee Company 1: *"When productivity goes up because of the improvements, it is extremely important that you stay on point and do a lot of checks on the output. You must have a good quality system and you set this up during the first test period."*

Interviewer: "*Is this something you developed solely during the testing periods or would you continue to do so afterwards?"*

Interviewee Company 1: *"After the green light for production, this must be followed up and improved on the basis of the generated and analyzed data. Keep improving."*

The developed quality control system of Company 1 contains several quality parameters. It enables them to analyze the functionality and performance of the production technology on several levels. Such analyses make it easier for Company 1 to quickly identify if and how the performance/output of the production technology differs from its parameters. Consequently, problems can be solved within a short period of time. The interviewee indicated that their quality control system enabled them to have a strong focus on and control the performance of the production process and the quality of the output. This focus and control were used to further optimize the functionality of the production technology which led to a higher-than-planned availability rate of the production technology and quality of the output. Both had a positive impact on the financial result of the organization. Therefore, it can be stated that an identified best practice within this process step is, is to gather and use production data from the production technology during the factory acceptance test/first round of testing and start with the development of a quality control system. The developed quality system should be tested and improved during all rounds of testing later in the process and during production.

5.2.3.1 Phase 3 – Best Practice 2: Develop a training program with the supplier to gather knowledge of and develop skills for the production technology

Most interviewed companies started gathering knowledge and skills for the production technology once it was installed within their company. This either happened during or right after the site acceptance test through training that was given by either the supplier or employees of the company itself. Differing from that approach, Companies 1 and 4 started their training earlier in the process; right before or after the factory acceptance test. That training mostly concerned the transfer of knowledge. This is visualized in statement 8 below.

Statement 8:

Interviewee Company 4: "*It is a collaborative trajectory. We buy the machine from them and it is a new technique that we know nothing about, so we also said to them: you must help us with this. The supplier replied that it could. Then it is actually a kind of agreement that we buy a number of hours at the machine. We therefore not only buy the machine, but also the knowledge of the supplier. We collect this knowledge from them through weekly meetings or training sessions."*

The example from the statement indicates that the development of a collaborative training program was initiated by Company 4. This was confirmed by the interviewee and this also accounted for the training program that Company 1 set up during their process. Both interviewees indicated that this approach ensured that their employees were well-informed about the production technology. This caused both organizations to experience a steep learning curve. And, according to the interviewees and based on the values in their assessment frameworks, this caused the actual performance of the production technology, involved employees, and organization to be higher than planned. All interviewees indicate the beneficial role of setting up a collaborative training program with the supplier to gather the required knowledge and skills for the production program. Therefore, the development of a collaborative training program with the supplier through which knowledge is gathered and skills are developed is identified as a best practice during this process phase. However, it is still arguable if internal training alone is sufficient or if external training should be included in the roadmap due to its beneficial role. This is because the approach of Companies 1 and 4 are more successful according to their statements and assessment frameworks.

5.2.4 Phase 4: Execution and advancements

The final phase of the implementation process entails the adoption of the production technology within the running production process and the analysis and optimization of its performance. The latter is a continuous process. In many of the researched cases, the supplier assisted in the first period of that continuous process of performance analysis and improvement. This was the case for Company 4. The relationship they had with their supplier was previously discussed in Section 5.2.1.3. The beneficial role a supplier can play during this time in the process once again highlights the value of the identified best practice in process step 3: companies should search for a supplier that is willing and able to deliver the desired production technology and level of service. However, sometimes the companies also relied on tools. For instance in the case of Company 1. According to the interviewee, their previously discussed quality control system has played an important beneficial role in optimizing the performance of their production technology. It allowed them to have great knowledge of and control over the functionality of the machine and the produced quality. This highlights the value of the identified best practice in process step 3: develop a quality control system using data collected during all rounds of testing. Besides the beneficial roles of the supplier and tools, no other best practices were identified during this process phase.

5.2.5 Company- and production technology characteristics that have an impact on the structure of the process and the actions within

As discussed in the previous section, the implementation processes that the interview companies conducted show similarities in the various process steps they included. Still, the interviewed companies, as well as the implemented production technologies, are unalike, as can be seen in Table 6 on pages 27-28. The differences between the companies, and the cases, have their impact on the implementation process, its steps, and the set of actions that need to be undertaken during these steps. Two levels of differences were identified, being [1] the characteristics of the company, and [2] the characteristics of the production technology. The characteristics of the company, in its turn, also influence the (required) characteristics of the production technology. How the company characteristics influence the characteristics of the production technology and what impact the identified differences between the cases have on the implementation process is further discussed below.

5.2.5.1 Characteristics of the company that have an impact on the structure of the process

While analyzing each company, one organizational characteristic could be identified that influenced the duration and structure of the implementation process. The influencing aspect is the level of digitalization and automation that is present within the company or sought after in the future. It influences the process in three correlating ways; [1] how the concept for the production technology is formed, [2] the search for a supplier, and [3] how the production technology is integrated within the company. This was most noticeable in the process of Company 3, as can be seen in statement 9. Therefore, they are used throughout this subsection as examples.

> <u>Statement 9:</u>
>
> Interviewee Company 3: *"We are actually a very automated process employing many physical operators. Our operators may know less about operating our machines than they might at fellow companies. We have standardized and automated our process to such an extent that it has mainly become logistics employees."*

In their process of implementing a new production technology, Company 3 put a high emphasis on the digital requirements and level of automation of the technology. Their production process is currently running at a high level of automation; autonomous machines, machine-to-machine-communication, and Automated Guided Vehicles (AGV). Consequently, other requirements are put on the production technology than just the functional or operational. This is so that their production process not only improves its operational performance but also its level of automation. An example of this is given in statement 10 below.

> <u>Statement 10:</u>
>
> Interviewee Company 3: *"We are now working on the next step; automation for sorting finished products. So that, for example, it can be packed immediately in the process and shipped to the customer. We currently still do this sorting and packing by hand. We are therefore looking for automation options for this within the new production technology."*

The requirements that are put on the production technology make it potentially harder for a company to find a supplier that is able to answer such demands. Another aspect that makes it harder to find a suitable supplier is the digital environment of the company (that runs the automated production process). This is because the production technology should be able to be integrated within and cope with the digital environment of the organization. It makes the selection process of finding a suitable supplier different from others as both functional and digital analyses of their production technology need to be conducted. An example of this is given in statement 11 below.

> <u>Statement 11:</u>
>
> Interviewee Company 3: *"Our ICT checks whether we can link the software of the machine to our own software systems. And also whether the software is robust enough. So if we fill the software with data, then the software is also strong enough to process it. For example, with previous machines we had the problem that the supplier's software worked well when controlling 1 machine, also with 2, but it went wrong when controlling 3 machines. The software couldn't handle it anymore."*

The examples discussed above indicate how Company 3 has put more focus on the digital aspects of their production technology in the initial steps of the process, compared to other companies. Due to the shift in focus, the integration of the production technology in the company also differs. While other companies mainly focus on physical integration, Company 3 puts a lot of energy and effort into the digital integration of production technology. An example of this is given in statement 12 below.

> Statement 12:
>
> Interviewee Company 3: *"The machine is of no use to me if it cannot be connected to our network. So, for example, we do the interface with the AGVs ourselves. This so that the AGV also knows when to drive or stop. The physical integration is therefore mainly done by the supplier. We do the digital integration. That cooperation is very important."*

In conclusion, the level of digitalization and automation that is present within the company influences the process through which a company implements a new production technology. The impact is not necessarily noticeable in the duration of the process but in the set of actions that need to be undertaken during the process. More, and mostly other effort needs to be put into the formulation of digital/automation requirements, finding a suitable supplier, and integrating the production technology into the digital architecture of a company. It does not impact any of the identified best practices but underscores two; formulate functional specifications for the production technology; set expectations that are precise and communicate these with all involved parties (Section 5.2.1.2), and search for a supplier that is willing and able to deliver the desired production technology and level of service (Section 5.2.1.3).

5.2.5.2 Characteristics of the production technology that have an impact on the structure of the process

Differing from the other companies, Companies 5 and 6 relied more on market research, feasibility testing, and engineering to be able to formulate a concept for their machine. Their production technology has, compared to the production technology of the other companies, a higher degree of uniqueness; the technology within the machine is (one of the) first in their industry. This meant that, within their process, a strong emphasis was put on researching, engineering, and developing a production technology that works and is feasible for production. It also meant that these companies were more dependent on the expertise and cooperation of suppliers during the development of their production technology which was also confirmed during the interviews. An example of this dependency on and cooperation with the supplier is given in statements 13 and 14 below.

> Statement 13:
>
> Interviewee Company 5: *"In this case, because it is a new principle for us, you have a very strong interaction with the supplier. That you constantly ask back and forth: is this what you want? And is this possible?"*

> Statement 14:
>
> Interviewee Company 6: *"The whole idea is to have a concept for which a machine builder could be sought, so to speak. You know, of course, that this takes a long time. You have to investigate that extensively, find it, consult with people and then come to a contract."*

The process through which Companies 5 and 6 developed a concept of a production technology that was ready for construction differs from some of the other companies. They were more 'catalog shopping' their production technology. In catalog shopping, a company is occupied with choosing options for an existing technology/machine in order to optimize its fit within the production process. These options often have to do with the practical aspects of the production technology. For instance the set of tools that are integrated within the production technology. An example of such catalog shopping is given in statements 15 and 16 below.

Statement 15:

Interviewee Company 1: *"Because we had previous experience with these types of machines and therefore had a clear picture of what we wanted, we were able to get started quickly with the next step: choosing a supplier. During the conversation with the supplier you discuss which specifications, configurations and options the machine must meet."*

Statement 16:

Interviewer: *"So then you have the idea, you draw up functional specifications for the machine and then look for a supplier. What is the next step then?"*

Interviewee Company 7: *"You then go to the table with the supplier to discuss all options, but also to further specify the machine with regard to the options that will all come on the machine."*

The impact the difference has can be noticed especially throughout the beginning of the process. As indicated by the interviewee from Company 5 and 6, it means that more pressure is put on the research that needs to be conducted and it thus takes longer to formulate an initial and final concept of the production technology with which the construction of the machine can begin.

5.3 Barriers within the implementation processes

Even though many successful actions and best practices could be identified, most of the companies still stumbled upon barriers during the implementation process of their production technology. All identified barriers, their cause, and their impact will be discussed below and can be seen in the overview in Appendix G.

Companies 4 and 6 experienced that they initially had a shortage of knowledge. For Company 4, this meant that they were ignorant of various features of the machine. The interviewee indicated that this was caused by a lesser degree of communication with the supplier, as can be read in statement 17.

Statement 17:

Interviewer: : *"What obstacles have you encountered?"*

Interviewee: *"Well, for example, that certain features of the printer were not mentioned by the supplier. What we then run into is that we do not take this into account and that it does influence the production process."*

Interviewer: *"How does such miscommunication arise?"*

Interviewee: *"Well, if you buy something that you don't know well enough yourself, then you don't know what to ask about during the interviews. With the knowledge, we would now know exactly what to ask. At that time we were more dependent on the supplier."*

When asked about it, the interviewee also stated that their employees could have done more research on the production technology. However, they found out that other customers of the supplier have encountered the same barriers as they have. So they believe that the supplier could have communicated all features of the machine more decently and completely. Company 4 also experienced how their ignorance of the machine has caused them to miss certain tools for it. Both barriers, being unaware of features of and missing tools for the machine, caused Company 4 to have less control over the machine than planned. This resulted in an operational performance of the machine that was below expectation, and the throughput time of the organizational process increased, which both harmed the financial performance organization. However, it also made Company 4 highly aware of the learning curve they needed for which they then took action and created a learning program with their supplier. Ultimately, they had more control over the machine which caused its operational performance to be higher than planned.

Differing from Company 4, Company 6 did not find out they had too little knowledge of the technology when it was installed in their organization. Contrary, they experienced a lot of trouble with translating the theoretical concept from the business case to a physical concept of a machine. As a result, the first phase and first parts of the second phase of the process took way longer than expected. Thus, their shortage of knowledge mostly negatively influenced the duration of their process. Their shortage of knowledge also influenced the communication between the company and its supplier. The supplying organization wanted to work out the 'vague' concept in detail whereas Company 6 wanted to start with the construction of the machine and work based on a trial by error method. According to the interviewee, the differing level of expectations between their company and the supplier ultimately caused frustration and loss of time.

The interviewee from Company 2 stated that they did not have a shortage of knowledge to develop a concept of the desired machine. They relied heavily on the expertise and knowledge of one experienced head operator during the development of the concept. However, the interviewee indicated that the chosen operational specifications, which were advised by the operator, were inaccurate. As a result, the machine was produced at a lower quality than planned. Also, it caused frustration among the other operators who had other opinions on the operational specifications than the head operator. This resulted in job satisfaction and employee engagement that was much lower than planned, which can be seen in the assessment framework of Company 2 in Table 11.

According to the interviewee of Company 2, the company also missed the financial resources to complete the construction of its machine. As a result, the construction of the machine was only 70-80% finished. However, this did not stop the company from adopting the machine into the production process. Because the machine was only 70-80% finished, the company experienced a lower-than-planned availability rate, and quality of production. That, together with the increased repair and maintenance jobs, has had a big negative impact on the financial performance of the organization. This can also be seen in the values from their assessment framework in Table 11.

Differing from Company 2, Company 7 knew that they did not possess the human resources to both include the operators in the implementation process and to keep the production process running. However, they deliberately chose to include the operators in the process, leverage their knowledge and expertise, and organize a program to improve their knowledge and skills. As a result, the existing production process experienced a lower availability rate and production rate. Yet, it improved their knowledge and control over the new machine which had a positive impact on its performance as can be seen in Table 20. Thus, they accepted a negative impact on the financial performance of the organization (added costs/loss of turnover) to pursue their innovative idea.

Lastly, Companies 5 and 7 experienced how bad communication between a supplier and its contractors, together with a global pandemic, can result in barriers during the process. Both companies experienced how the deliverance of certain hardware components was delayed due to the global COVID-19 pandemic which caused the construction of the machine to be postponed. This harmed the duration of the entire process. Furthermore, Company 5 experienced how bad project management of the supplier can delay a process. Sub-contractors were poorly informed which delayed the process.

A barrier that could not have been prevented occurred for Company 3. As discussed prior, their production process differs from that of other end-users of the implemented technology. As a result, they experience difficulties with finding a supplier that can build a machine that fits the level of digitalization and automation.

5.4 Points of improvement for future processes

To improve the discussed implementation processes, the interviewees identified various points. The identified points of improvement are discussed below and can be seen in an overview in Appendix H.

The most important point of improvement for future projects that can be identified is the enhanced role of the supplier. This point of improvement was mentioned by the interviewees of Companies 1, 2, 3, 4, and 5. The companies want to enhance the role of the supplier because they would like to have a greater transfer of knowledge between both organizations. When asked why, the interviewees stated that it would enable both organizations to have a clear idea about the expectations concerning the functional specifications of the machine. This would contribute to the ability of both organizations to collaboratively formulate detailed specifications in the next steps of the process. In doing so, they believe that the actual operational performance of the production technology would get closer to the planned operational performance once it is constructed. Thus, much sooner in the process. The interviewee from Company 3 also stated that it would enable them to 'test' more accurately whether the supplier can build what is desired. However, to do so, the engineers of both companies need to be involved as there are the technology experts. This would create a direct transfer of knowledge between the technology experts of both companies which improves the integrity and accuracy of the information that is shared. It also creates a best practice that can be placed in between the search for a supplier and the formulation of detailed specifications for the production technology. The best practice in between phase 1 and phase 2 is:

> <u>Best Practice in between Phase 1 and Phase 2:</u>
>
> *“Create a direct stream of communication between the technology experts of all involved parties.”*

According to the interviewee of Company 1, knowledge transfer between both parties is also necessary to gain control over the machine and decrease the dependency on the supplier. This mostly concerns improving the knowledge and skills of involved employees/engineers/operators. The interviewees from Companies 2 and 4 stated that they would like to receive such training much sooner in the process. This would give employees the time to practice and master the lessons learned. When asked ‘when’ they would like to start the training, they indicated that they would like to receive it before the production technology is installed in their organization; preferably before the factory acceptance test. In doing so, the employees would be more able to analyze and optimize the machine before it’s put into use. For instance during the factory acceptance test. This could enable the identification of detailed characteristics of the production technology that must be changed, added, or removed. For example, Company 4 could have identified which tools it wanted within the production technology. According to the interviewee from Company 2, the external training would not only have a positive impact on the operational performance of the production technology but also the job satisfaction of involved employees and their level of engagement. This is because they would feel much more in control of the production technology which enables them to do their job better. As discussed in Section 5.2.3.1, Companies 1 and 4 received such external training before the factory acceptance test. The external training was given by the supplier at the site of the supplier with their own constructed production technology. It made both organizations and their personnel well-prepared for the changes that would come. As a result, they managed to get the actual performance of the production technology to be higher than planned. Also, their employees were more satisfied with and engaged in their work. This confirms the thought of the interviewee from the Company. Thus, a process step must be included in the roadmap; external training for employees. This impacts the timing of an identified best practice; the development of a collaborative training program with the supplier to gather knowledge and develop skills should happen before and during the construction of the production technology. This would ensure that the involved employees could follow training already during the construction and, more importantly, before the factory acceptance test. According to the interviewee of Company 1, external training could also be used to develop a first version of a quality control system. The system could then be tested and improved during the factory acceptance test and all the rounds of testing and production after.

Another point of improvement was mentioned by the interviewees from Companies 2 and 7. They stated that they would like to include more operators during the first two phases of the process. The interviewee from Company 7 added to that by saying that he would like to include a variety of operators; (at least) 1 experienced person from the older generation, 1 young person who likes to innovate, and 1 person in between. In doing so, a company can rely on more knowledge and expertise during the formulation of functional and detailed specifications for the production technology. For instance, the operators could advise about the technique or tools that must be included in the production technology or about practical matters that would improve its useability. This causes the business case, including functional specifications to be more complete and precise, which was a point of improvement for Companies 4 and 6. A more complete and precise business case is also beneficial for and during the transfer of knowledge with the suppliers that was discussed above.

Lastly, the interviewee from Company 1 indicated that he would like to have a ‘specialist’ within his organization. That specialist would be highly informed about the production technology and would be better able to get more value from the generated data and/or develop and use the different parameters of the machine. Assigning a specialist to the project was previously discussed in Section 5.2 as a best practice. The best practice is thus confirmed by the interviewee from Company 1.

5.5 A roadmap for implementing digital production technology

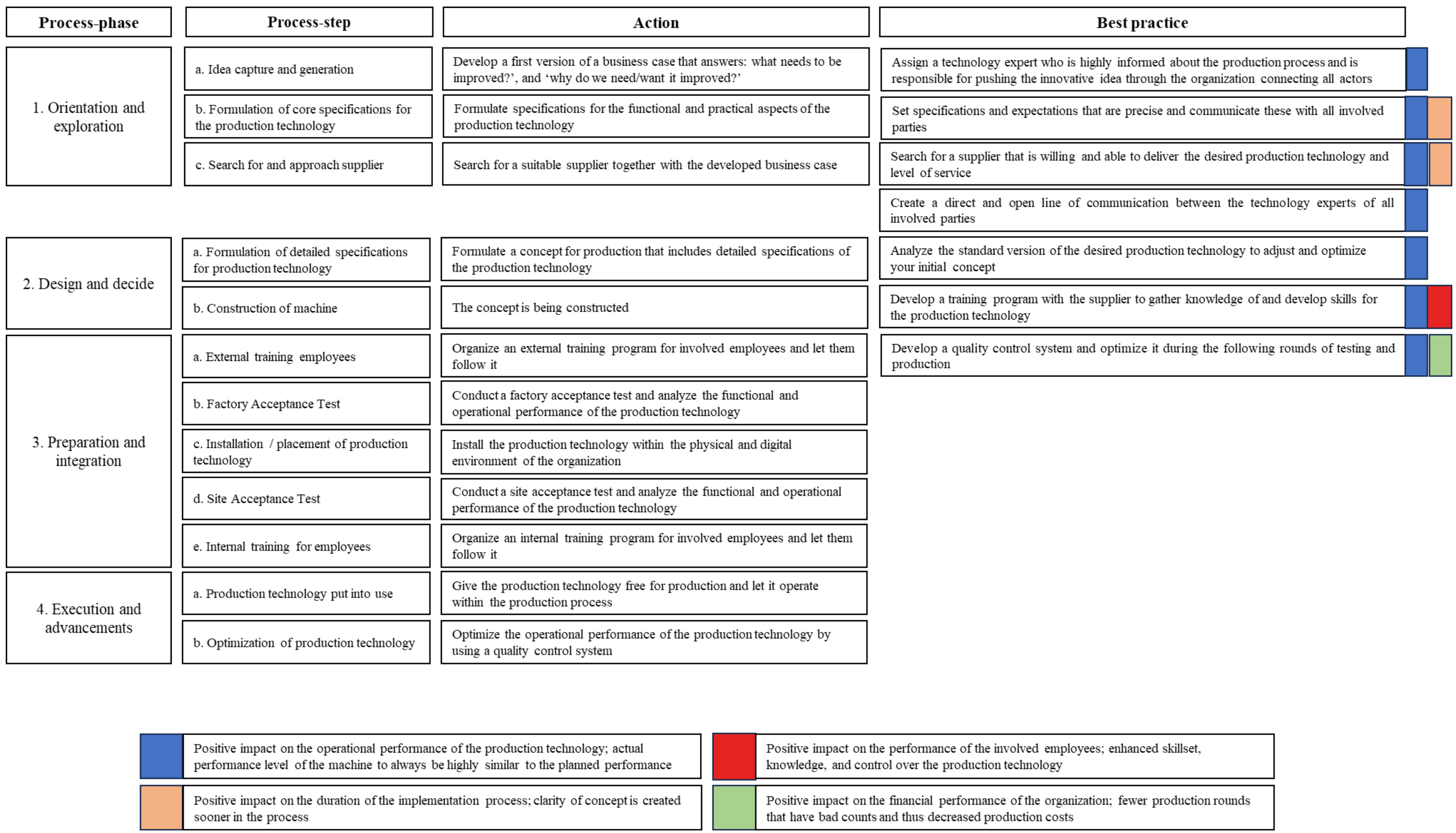
The best practices that were identified in Sections 5.2 and 5.4 are now integrated into the model that was developed in Section 5.1. The comprehensive roadmap, visualized in Figure 6 on page number 73, outlines a sequential series of process steps and actions through which organizations can implement digital production technology in their organization and pursue a digital transformation. It also clearly visualizes how the best practices that were identified in this research are integrated into the roadmap. Best practices that were identified in previous research but not in this study could not be integrated into the roadmap. This is because no data is indicating when or how in the process these best practices should be integrated or carried out. Further, the roadmap does not visualize how the division of responsibility for the actions or best practices should be done as no common pattern emerged from the identified cases. However, it does show that an essential aspect of the roadmap is to assign a technology expert/digital leader to lead the project. This expert should possess in-depth knowledge of the production process and is responsible for driving innovative ideas throughout the organization, ensuring effective communication and collaboration among all stakeholders. Therefore, it could be argued that the digital leader is in charge of the division of responsibility within their organization.

The roadmap can be used by the assigned digital leaders to identify which process steps and actions need to be undertaken. It will also contribute to their ability to identify what human and capital resources are required to execute the various actions. Then, the digital leader can make a plan on when and how these resources need to be acquired. In conclusion, the developed roadmap effectively addresses the main research question and provides a practical guide for organizations seeking to successfully implement digital production technology. It contributes to an organization's ability to innovate, to ensure they won't die.

The process in the roadmap should be conducted in a sequential order (from top to down). Each row in the roadmap should be interpreted from left to right; process-phase, process-step, action within the process-step, and best practice for that action. The best practice in between phase 1 and phase 2 could not be assigned to a specific process-step or phase. Therefore, it should be viewed as an individual action that should be conducted in between both phases. Each best practice is color coded with the potential impact it might have. The assigned impact is based on the statements of interviewees and an analysis of the assessment frameworks from the researched cases. The color-coded indicators enable digital leaders to identify which best practices they should focus on to get the desired result. Thus; it enables them to customize the roadmap to fit with their organizations' goals and desires. The complete roadmap can be seen in Figure 6 on page number 74.

Figure 6.

A Roadmap for Implementing Digital Production Technology



6. Discussion

6.1 Theoretical implications

Technology implementation approaches that Goodman and Griffith (1991) and Harrison (2004) have previously developed, focused on the processes through which an organization can adapt itself to integrate/implement a new technology. However, their approaches did not specify when the actions within each process should be undertaken which causes unclarity. Contrary, the implementation approach that was developed by Plinta and Radwan (2023) visualizes the process steps through which an organization can implement a new technology. Yet, their model did not include specific actions that need to be undertaken during those process-steps nor does it imply the changes that need to be made so that the technology can be implemented. This also causes unclarity. Lastly, all three approaches focus on implementing new technology and do not specify how digital characteristics of a technology might influence the approaches. This is relevant in the scope of this research; the digital transformation of production technology.

Previous research on digital transformation, on its turn, has been focused on understanding its transformative dimensions (Matt et al., 2015) and identifying its potential for manufacturing companies (Liere-Netheler et al., 2018; Tortorella et al., 2022). Other research focused on the various barriers that can occur during a digital transformation (Garrido-Vega et al., 2015; Vogelsang et al., 2019) and identified how integrating digital leaders within an organization is one of the most important best practices for tackling the barriers and achieving a successful digital transformation (Romero et al., 2019; Fernandez-Vidal et al., 2022; Van Veldhoven & Vanthienen, 2022; Cichosz et al., 2023). The research showed that digital leaders can initiate, organize, and fulfill best practices for many other success factors of digital transformation, such as creating an urge for and promoting change throughout the organization, fostering open communication, developing employee and partner engagement, aligning business strategies, set up employee training and skills development (Romero et al., 2019; Kraus et al., 2021; Van Veldhoven & Vanthienen, 2022; Cichosz et al., 2023). However, digital leaders may face challenges in identifying necessary actions or resources, and/or dividing responsibilities because there is a lack of knowledge on how to integrate the identified best practices into a comprehensive digital transformation strategy (Albukhitan, 2021). This lack of clarity can negatively affect the overall quality of the digital transformation strategy and can potentially cause an unsuccessful outcome of the transformation. All combined provided the basis for this research. The main objective of this research was to map out how organizations can successfully manage the digital transformation of their production technology by using a roadmap for implementing digital production technology that consists of sequential process steps, actions within the process steps, and a division of responsibilities for those actions. This led to the formulation of the following research question:

How can organizations successfully manage the digital transformation of their production technology, using a roadmap for implementing digital production technology that consists of sequential process steps, actions within the process steps, and a division of responsibilities for those actions?

A roadmap was developed that outlines how digital production technology can successfully be implemented within an organization. The roadmap consists of a sequential series of process phases, process steps, actions, and best practices. It does not visualize how the division of responsibility for the actions or best practices is as no common pattern emerged from the identified cases. Therefore, it can be concluded that the developed roadmap for implementing digital production technology partly answers the main research question.

The roadmap contributes to the previous research in several ways.

First, the beneficial role a digital leader can have during a digital transformation, which was previously discussed in the research of Romero et al. (2019), Cichosz et al. (2020), and Van Veldhoven and Vanthienen (2022), was also identified during this research. Thus, confirming that a digital leader is also desired by the interviewed companies organizations that aim to digitally transform their production technology.

Second, some of the key factors and best practices for digital transformation that were previously identified in the research of Osmundsen et al. (2018), Vogelsang et al. (2019), Chichosz et al., (2020), Ghobakhloo and Iranmanesh, (2021), Colli (2022), Ghosh et al. (2022), and Van Veldhoven and Vanthienen (2023) were also identified in this research. This research thus confirms the accuracy of the identified key factors and best practices and builds on them as more shape is given to them. This, because the identified key factors best practices are integrated in and assigned to specific moments in the implementation process.

Thirdly, actions and process-steps that are included in the production technology implementation approaches of Goodman and Griffith (1991), Harrison (2004), and Plinta and Radwan (2023) were also identified during this research. This confirms the accuracy of their approaches. The roadmap that was developed in this study extends their approach by being specifically applicable for the implementation of new production technology with digital features and functions. This expands the variety of approaches within the literature.

Finally, Matt et al. (2015) add to this by stated that it is important to identify the role of external parties during the implementation process as it can potentially be beneficial to the result. The roadmap that is developed in this study gave form to the role of an external party during the implementation process and confirmed its beneficial role. In doing so, this study confirms the presumption of Matt et al. (2015) that an external party can be beneficial to the result and builds on it by giving more shape to the role of the external party.

6.2 Managerial implications

The developed roadmap in this research visualizes the process through which organizations can successfully implement digital production technology in their organization and pursue a digital transformation. The roadmap outlines the phases and steps of the process. Furthermore, the roadmap gives summary statements for the actions that need to be conducted during each step of the process and the best practice that can contribute to it. The process in the roadmap should be conducted in a sequential order (from top to down). Each row in the roadmap should be interpreted from left to right; process-phase, process-step, action within the process-step, and best practice for that action. However, it must be noted that the roadmap can be customized to optimize its fit to a specific scenario. For instance, by expanding or removing actions or best practices that are in the developed roadmap or by adding new ones. The roadmap can be used by digital leaders in numerous practical ways. The managerial implications are discussed below.

First, the roadmap serves as a visual guide that supports digital leaders during the formulation of their own implementation plan. By following the sequential order of phases and steps, digital leaders can develop a timeline for each action and best practice. For instance, if a certain step requires conducting employee training, the roadmap helps digital leaders allocate time for training sessions and ensure they are aligned with the overall implementation schedule.

Second, the roadmap provides a clear visualization of the actions and best practices required at each step of the process. Digital leaders can use this information to identify the human and capital resources that are needed for each task. For example, if a particular best practice involves establishing multi-disciplinary teams, digital leaders can allocate and assign the required personnel to ensure a successful execution.

Third, the color-coded indicators assigned to the best practices offer digital leaders insights into their potential impact. Digital leaders can focus on implementing best practices that align with their organization's specific goals. For instance, if improving the duration of the implementation process is a priority, digital leaders can concentrate on best practices that are associated with it.

Fourth, as discussed above, the roadmap is customizable which allows digital leaders to adapt the implementation plan to fit with their organization's unique scenario. Digital leaders can include or remove actions and best practices based on their organization's current capabilities and requirements. For example, if the organization already possesses a certain physical or digital infrastructure, digital leaders can adjust the roadmap to skip or modify related actions.

Fifth, the roadmap can be shared with key stakeholders, providing a clear overview of the implementation process. Digital leaders can use the roadmap to create transparent communication by presenting the implementation approach and the expected outcomes. Progress reports can be aligned with the roadmap's milestones, making it easier to communicate achievements and challenges to the relevant parties

Sixth, as digital transformation often involves collaboration across various departments, the roadmap helps digital leaders coordinate multiple teams effectively. Each team can align their efforts with the specific actions and best practices assigned to their own department. For example, if data integration is a critical step, the IT team can work closely with other relevant teams to ensure a smooth integration.

Finally, the roadmap can be used for continuous monitoring of the implementation process. Digital leaders can compare actual progress with the anticipated timeline and adjust their strategy and actions if needed. If a certain step is taking longer than expected, digital leaders can adjust their resource allocation or adapt the timeline accordingly.

In summary, the roadmap provides digital leaders with a comprehensive tool to strategize, plan, allocate resources, and communicate effectively during the implementation of new digital production technology. Its practicality lies in its ability to guide the entire process while allowing customization based on the organization's needs and priorities.

6. Limitations and future research

Initially, this qualitative exploratory research aimed to map out how organizations can successfully manage the digital transformation of their production technology by using a roadmap for implementing digital production technology that consists of sequential process steps, actions within the process steps, and a division of responsibilities for those actions. However, the small sample size in this study (seven participants) hinders the possibility of generalizing the developed roadmap. As a result, future research should concentrate on validating the qualitative findings through quantitative research (Queirós et al., 2017, p. 370). Thus, increasing the sample size. For instance, researchers could collect data from a larger and more diverse group of organizations from different industries and sizes. Such an expanded sample size would allow for a more comprehensive understanding of how the roadmap's principles apply across various contexts. By conducting for instance surveys, questionnaires, or a Delphi study, quantitative research could assess the accuracy and effectiveness of the roadmap. Thereby ultimately validating its practicality on a broader scale. Such an approach would enhance the generalizability of the developed roadmap.

Second, the characteristics of the interviewed companies and the digital production technology they implemented were different. During this research, it was established that both characteristics influence the organization of the implementation process. It also mapped out how both aspects influence the structure of the implementation process. Nevertheless, further research should focus on analyzing companies that have similar organizational characteristics and have implemented similar digital production technology. Thus, it would entail changes in the research sample based on its composition. In doing so, an implementation roadmap can be developed for specific companies, industries, and/or digital production technologies. For example, researchers could shift their focus to specific industries, such as automotive manufacturing or electronics, where digital production technology are commonly adopted. By selecting organizations that share similar characteristics and have implemented comparable technologies, researchers can dive deeper into how these aspects influence the structure of the roadmap. This research approach could result in the creation of a more customized implementation roadmaps designed for specific industries or technologies, enhancing the practical relevance of the findings and the roadmap.

Finally, there are still many best practices for digital transformation that exist in the literature that are not included in the developed roadmap. Future research should focus on identifying how the remaining best practices can be integrated into the roadmap. Researchers could conduct a comprehensive literature review to identify additional best practices that could be integrated within the roadmap. Subsequent qualitative research could explore the feasibility of integrating these practices into the roadmap, considering for instance the perspectives of industry experts. Such qualitative research could be done in the form of a Delphi study. This approach will contribute to the completeness of the literature as well as the developed roadmap. Also, it improves the ability of an end-user of the roadmap to customize it by selecting the most suitable best practices for their specific scenario.

In conclusion, future research could follow various directions to enhance the generalizability and applicability of the developed roadmap. By conducting quantitative research, focusing on sample size or organizational characteristics, and incorporating additional best practices through qualitative research, researchers can improve the accuracy and useability of the roadmap. This will further support organizations during their digital transformation journey.

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8. Appendices

Appendix A: Interview guide

Interview guide

This is an interview guide for the master thesis of Ilco van Buuren for his master Business Administration at the University of Twente. The research is conducted at Demcon industrial systems Enschede BV (DIS), located in Enschede, the Netherlands. The aim of the research is to map out the entire implementation process (from idea generation to commissioning of the machine) that the interviewed companies went through. I am also interested in who was involved in the process and what actions they took during the process. The ultimate goal is to create a generic model that shows how a 'digital' production technology can be implemented. This model could possibly serve as a tool for companies that want to deploy a so-called 'digital transformation' of their production technologies. To give a clear picture of what I mean by a digital production technology, I will briefly explain this below.

The research focuses on all digital production technologies implemented within a company. You can think of:
- The use of a production technology with sensors that measure and monitor industrial processes; e.g. temperature sensors that monitor the temperature of an object or process
- Using a production technology with artificial intelligence and machine learning to analyze (production) data and automate processes
- Deploying a production technology with ERP systems that are connected to 'the cloud', making it easier for employees to collaborate on projects or access information

Participants will be interviewed on the implementation process of their production technology and how they believed it could have been improved. The interview will take in between 30 and 45 minutes. Participation in the research is voluntary and confidential. Meaning: personal information of participants will not be included in the research in any form nor will their company be mentioned by name. Also, participants can terminate their participation at any moment before, during, or after the interview. If agreed upon by the participant, the research is recorded and stored to make sure that valuable data is not left out of the research. All recordings are deleted once the research has been completed.

Section 1

2.1 – What is the production technology you have implemented?

2.2 – Does the implemented production technology follow a legacy technology or is it a first variant?

Section 2

3.1 - Which phases did you experience during the manufacturing technology implementation process (e.g., all phases from ideation to deployment)

3.2 – What actions took place at each stage?
Example follow-up questions:
How did you arrive at…. Vision, Specifications, Setup, Supplier

Section 3

4.1 Who were involved in the process?

4.4.1 Was the supplier in the project team?
If so. With what role?

4.2 Were the stakeholders involved at each stage?
At which specific phases were they involved?

What specific responsibilities were they given during each stage?

Section 4

5.1 In addition to purchasing the hardware, did you also purchase software?

What kind(s) of software?

How is the software used? (For what functions/purposes?)

Section 5

6.1 - Did everything go well throughout the process?

If not, what barriers did you encounter during the process?

6.2 Have the barriers affected the performance of the production technology?

6.2.1 What kind of influence has each barrier had?

6.3 What actions would you identify as driving the process?

6.3.1 What impact have these actions had on the process and performance of the technology/people/organization?

Section 6

7.1 Knowing what you know now, would you have changed things about the process (and why)?

7.2 What impact will these changes have on the performance of the technology/people/organization?

Section 7

Assessment of the performance of the acquired production technology and its impact on the organization.

Key Performance Indicators			Unit of metrics	Value ***		
Area of analysis	**Category**	**Indicator**		**Planned**	**Actual**	**Difference**
Production technology	OEE	Availability rate	Run time / planned production time (%)			
		Quality of the output	Good count / total count (%)			
	Production efficiency	Raw materials used	Residual material (%)			
		Energy consumed	kWh (%)			
		Personnel required	Required man-hours / actual man-hours (%)			
		Repair and maintenance costs	Total number of repair and maintenance actions (%)			
		Lead time	Production time single unit (%)			
Individuals/employees *	Performance	Productivity rate	Operating time / planned operating time (%)			
		Issues, compliance, and error logs	Total number of issues, compliance, and error logs (%)			
	Emotion and behavior	Job satisfaction	Rate 1-10			
		Employee engagement	Rate 1-10			
Organization **	Operational performance	Throughput time	Total process time (%)			
	Financial performance	Contribution to total costs	Total operating costs (%)			

Appendix B: Overview of identified organizational motivation to implement digital transformation of production technology

	Motivation to implement digital transformation of a production technology											
Source	Improved productivity	Reduced Operating costs	Improved product quality	Product innovation	Increased efficiency	Improved production flexibility	Economic benefits	Improved production resilience	Process improvement	Employee support	Innovation push	Improved safety
Abdallah et al. (2021)						X						X
Albukhitan (2021)	X	X	X			X						
Colli et al. (2022)					X							
Dokuchaev (2020)	X						X					
Favoretto et al. (2022)			X		X							
Fernandez-Vidal et al. (2022)								X				
Ghobakhloo and Iranmanesh (2021)	X	X	X	X								
Kraus et al. (2021)	X	X										
Lammers et al. (2019)					X		X					
Lola and Bakeev (2020)	X	X			X		X					
Lierre-Netheler et al. (2018)		X							X	X	X	
Matt et al. (2015)	X			X			X					
Mugge et al. (2020)							X					

Vial (2021)	X				X			X				
Lin and Xie (2023)					X							
Total	7	5	3	2	6	2	5	2	1	1	1	1

Appendix C: Overview of identified barriers to implement a digital transformation of production technology

	Barriers to the digital transformation of a production technology								
Source	Overall complexity	Missing knowledge	Organizational infrastructure and alignment	Missing internal capabilities	Missing managerial capabilities	Risk-aversion	Missing DT strategy	Organizational culture and commitment	Financial resources
Abdallah et al. (2021)			X	X		X	X		
Abou-Gabal (2023)		X	X						
Albukhitan (2021)							X		
Colli et al. (2022)	X								
Dokuchaev (2020)			X	X					
Favoretto et al. (2022)		X	X	X	X			X	
Fernandez-Vidal et al. (2022)				X	X				
Ghobakhloo and iranmanesh (2021)	X	X							
Ghosh et al. (2022)			X	X	X				
Kraus et al. (2021)		X	X	X			X	X	X
Lammers et al. (2021)									

		X	X	X				X	X
Lola and Bakeev (2020)		X	X						X
Matt et al. (2015)			X	X			X		X
Mugge et al. (2020)			X		X		X	X	X
Omrani et al. (2022)		X	X	X				X	
Osmundsen et al. (2018)		X	X	X			X	X	
Robu and Lazar (2021)		X		X	X		X	X	
Vial (2021			X	X	X			X	
Cirillo et al. (2023)		X		X					
Total	2	10	14	12	6	1	7	8	5

Appendix C: Conceptual framework digital transformation

Technologies	Management / Processes	People
▪ Data ▪ Big data ▪ Cloud ▪ Mobile devices ▪ Social media ▪ Software ▪ Analytics ▪ Embedded devices ▪ Artificial intelligence ▪ The Internet of Things ▪ Cybersecurity ▪ App marketplaces	▪ Business models ▪ Operating models ▪ Operational processes ▪ Strategies ▪ Business activities ▪ Organizational structure ▪ Organizational culture ▪ Coordination mechanism ▪ Products ▪ New services	▪ Customers ▪ Employees / workforce / people ▪ Managers ▪ Executives ▪ Talents ▪ Owners ▪ Suppliers ▪ Partners ▪ Stakeholders ▪ Competencies

Appendix D: Statistical analysis to identify a common structure of the implementation process

Process step	Company 1	Company 2	Company 3	Company 4	Company 5	Company 6	Company 7	Count
1.	Idea generation	Idea generation	Idea generation	Idea generation	Idea generation	Idea generation	Idea generation	100%
2.				General machine test	Feasibility testing			29%
3.	Formulate machine specifications	Research and design	Design / specifications	Design / specifications	Formulate functional specifications	Formulate functional specifications	Formulate minimum functional specifications	100%
4.	Search for and approach supplier	Search for and approach supplier	Search for and approach supplier		Search for and approach supplier	Search for and approach supplier	Search for and approach supplier	86%
5.							Reference research	14%
6.	Formulate detailed machine specifications				Formulate design and engineering specifications machine	Formulate detailed machine specifications	Formulate detailed specifications	57%
7.		Develop machine components						14%
8.						Engineering phase		14%
9.	Construction of machine	Construction of machine	Construction of machine	Construction of machine	Construction of machine	Construction of machine	Construction of machine	100%
10.	Testing / Factory Acceptance Test	Testing	Testing					43%
11.	Training externally			Training externally				29%
12.		Factory Acceptance Test		Factory acceptance test	Factory acceptance test	Factory Acceptance Test		57%
13.	Digital layout factory							14%
14.	Installation / placement of machine	Installation / placement of machine	Installation / placement of machine	Installation / placement of machine	Installation / placement of machine	Installation machine	Installation machine	100%
15.	Safety check / Site Acceptance Test			Site Acceptance Test	Site Acceptance Test	Site Acceptance Test		57%
16.						Recipe Development		14%
17.	Internal training operators	Internal training operators		Internal training operators		Internal training operators	Internal training operators	71%
18.	0 series / test internally							14%
19.	Safety check/test							14%
20.	Machine put into use	Machine put into use	Machine put into use	Machine put into use		Integration of machine into production process	Machine put into use	86%
21.	Optimization of machine	Optimization of machine	Optimization of machine		Optimization of machine		Optimization of machine	71%

Appendix E: Summary statements for the set of actions within each process step

Process step	Company 1	Company 2	Company 3	Company 4	Company 5	Company 6	Company 7
Idea generation	Develop business case and spread/push the idea through the company to gain approval and support	Develop business case and spread/push the idea through the company to gain approval and support	Develop business case and spread/push the idea through the company to gain approval and support	Develop business case and spread/push the idea through the company to gain approval and support	Develop business case and spread/push the idea through the company to gain approval and support	Develop business case and spread/push the idea through the company to gain approval and support	Develop business case and spread/push the idea through the company to gain approval and support
Formulation of functional specifications machine	Formulate functional, digital, and quality specifications for the machine and integrate safety requirements into the concept.	Develop a concept of design for the physical and digital machine architecture	Formulate functional, practical, and digital specifications and requirements for machine	Formulate functional specifications for the machine and discuss internally	Formulate functional specifications for the machine	Analysis of the fundamental aspects of the machine and formulation of initial functional specifications	Formulate minimum specifications and gain approval for concept
Search for and approach supplier	Search for a suitable supplier and transfer knowledge about concept	Search for suitable suppliers of components and transfer knowledge about concept		Transfer knowledge about concept	Search for a suitable supplier and transfer knowledge about concept and idea	Search for a suitable supplier and transfer knowledge about concept	Search for a suitable supplier and transfer knowledge about concept
Formulate detailed machine specifications	Configure machine and set up its complete architecture					Analysis of the fundamental aspects of the machine and formulation of detailed functional and design specifications	Formulate detailed specifications for the machine
Construction of the machine	Construction of machine by supplier	Assemble machine parts to construct machine	Construction of machine by supplier	Construction of machine by supplier	Construction of machine by supplier	Construction of machine by supplier	Construction of machine by supplier and digital integration of machine into company
Factory Acceptance Test	Analyze the functional performance of the machine and develop its software and quality management system	Analyze functionality of hard- and software and analyze operational performance		Analyze functionality of hard- and software and analyze operational performance	Analyze functionality of machine	Analyze the functional performance of the machine, analyze its produced quality and document control- and functional properties	

Installation / placement of machine	Integrate machine in physical and digital environment of the company and adjust performance of machine to developed parameters	Integrate machine in physical and digital environment of the company	Integrate machine in physical and digital environment of the company	Integrate machine in physical and digital environment of the company	Integrate machine in physical and digital environment of the company	Integrate machine in physical and digital environment of the company and document control- and functional properties	Prepare physical environment for integration of machine and integrate machine
Site Acceptance Test	Analyze the functional performance of the machine and its safety			Analyze operational performance and digital functionality of machine	Analyze functional performance of machine	Analyze functional performance of machine and initiate learning process for operators	
Internal training operators	Arrange internal training for the concerned operators	Set up internal training for the concerned operators	Arrange internal training for the concerned operators	Arrange internal training for the concerned operators		Arrange internal operational training for the concerned operators	Arrange internal training for the concerned operators
Machine put into use	Initiate first production rounds and analyze its performance based on the developed quality management system	Initiate first production rounds	Initiate first production rounds	Initiate first production rounds and analyze its performance		Analyze physical and digital integration of machine into factory, test- and release machine in production process	Initiate first production rounds
Optimization of machine			Analyze and adjust functional and operational performance of machine		Analyze production data to optimize functional machine performance		Analysis and improvement of alignment between control program and machine functionality

Appendix F: Overview of identified best practices

Overview of the Identified Best Practices to the Implementation Process

Company	Best Practice(s)	Impact
1	Step-by-step configuration and installation of the machine Development and use of the quality system External and internal training of employees	1. Well-prepared organization and personnel 2. Improved safety and user-friendliness 3. Improve productivity rate for machine and employees 4. Improved throughput time
2	None	
3	Continuously searching for opportunities to optimize and expand digital environment	1. Improved digital environment of the organization
4	Availability of and offered service by the supplier Advising role of the application engineer (supplier) during the process	1. Steep learning curve in machine knowledge and skills 2. Achieved the level of planned operational performance faster than expected 3. Machine is now performing above expectations

		4. Improved throughput time 5. Improved financial result organization
5	General knowledge, skills and involvement of the employees Multiple phases of testing and rounds of analysis	1. Improved ability to quickly identify and resolve barriers
6	Knowledge, experience and involvement of employees	
7	Formulating a well-defined business case Preparation and education of the organization and its employees	1. Development of an advanced degree of control over the machine

Appendix G: Overview of identified barriers to the process

Overview of the Identified Barriers to the Implementation Process

Company	Barrier(s)	Cause	Impact
1	None		
2	Machine was only 70-80 finished when put into use Operational specifications were inaccurate	Lacking financial resources to complete the construction Missing knowledge to formulate accurate operational specifications	1. Lower availability rate of machine 2. Lower quality of the output expectations 3. Higher repair and maintenance costs 4. Lower job satisfaction 5. Lower employee engagement 6. Negative impact on financial performance organization
3	Finding a supplier that is able to build a machine that fits the level of digitalization and automation	Production process differs from that of other end-users of the implemented technology	1. Operational performance of machine was below expectation 2. Lower degree of automation within organization
4	Ignorance of the various features of the machine Less control in operating the machine Machine has an incomplete set of tools	A lesser degree of communication with the supplier Training period was too inadequate Inadequate knowledge of the needed set of tools	1. Operational performance of machine was below expectation 2. Throughput time of organizational process increased 3. Negative impact on financial performance organization
5	Non-working hardware Delayed arrival of machine (components)	Bad communication between supplier and their subcontractors	1. Lower availability rate of machine 2. Longer lead time 3. Lower job satisfaction 4. Lower employee engagement
6	Formulating functional specifications of machine Finding a suitable supplier Communication with supplier	Tuning and translating a theoretical concept into a physical machine Technology is new and unique Differing expectations about functionality of machine at various stages	1. Implementation process took longer than planned 2. Frustration among those involved

7	Shortage of time to both implement the machine and keep the factory running Shortage of parts to finish construction of machine	Shortage of (well-trained) personnel Global pandemic and underperforming subcontractors	1. Lower production rate of other machines in factory which had a negative impact on the financial performance of the organization 2. Implementation process took longer than

Appendix H: Overview of identified points of improvement

Overview of identified points of improvement for the implementation process

Company	Point(s) of improvement	Reason	Potential result(s)
1	The development of a well-defined quality system for production process An enhanced role for the supplier Assign a specialist to the machine who is continuously involved throughout the process	Enhanced quality control and control of process A greater degree of knowledge transfer between supplier and buyer The specialist would be better able to get more value from the software/generated data and use the different parameters of the machine	1. Improved ability to pursue and implement new technological advancements 1. An increasing amount on independence 1. Stricter attention can be paid to the quality of the production which will have a major positive impact on both the operational and financial results of the machine and process.
2	Involve more operators in the design phase and during the process Offer training to the people involved earlier in the process Extend the test period to generate more production data from the machine	More accurate and therefore more efficient transfer from knowledge to formulation of operational specifications of the machine Improved control over the machine and process Enhanced ability to analyze and optimize the machine before it’s put in use	1. Fewer dropouts 2. Better quality output 3. Positive financial impact 4. Higher degree of job satisfaction 5. Higher level of employee engagement
3	An enhanced role for the supplier	The customer can 'test' more accurately whether the supplier can build what is wanted	1. Actual operational performance of the production technology stays closer to the planned operational performance
4	Drafting the business case and technical specifications in detail Increase the exchange of information between engineer customer and supplier to Allow knowledge transfer process and training to take place earlier in the process	Create more clarity about machine functionality expectations Improved ability to write specifications for a machine	1. Actual operational performance of the production technology stays closer to the planned operational performance
5	Greater degree of cooperation with supplier Fewer subcontractors More extensive test phases	Create a joint project Increases the amount of control in the process Enhanced ability to analyze and optimize the machine before it’s put in use	1. Actual operational performance of the production technology stays closer to the planned operational performance 2. Lower levels of employee frustration
6	Invest more time in formulating the specifications of the machine in the preliminary phase	Removes a feeling of vagueness from the supplier	1. This saves unnecessary costs 2. Process is ultimately executed faster

7	In case the company grows, a selection will be made from the operators involved in the process	Including (at least) 1 experienced person from the older generation, 1 young person who likes to innovate and 1 person in between to rely on different characteristics from the operators	1. Improved speed and efficiency of the process 2. Improved degree of integration and operational performance of the machine in the company 3. Improved internal support for the project