Lars Even Lyse Kåstad

Implementing Real-Time Data Collection for SME in the Manufacturing Industry

Master's thesis in Global Manufacturing Management
Supervisor: Fabio Sgarbossa
June 2023

Master's thesis

NTNU
Norwegian University of Science and Technology
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Abstract

This assignment aims to determine how real-time data collection can be introduced in small and medium enterprises. Introducing Industri 4.0 tools in SMEs is challenging as the tools can require significant investment and a high level of expertise. SMEs often have a short-term strategy and believe the risk of implementing new technology is too considerable. By collecting data, companies can maintain a competitive advantage, gain control, confirm the need for improvement measures or confirm that the measures are working. And that scientific studies show that obtaining an overview of the process through data collection is the first step in improving it.

The study has been carried out in collaboration with an SME within the prefabricated wooden element production industry. Through the case study, it is illustrated how real-time data collection can be implemented. The first step in implementing real-time data collection is to map the focus area. A literature study was therefore carried out to find methods for mapping. The next step is to map the area, in this case, a production line, where value stream mapping was conducted. The last step was to find technologies that can collect data in real-time.

Three methods were found to map, value stream mapping, the control model methodology and flowchart methodology. The methods were compared, and advantages and disadvantages were acquired. Through value stream mapping, data from the production line was collected. A comparison of which data to collect in real time was conducted. The literature study found three technologies to collect data in real-time: RFID, smart devices and sensors. Proposals for implementing the technologies in the production line were introduced, and the advantages and disadvantages of the proposals were carried out.

Results from this assignment contribute to knowledge about how SMEs can introduce Industry 4.0 by implementing real-time data collection. The assignment focuses on a company in the prefabricated wooden element production industry but may apply to companies and industries operating in similar environments. For the case company, Overhalla Hus, the assignment has contributed insight into how they can introduce Industry 4.0 technology.

Sammendrag

Denne oppgaven tar sikte på å finne ut hvordan sanntidsdatainnsamling kan introduseres i små og mellomstore bedrifter. Å introdusere Industri 4.0-verktøy i SMB er utfordrende da verktøyene kan kreve betydelige investeringer og høy kompetanse. SMB har ofte en kortsiktig strategi og mener risikoen ved å implementere ny teknologi er for stor. Ved å samle inn data kan bedrifter opprettholde et konkurransefortrinn, få kontroll, bekrefte behov for forbedringstiltak eller bekrefte at tiltakene virker. Og at vitenskapelige studier viser at det å skaffe seg oversikt over prosessen gjennom datainnsamling er første skritt for å forbedre den.

Studien er utført i samarbeid med en SMB innen prefabrikkerte treelementproduksjonsindustrien. Gjennom casestudien er det illustrert hvordan sanntidsdatainnsamling kan implementeres. Det første trinnet i implementering av sanntidsdatainnsamling er å kartlegge fokusområdet. Det ble derfor gjennomført en litteraturstudie for å finne metoder for kartlegging. Neste steg er å kartlegge fokus området, i dette tilfellet en produksjonslinje, hvor verdistrømskartlegging ble utført. Det siste trinnet var å finne teknologier som kan samle inn data i sanntid.

Det ble funnet tre metoder for å kartlegge, verdistrømskartlegging, styringsmodellmetodikken og flytskjemametodikken. Metodene ble sammenlignet, og fordeler og ulemper ble tilegnet. Gjennom verdistrømskartlegging ble data fra produksjonslinjen samlet inn. Det ble utført en sammenligning av hvilke data som burde samles inn i sanntid. Litteraturstudien fant tre teknologier for å samle inn data i sanntid: RFID, smarte enheter og sensorer. Forslag til implementering av teknologiene i produksjonslinjen ble introdusert, og fordelene og ulempene ved forslagene ble gjennomført.

Resultater fra denne oppgaven bidrar til kunnskap om hvordan SMB kan introdusere Industry 4.0 ved å implementere sanntids datainnsamling. Oppgaven fokuserer på en bedrift i prefabrikkert treelementproduksjonsindustri men kan gjelde bedrifter og bransjer som opererer i lignende miljøer. For casebedriften Overhalla Hus har forskningen bidratt med innsikt i hvordan de kan introdusere Industri 4.0-teknologi.

Preface

This thesis concludes my master's degree in Global Manufacturing Management at the Department of Mechanical and Industrial Engineering at the Norwegian University of Science and Technology (NTNU) in Trondheim. The assignment was conducted in spring 2023 in connection with the subject TPK4430 Production management, master's thesis and corresponded to a workload of 30 credits.

This thesis looks at the possibilities for introducing real-time data collection in a prefabricated wooden element production. A specialisation project carried out in the autumn of 2022 lays the foundation for the thesis. The specialisation project had a broader approach, and continuing with the same theme was desirable only with a more specified approach.

It was written in collaboration with Overhalla Hus, and I would like to thank the staff for their contribution. In particular, I would like to thank Ola Lauve for the trust, good discussions and encouragement. I would also like to thank Magnus Moa Frisendal for all his cooperation and good conversations.

I would also like to express my gratitude to my supervisor, Fabio Sgarbossa, for his valuable guidance, input, feedback, and contributions in defining the scope of the thesis. Last but not least, I would like to thank my family and friends for all their support, especially Ludvik for his patience and encouragement and Helene for motivating and reading through.

Lars Even Lyse Kåstad

Trondheim, June 2023

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Abbreviations

BPMN	Business Process Model and Notation
CODP	Customer Order Decoupling Point
CSM	Current-State Map
C/T	Cycle Time
EPC	Event-driven Process Chain
ERP	Enterprise Resource Planning
ETO	Engineer To Order
FSM	Future-State Map
MES	Manufacturing Execution Systems
NVA/T	Non-Value-Added Time
PCE	Process Cycle Efficiency
RFID	Radio Frequency Identification
SMEs	Small and Medium Enterprises
U/T	Uptime
VA/T	Value Added Time
VSM	Value Stream Mapping

1. Introduction

This section presents the background and motivation for this thesis, the aim and the research questions. The scope of the research will be presented, followed by the research design. Lastly is an overview of the structure of the thesis.

1.1. Background

Advanced digitalisation within factories, combined with internet technologies and forward-looking technologies within smart objects, has resulted in a new fundamental paradigm shift in industrial production called Industry 4.0 (Lasi et al., 2014). Moeuf et al. (2018) and Rosina et al. (2020) present a global definition for Industry 4.0 created by The CEFRIO: “a set of initiatives for improving processes, products and services allowing decentralised decisions based on real-time data acquisition”. The emergence of new technologies is the basis for Industry 4.0, such as cloud computing, the “Internet of things”, cyber-physical systems and big data. These technologies should improve the transfer of information throughout the enterprise, enabling better control and operations to be adapted in real-time according to varying demands (Moeuf et al., 2018).

To maintain a competitive advantage and respond to customer expectations, small and medium enterprises (SMEs) must constantly improve planning, use of resources, control of production and measurement and evaluation of operational performance (Moeuf et al., 2018). Information and communication technology systems are only partially implemented within SMEs (Bai et al., 2020; Uhlemann et al., 2017). Introducing Industry 4.0 tools in SMEs is challenging as the tools can require significant investment and a high level of expertise. SMEs often have a short-term strategy that makes significant long-term investments difficult. At the same time, introducing new technologies and practices is risky for SMEs (Moeuf et al., 2018).

The German National Academy of Sciences has proposed a maturity index that defines different stages of the development of Industry 4.0. The first step is "inventory", where the goal is to collect and highlight company data to understand the production processes better. The second step is “horizontal integration", which aims to optimise the process chain. The third and last step is "Smart", which aims to include new functions such as autonomy, flexibility, adaptation, etc., in the production process. To reach these steps, technologies must be implemented (Benfriha, et al., 2021).

Through research, this thesis will present different ways of introducing Industry 4.0 for SMEs in the manufacturing industry. Following The German National Academy of Sciences maturity index, the first step is inventory, where the goal is to collect high-quality data and better understand the production process. By collecting data, enterprises can improve production planning and control management. The assignment will conduct research based on a case study of an SME within the wooden element production industry, including a case company that wants to improve its production. Based on insights from the literature and case-specific details, this thesis will propose case-specific implementations to collect data, which can also inspire other companies.

1.2. Motivation for research

This thesis is conducted in collaboration with Overhalla Hus. Overhalla Hus is a supplier of houses and prefabricated wood elements located in Overhalla, north of Trøndelag. Overhalla Hus can be described as an SME. The company designs and produces roof trusses and prefabricated wood elements for walls, roofs, and floors. In addition to offering custom-built solutions, they also have a selection of standard models. The products are produced in low volumes with a complex product structure, where the size and complexity of the projects can thus vary from garages to apartment buildings. At Overhalla, the company is divided into two buildings, one administration building and a production hall. The production hall is divided into four units, an element line, a manual line, pre-cut and roof truss production.

"In today's globally competitive market conditions, manufacturers are striving to rapidly develop high-quality products at a lower cost and in a shorter period of time" (Chirumalla et al., 2018), and Overhalla Hus is no exception. To determine the progression of the production, Overhalla Hus calculates the produced number of square meters of wood elements. However, the progression has not been as significant as the company desires in recent years. Overhalla Hus is therefore interested in collaborating with NTNU to investigate why.

The CEO of Overhalla Hus, Ola Lauve, indicates that the element line has great potential to increase its annual production volume. The company, therefore, wanted an analysis of their element production line. However, analysing the element line seemed challenging based on the absence of production data. The motivation for the research was thus aimed at investigating how data collection can be carried out in SMEs by combining a practical issue with the literature.

1.3. Aim and Research Questions

This thesis aims to determine how real-time data collection can be introduced in small and medium enterprises in the manufacturing industry. This is illustrated through a case study of a prefabricated wooden element manufacturer. By introducing real-time data collection, Overhalla Hus will gain a better overview and control, which makes it possible to improve the production process and increase the annual production volume. The research will be conducted considering the following proposed research questions:

RQ1: *To form a basis for real-time data collection, what are the advantages and disadvantages of the presented mapping methods?*

RQ2: *To create a real-time data collection, which data should be prioritised, particularly regarding the case company?*

RQ3: *To create a real-time data collection, what technologies are available, and what are the advantages and disadvantages of implementing them in the case company?*

1.4. Research Scope

The project's scope involves real-time data collection for small and medium enterprises. In this context, SMEs comprise enterprises with less than 250 employees, less than 50 million euros in turnover, or a balance sheet total of fewer than 43 million euros (European Union, 2023). While searching for technologies to create real-time data collection, less resource-intensive technologies and technologies that do not require high expertise will be selected.

The study of the case company focuses on the element line in the production. The activities of the overall production process have yet to be assessed, but parts are included to give an overall picture of production. All proposals and discussions will be limited to the existing layout and machinery, and expanding facilities will not be considered.

1.5. Research Design

The figure below visualises the research design of this thesis. The thesis is motivated by both the literature and a case company, which inspired the research topic. The research topic was further divided into three research questions. Literature and case studies were conducted to answer the research questions. Lastly is the primary outcome of the research presented.

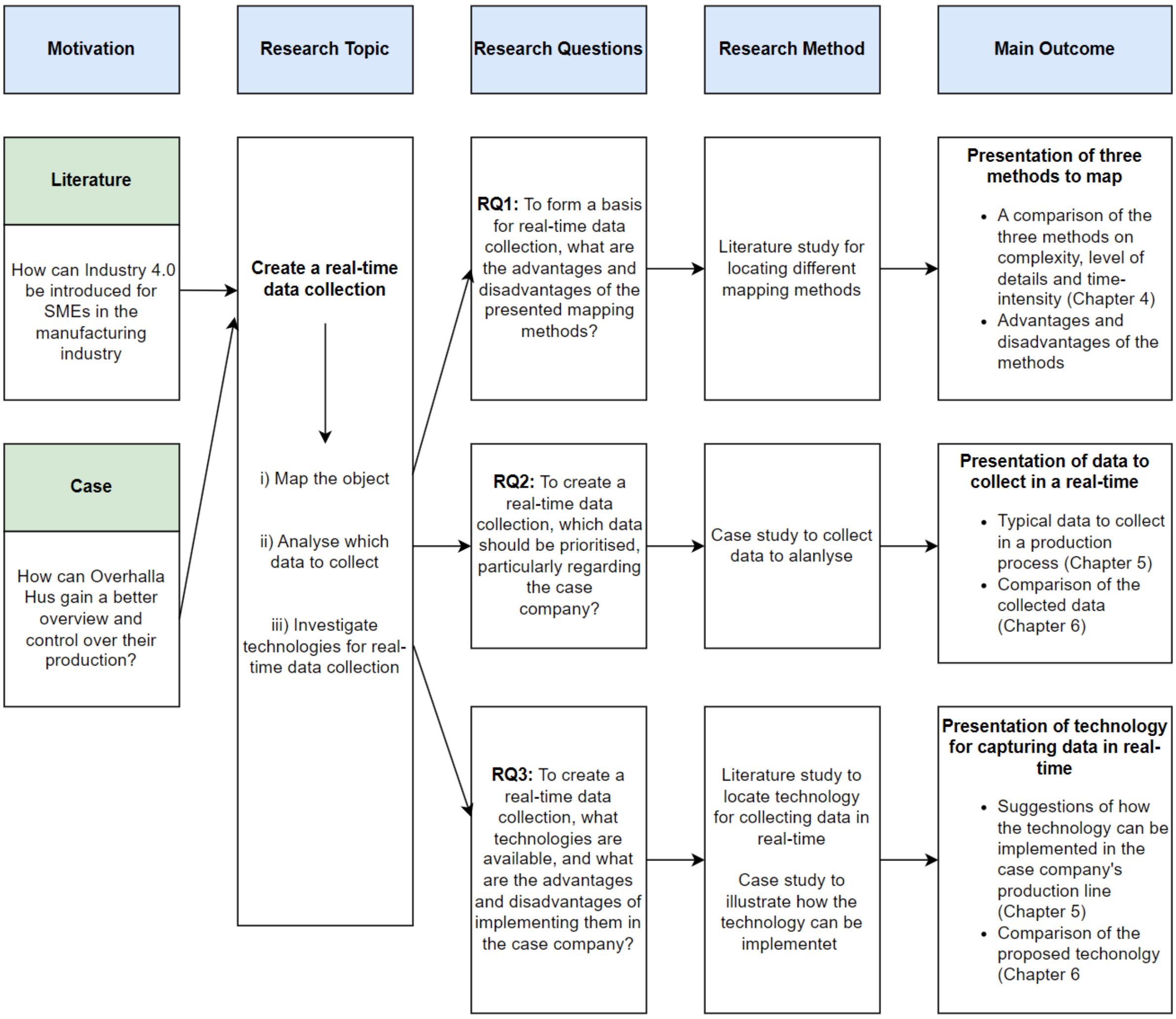

Figure 1: The research design of this research study, showing the relationship between motivation, research topic, research questions, research method and the primary outcome.

1.6. Structure

Tabel 1:Thesis structure

Chapter	***Content***
Chapter 1: **Introduction**	This chapter describes the background and motivation for the research, the thesis's aim and research questions, followed by the research's scope and design.
Chapter 2: **Methodology**	This chapter describes the research methods used in this thesis. First, is the literature study described, which will aid in answering RQ1. Followed by a description of the case study, which will aid in answering RQ2 and RQ3.
Chapter 3: **Theoretical Background**	This chapter describes the theoretical basis for the thesis. First various methods and principles within lean manufacturing are described. Further follows a description of an engineer-to-order production environment. Finally, various technologies within manufacturing process control will be described.
Chapter 4: **Literature Review**	This chapter describes the results of the literature study. First is the method of Value Stream Mapping described. Followed by a description of the control model methodology. Finally, the flowchart methodology is described. To summarise the chapter, there is a comparison of the presented methods. This chapter will aid in answering RQ1.
Chapter 5: **Case study**	This chapter describes the results of the case study. First is the case company's market and products described. Followed by an explanation of the case company's ETO environment. Then the phases of the case company's production process are explained, followed by a description of the production phase. Here a VSM of the case company will be described, which will aid in answering RQ2. Lastly, the implementation of various technologies found in the literature study will be described, which will aid in answering RQ3.
Chapter 6: **Discussion**	This chapter will present a discussion regarding the results found in the thesis. The three research questions will be answered.
Chapter7: **Conclusion**	This chapter presents the conclusion of the thesis. First, a summary of the thesis findings will be presented, followed by the limitations of the research. Lastly, further work will be described.

2. Methodology

The following section presents the methods for addressing this thesis's aims and research questions. The methodology justifies the methods used and describes how the research problems have been systematically approached (Karlsson, 2016). In this thesis, both qualitative and quantitative methods have been used. First, the literature study will be presented, and how it has contributed to answering the research questions. Then the case study will be described, contributing to answering RQ2 and RQ3. The chapter aims to describe how well the research has been carried out and convince readers that they can trust the results.

2.1. Literature study

A literature study was carried out to identify existing research related to the aim of the thesis, which was further used to examine methods, concepts and theory. According to Karlsson (2016), there are four reasons to carry out a literature study:

1. Through studying existing literature, gaps in knowledge can be identified and further used as a research topic.
2. Existing literature may inspire the choice of a research topic or research method.
3. Existing literature can contribute with theories, models and frameworks that can be applied in a research topic.
4. A literature study improves critical research skills and the ability to handle and classify large amounts of information.

The literature study contributed to establishing the scope of the thesis and developing the research questions. This thesis's starting point consisted of the case company's dilemma, where the existing literature was examined to find solutions. This began broadly, focusing on locating methods to map production lines. At the start, the plan was to analyse the production of the case company, and the method’s ability to analyse became a factor. However, this was changed due to insufficient analysis data, and the new focus, in addition to mapping, was to find ways to collect data. The literature study was divided into two parts, the first part included examining mapping methods and the second involved exploring the possibilities for data collection, especially in real time. A research area was chosen, and the literature study was further specified.

Existing literature inspired the choice of methods and contributed with theories, models and the framework. Methods and theory obtained through the candidate's education also contributed to forming a basis for literature study by expanding knowledge.

During the search for relevant literature, various keywords were selected. These keywords were divided into primary and secondary to specify the search further. First, more general literature was identified to gain knowledge about the field of interest. Secondary keywords narrowed the search results with the primary keywords, which helped define the research topic. The keywords are listed in the table below.

Table 2: Keywords used in the literature study

Primary Keywords	Secondary keywords
Mapping	Production Process Manufacturing Methodology Techniques
Value Stream Mapping	Methodology Engineer to order
Control Model Methodology	
Flowchart Methodology	Mapping Manufacturing Methodology

Scopus, Google Scholar, Science Direct, Emerald and NTNU's database, Oria, were used when searching for scientific literature. An advantage of using different search engines is that a wide range of scientific articles can be identified while reducing the risk of avoiding relevant literature. A wide range of sources can be found, particularly concerning Google Scholar, which includes different databases, meaning one must be critical of sources.

For this thesis, both Norwegian and English articles were included. The year the article was published was considered, as technology and industry change rapidly, and older research may be less relevant today. Therefore, articles published in 2010-2023 were prioritised. No relevant articles were discovered in this period for some topics, leading to older articles and books being used. Another factor that affected the literature search is that some articles required payment. Thus, only articles and books that are free or available through the NTNU license have been used. Articles were selected based on credibility to ensure that the information found was reliable and applicable.

The snowball approach method was used when the databases did not provide relevant publications for the desired topic. This process involves assessing the references or articles that refer to reviewed articles, aiding the identification of other articles that have yet to be recognised (Dobrovolskyi & Keberle, 2018). This increases the chance of finding credible sources since they have been cited or used as a source. For example, while searching for information on Value Stream Mapping, much of the literature referred to the book *Learning to See* written by Rother and Shook.

In general, the literature study helped define the scope of the thesis. It provided an overview of methods that can be used to map and an overview of available technology to implement real-time data collection.

2.2. Case study

A case study was one of the methods used in this thesis, where its usage aimed to explore theory as a practical example and contribute to further developing the research.

Through a case study, a researcher can go beyond the quantitative statistical results and understand the behavioural conditions through an actor's perspective. A phenomenon's process and result can be investigated using a combination of quantitative and qualitative data and through comprehensive observation, reconstruction and analysis (Zainal, 2007). Case studies can complement quantitative research, testing theories in concrete cases and helping to define their scope of application (Dubois & Araujo, 2007).

The case study for this thesis included both qualitative and quantitative methods. These qualitative methods comprise the main part of the case study and include mapping a production line, observations from the plant, semi-structured interviews and discussions with company employees. At the same time, the quantitative methods involve collecting production data to get an overview of what kind of data can and should be collected in real-time data collection. Due to limited time, only one company was included in this case study. The advantage of having only one company is a more in-depth study. The disadvantage is that several companies would have provided a broader perspective and augmented external validity (Voss et al., 2002).

This case study continues the work on a specialisation project carried out in collaboration with Overhalla Hus in the Autumn of 2022. The project aimed to investigate which production environment Overhalla Hus operates in and how this affects its overall production process. Qualitative methods were used in the project, as well as a thorough overview of the overall production process was acquired through company visits, dialogues with employees, and observations. This created a better understanding of the activities in the production planning process, the interaction between the various departments and the purchasing process. Various difficulties, primarily related to the production environment, were identified. These difficulties also affect production, which is the focus of this case study, and is a factor that should be included in this thesis. The specialisation assignment helped to provide a good insight into the overall production process, which further created the basis for this thesis to specialise in production.

A company visit to the factory in Overhalla, in northern Trøndelag, was carried out on the 27th – 29th of March, 2023. The visit was necessary to establish the mapping of Overhalla Hus' production. The first day involved creating an overview of the production facilities and the various processes that take place there. During conversations with the CEO and production manager, the plan for the visit was discussed. On the second day, the mapping began, where first observations were made, and thoughts regarding the production of the element line were noted. Eventually, the data collection started, which continued until the third day. The opportunities for establishing real-time data collection were also investigated during the visit. The company visit resulted in a qualitative and quantitative survey of the production process and facilities.

Interviews were included in the case study, as these can provide insight into understanding a phenomenon or a process via the people involved (Diefenbach, 2009). On the third day of the company visit, semi-structured interviews were conducted with the operators who work at the element line. There was a big difference in the operators' age and work experience; some had worked in the company for a few weeks, others for several years. The questions focused on what they thought was problematic about how production occurs on the element line today. The operators were then asked how they would fix it. For example, the elements have become more complicated and thus take longer to make, and some think that the production activities are too accurate. Many expressed a desire for more equipment and more employees. The interviews helped better understand what the operators consider the most problematic and potential solutions.

The case study gave insight into how the theory can be used in practice, what kind of technology can be used, the operators' observations and thoughts and mapping of the case company's production.

3. Theoretical Background

The following section presents the theoretical basis for this thesis. The basis consists of various books and scientific publications. First, various methods and principles within lean manufacturing will be described. Lean manufacturing is an essential part of production management, and a lot of knowledge is needed if this is to be able to form a proper mapping of a production line. Furthermore, the theory focused on the engineer-to-order production environment to describe the characteristics of such an environment. Finally, manufacturing process control will be described. Two manufacturing software will be described here, as software is necessary to form real-time data collection.

3.1. Lean manufacturing

Lean manufacturing was first used in the article *Triumph of the Lean Production System* 1988. However, the term became best known through the book *The Machine That Changed the World*, published in 1990 (Dekier, 2012; Rolfsen, 2021). The book and the article are reports from researchers from the International Motor Vehicle Program (IMVP) at the Massachusetts Institute of Technology. The researchers looked at the performance gap between the Western and Japanese car industries, which started in the late 1970s (Bhasin & Burcher, 2006; Rolfsen, 2021). The research found that Japanese car manufacturers, particularly Toyota, were organised in a way that provided higher productivity, better quality and greater flexibility (Rolfsen, 2021). Toyota's organisation model was dubbed lean production, and it has been developed to apply to more than Toyota and car production (Rolfsen, 2021). There is still no clear definition of what lean means. Rolfsen (2021) presents four approaches based on a literature study: Lean as an organisational trend, Lean as a management philosophy, Lean as a set of principles and Lean as a set of practices. This sub-chapter will describe various methods and principles that have evolved from Lean and are used in this thesis.

Value

Part of the lean principles is the aspect of *value*. Value is the extent of expense a person is willing to offer, where their perceived product value defines their limit (Nicholas, 2018). Accordingly, the vendor must account for this to prevent the price from exceeding the customer's value. One of the main principles of lean thinking is thus to define value from the customer's perspective. The organisation must therefore evaluate who its actual customers are and what these customers consider to be valuable (Thangarajoo & Smith, 2015). For manufacturers, this involves ensuring that the cost of production activities is not greater than the product's perceived value. Although all production and supportive activities increase the product's cost, it does not necessarily contribute to its value (Nicholas, 2018). As a result, the production and supportive activities can be divided into value-adding and non-value-adding activities.

Value-adding activities are defined by Nicholas (2018) as activities which "directly add value to the output, whether product or service and, as such, they are also something a customer would willingly pay for". On the other hand, Womak and Jones (1996) define value-adding activities in a more physical sense: transforming the raw materials fit, form, or function and as advancements to the finished product. Determining which activities are value-adding is summarised in the famous quote by Henry Ford: "If it doesn't add value, it's waste".

Jolley (2004, referred to in Thangarajoo & Smith, 2015) defined non-value-adding activities as "inhibitors of a system in the form of waste, variability and inflexibility that add costs in the form of time and or expenses that do not add value for the customer".

Yet, some non-value-adding activities are still necessary. Here the organisation must assess which activities are essential and consider removing those deemed unnecessary. According to Nicholas (2018), this is often challenging as many organisations perceive unnecessary activities as necessary. Nevertheless, it is possible to fulfil many seemingly valuable purposes by reducing the need for non-value-added activities. The organisation must then focus on improving the value-adding and necessary non-value-adding activities (Nicholas, 2018).

Bottleneck operations

A bottleneck can be identified as the process that takes the longest or has the highest average utilisation rate and work effort (Rolfsen, 2021). A bottleneck operation is a process where the scheduled work exceeds the work capacity. This affects the entire production process because production cannot produce faster than the bottleneck. The bottleneck thus determines the speed of the production flow. Therefore, efforts to increase the throughput must start at the bottleneck (Nicholas, 2018). Pegels and Watrous (2005) argue that bottlenecks are the source of disruption to improve productivity and throughput. The bottleneck is not locked to one process because by improving the previous bottleneck, another process can become a new bottleneck, and the improvement focus must be directed towards it (Roser et al., 2003).

Gemba

Dalton (2019) states, "A Gemba walk is a technique used to observe and understand how work is being performed". Gemba comes from the Japanese saying *genchi genbutsu,* which means to go and see for yourself (Nicholas, 2018). A Gemba walk includes the following three elements: observation, location and teaming. The information is gathered by observing workers performing work where it happens and through interaction (Dalton, 2019). A Gemba walk provides a detailed view of a process and can help identify improvement opportunities (Dalton, 2019). A manager or administrative person often carries out the walk, and the tool is thus helpful in giving them an overview of the state of the process. They also can communicate with the operators, provide support, and show presence (Dalton, 2019; Nicholas, 2018).

Measurements

Cycle time is the time interval that elapses between occurrences of something and connotes different things, depending on how it is used (Nicholas, 2018). Most commonly, it is used about how long a process takes to complete a part (Rother & Shook, 1999). In any case, cycle time is used as a regularity or rhythm. Regular timing is beneficial because it reduces uncertainty and allows managers and operators to anticipate better and prepare for the future. The emphasis is on maintaining a steady, predictable production rate, not increasing it (Nicholas, 2018).

Lead time is the time it takes for one piece to move through a process or value stream from start to finish (Rother & Shook, 1999). From a customer's perspective, it is the time it takes from ordering an item until it is delivered (Rolfsen, 2021).

Takt time is how often an item should be produced given the available time and is based on a production target or customer demand (Nicholas, 2018; Rother & Shook, 1999). The time taken represents the production time in an ideal stage. Where production has no obstacles, and everything is produced smoothly (Nicholas, 2018). Tact time is used for synchronising production with demand, especially for the bottleneck. Also, it can be used as a reference number for the production rate for processes (Rother & Shook, 1999).

$$Takt\ time = \frac{Daily\ Time\ Available}{Required\ Daily\ Quantity}$$

Uptime is the time a resource is available for processing. If the resource is a machine, uptime is the time the machine spends producing a product. It can also be the time the machine could produce if it had the necessary materials. Uptime is the opposite of downtime, which can be maintenance, changeover or failure (Rolfsen, 2021).

$$Uptime = \frac{Actual\ Production\ Time}{Total\ Available\ Time} * 100\%$$

Pull and Push Systems

Push and pull systems are two principles for managing production and material flows. The push system, which is often the traditional way of production management, assumes that all production stages operate according to information about demand forecasts or customer orders for end products. The production order is released at the first step, and then the order is "pushed" through the production system (Olhager & Östlund, 1990).

In a pull system, the last production stage or the finished goods warehouse will process the information about customer orders and forecasts. If the item is not available, the item will be ordered, which becomes a series order system with subsequent production and transport orders. Throughout the process, materials are “pulled” from operation to operation (Nicholas, 2018; Olhager & Östlund, 1990). Pull and push systems can be summed up by Venkatesh (1996, referenced in Bonney et al., 1999, p.54) «In a push system, a preceding machine produces parts without waiting for a request from the succeeding machine. On the other hand, in a pull system, a preceding machine produces parts only after it receives a request from the succeeding machine».

3.2. Engineer To Order

Engineer-to-order (ETO) is a manufacturing situation related to companies designing and producing customised products (Cannas & Gosling, 2021). Examples of ETO industries can be construction, shipbuilding or machine production. This type of manufacturing situation often results in an environment whit complex engineering work, new design work and changing supply chain processes (Cannas & Gosling, 2021). Olhager et al. (2001) state that ETO environments produce goods in a low volume, not standardised and unique products, and are typically found in companies that produce specified products for one customer at a time. The competitive advantage of ETO companies is based on their degree of flexibility.

Gosling and Naim (2009) carried out a systematic literature review of the ETO supply chain, where they contributed to the development of a robust definition. The literature review found several commonalities in definitions of ETO supply chains:

- ETO supply chains operate in a project environment, and each product is different to the last.
- Production dimensions of the supply chain are entirely customised.
- The customer order decoupling point is located at the design stage.

According to Cannas et al. (2019), the customer order's decoupling point (CODP) "is the point in a process where a product becomes associated with a specific customer order, thus separating the activities performed based on forecasts from those performed based on orders". Barlow et al. (2003) point out that the placement of CODP for ETO companies implies that the company allows customers great freedom of choice and hence high flexibility, against which the company works to maintain high efficiency.

The differences in the definitions found in the literature review of Gosling and Naim (2009) are about the extent of the product's development. Does an entirely new design need to be developed, or can an existing design be changed? This question is the main difference between the definitions, making defining ETO situations difficult. Where is the limit set for engineering? (Gosling & Naim, 2009).

3.3. Manufacturing Process Control

Manufacturing systems involve producing goods using manufacturing resources and knowledge according to external demands and are subject to the environmental context, e.g. social and economic aspects. However, a manufacturing system has little utility without an appropriate supervisory control system (Leitão, 2009). In this sub-chapter, the real-time data collection method will be explained. Several types of manufacturing software can help control the manufacturing process, two of which will be described here.

Real-time data collection

According to Uhlemann et al. (2017), acquiring data and developing various alternatives in the production system and factory planning require up to 66% of the total necessary time resources. The digitisation of production systems allows for automated data collection. Unfortunately, paper-based data collection systems dominate production locations such as shop floors and warehouses, and as a result, the field data are often incomplete, inaccurate and untimely (Zhong et al., 2013).

Data collection involves capturing proper physical values generated by production events. The obtained data is further analysed and interpreted into optimal decisions to improve the performance of the production system (Xu, et al., 2020). Xu et al. (2020) have divided real-time data collection into four layers:

1. The production layer includes various production processes, such as product design or assembly.
2. The data layer includes monitoring and inspection during the production process, using various technologies, such as sensors, RFID, and smart devices, which are integrated into the production system. The data is collected, stored and visualised for data processing preparation.
3. The knowledge layer includes transforming raw data into insightful functions and data knowledge via data processing technologies.
4. The decision-making layer transforms knowledge into final decisions about accurate simulation, evaluation and prediction.

Enterprise Resource Planning

Enterprise Resource Planning (ERP) can be roughly explained as a database of a set of pre-built applications that work together to support core business processes in a company. ERP is usually considered the backbone of a company's business portfolio and interacts with other business software to serve users and actors (Sagegg & Alfnes, 2020). ERP are comprehensive, packaged software solutions that integrate the entire sequence of a company's processes and functions to present a holistic view of the business from a single information and IT architecture (Klaus et al., 2000). The various business units in an organisation connected to an ERP system can be finance, accounting, production and human resources. The units are connected to a tightly integrated single system with a common platform for information flow across the business (Beheshti, 2006).

Historically, ERP developed from material requirements planning and production resource planning MRP II systems in the 1970s and 1980s (Nazemi et al., 2012). In the 1990s, software developers created ERP software, a fuller suite of applications capable of connecting all internal processes. ERP systems are based on a value chain view of the business where functional departments coordinate their work, focus on value-adding activities and eliminate redundancy (Beheshti, 2006).

Manufacturing execution system

The manufacturing execution system (MES) is an information system application that emerged in the mid-1990s to address ERP's inadequacy in real-time management of shop floor operations. MES was developed to connect the shop floor and ERP, bridging the gap between planning and control systems and using production information to support production processes (Govindaraju & Putra, 2016; Mantravadi & Møller, 2019; Shojaeinasab et al., 2022). MES functionalities are production monitoring and control tasks, making shop data available and measuring real-time performance indicators. Examples of performance indicators include stock availability, quality status or equipment utilisation (Arica & Powell, 2017).

MES creates a detailed operations plan by combining preliminary production plans from ERP with real-time information about processes, materials and operations from the machines, controls and individuals on the shop floor. This enables real-time management of production activities. MES receives data about the status on the shop floor through actuators and sensors or other smart devices, which are part of the data collection system (Shojaeinasab et al., 2022).

Shojaeinasab et al. (2022) point out six main tasks for MES:

1. Coordinate the integration of facilities and trading partners.
2. Contribute to further integrating the processes within ERP within logistics, engineering, sales, compliance, quality, maintenance and operation.
3. Schedule tasks in the production line according to the machines' real-time capacity and the products' current status.
4. Implement advanced optimisation algorithms to modify the schedule of production and maintenance plans in case of failure.
5. Collect and store big data from the production processes and provide them with quality control and predictive maintenance tools.
6. Measure the KPIs of the production processes.

4. Literature Review

The following section presents the results from the literature study that was conducted. The literature study aimed to gain insight into methods for mapping a production line and contribute to answering RQ1. First, there is a description of the Value Stream Mapping method. Furthermore, a description of the Control Model methodology follows. Next, the Flowcharts methodology will be described, as well as two different types of flowcharts. Finally, there is a comparison of the various mapping methods found in the literature study.

4.1. Value Stream Mapping

Value-stream mapping (VSM) is a lean management tool and a flowchart method initially developed by Toyota under the name “Material and Information Flow Mapping” (Rother & Shook, 1999). This method became available to the public when Rother and Shook wrote the book *Learning to See* in 1998 (Duggan, 2013). VSM is defined by Rother & Shook (1999) as “a pencil and paper tool that helps you to see and understand the flow of material and information as a product makes its way through the value stream”. VSM has become the preferred method for implementing lean thinking in factories (Neitzert & Stamm, 2008). Unlike other process mapping techniques, VSM has a broad perspective as it includes the entire value stream.

Rother & Shook (1999) define the term value stream as all value-adding and non-value-adding activities required to lead a product through the main flows essential to every product, from the raw materials to the end customer. Value-adding and non-value-adding activities are explained in *Chapter 3.1., Lean manufacturing*. According to Neitzert & Stamm (2008; Rother & Shook, 1999), a VSM aims to “identify ways to get material and information to flow without interruption, improve productivity and competitiveness, and help people implement systems rather than isolated process improvements”. VSM consists of four steps (Duggan, 2013), which will be explained further below:

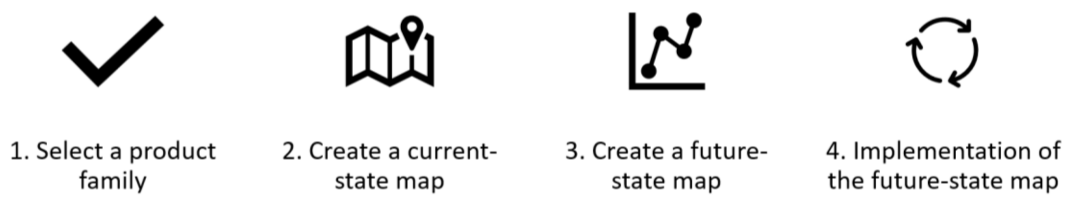

Figure 2: The four steps of value stream mapping.

The first step of VSM is to select a product family to focus on. Duggan (2013) states, "A product family is a group of products that pass through similar processes or equipment and have similar work content". The reason for focusing on one product family is that drawing the flow of all the products on one map is challenging. When identifying the product families, start at the end, i.e., the customer, and move up the value chain (Rother & Shook, 1999). To help identify product families, the organisation can create a matrix with a grid containing a list of processes and equipment on one axis and a list of products on the other. Here the products with the most similar equipment and processes are the product family (Duggan, 2013).

The following step is to create the current-state map (CSM). According to Rother & Shook (1999), the first step of the mapping is to walk along the entire door-to-door value stream and note the different process categories. This provides an overview, a sense of the flow and the entire sequence of processes. This method is recognised as the Gemba walk in lean philosophy, as explained in *Chapter 3.1.: Lean manufacturing*. After witnessing the general flow throughout the facility, choosing the accuracy of the mapping is more straightforward. This could enlighten whether each process step must be mapped or whether the mapping should include the value stream outside your facility (Rother & Shook, 1999).

The mapping is typically represented by hand drawing. This is because analytical mapping can help those responsible better understand the material and the flow of information (Rother & Shook, 1999). The VSM methodology has two dozen standard icons, presented by Rother & Shook (1999); still, the company can create its icons if desired. Icons represent different vital features of the process, such as the process steps, inventory, transferral of materials, operators, shipments, schedules, and manual and electronic information flow (Nicholas, 2018).

Mapping starts with placing the endpoint in the right corner, which can be a warehouse, a shop or the end customer (Rother & Shook, 1999). Below this, important information is noted, such as the customer's demand, cycle time or general information concerning production. A box further indicates the manufacturing processes, where the process is implied by the material flowing. This is because illustrating a box for each process step would clutter the map (Rother & Shook, 1999).

As the production processes are mapped, data is collected. The company decides which process data to calculate, but common data collected is cycle time, changeover time, uptime, batch sizes, number of operators, etc. This is collected during the mapping for consistency (Rother & Shook, 1999). Furthermore, inventory (raw materials, intermediate and finished goods), leading supplier(s), transport from suppliers, and production control are illustrated with different symbols. The mapping also includes information flow, where there is a distinction between electronic and oral information (Rother & Shook, 1999).

Push movement, explained in *Chapter 3.1., Lean manufacturing*, describes a process that produces a product without demand from the following process. These are marked with a striped arrow in the mapping (Rother & Shook, 1999). The last element to include in the CSM is a timeline drawn at the bottom. The timeline should symbolise the production lead time, which is the time spent on a segment through to the final step of the process (Rother & Shook, 1999).

The third step of the methodology is to create the future-state map (FSM). According to Brunt (2010), “the real utility of VSM is the ability to develop a vision of how good the value stream for the product could be”. The FSM is a drawing created from an analysis of the CSM and shows an ideal state. The proposed improvements in the FSM aim to point out where waste and non-value-adding activities are generated and suggest improvements to handling, reduction, and elimination, if possible (Ramani & KSD, 2019). Before drawing the FSM, an analysis of the CSM must be completed.

Rother and Shook (1999) have created seven guidelines to assist the conduction of the analysis. They emphasise the importance of remembering that a part of the waste in a value stream will result from the product's design, the purchased processing machinery and the external location of certain activities, where these features are unlikely to be immediately changeable. Brunt (2010) has further modified the guidelines into questions which are divided into the following four areas:

Demand

1. What is the takt time?
2. Should the company construct a finished goods supermarket or ship directly?

Material flow

3. Where can the company adopt continuous flow processing?
4. Where are pull systems necessary?

Information flow

5. At what single point in the production chain will the company schedule production?
6. How will the company equalise the production mix at the bottleneck process?
7. What increment of work will the company consistently release and take away at the bottleneck process?

Supporting improvements

8. What supporting process improvements are necessary (key improvement initiatives and critical success factors for implementing the FSM)?

Based on the answers to these questions, one should write down ideas and thoughts directly on the CSM. The FSM should be drawn after determining thoughts on the future state (Rother & Shook, 1999). In summary, the development of the FSM is iterative, and as ideas are accumulated, CSM is modified and morphed, resulting in the FSM (Nicholas, 2018).

The final step is the implementation of the future-state map. Rother and Shook (1999) recommend creating an annual value-stream plan to achieve the ideal stage. The plan should explain each step to achieve the ideal stage by creating measurable goals, clear checkpoints with deadlines, and engaging responsible people. Still, changing the entire factory flow at once can be difficult, and Rother and Shook (1999) recommend dividing the FSM into segments or loops and working section by section.

4.2. Control Model Methodology

The control model methodology originates in the professional production logistics and management environment at NTNU and SINTEF. The book *Produksjonslogistikk 4.0*, written by Strandhagen et al. (2021), explains the methodology and forms the basis for this sub-chapter.

The control model is an abstraction of a company or a value chain, describing the organisation and management of logistics and production processes (Strandhagen et al., 2021). This methodology aims to improve the performance of the logistics and production processes (Strandhagen et al., 2021). It is adaptable because the organisation determines the focus, and the methodology involves different methods, principles and systems. Which means the methodology adapts to the company or the value chain (Strandhagen et al., 2021). The value stream mapping methodology, explained in the chapter above, was an inspiration for the control model methodology. For example, the control model methodology includes mapping the current situation (AS-IS) and the desired future situation (TO-BE).

The model focuses on five dimensions that are part of the methodology, which help support the development and preparation of the overall control model. The five dimensions are resources, processes, materials/products, information and organisation (Strandhagen et al., 2021). Executing the methodology involves six steps: project start, mapping, analysis, design, implementation and project management, which are visualised in the figure below. Activities occur in parallel, although they are divided into six stages. For example, many of the activities in step six start at the start of the project. The six steps will be explained further (Strandhagen et al., 2021).

Figure 3: The six steps of the control model methodology

Step 1: Project start

The first step starts by explaining the company's motive to complete the project and defining a goal. According to Strandhagen et al. (2021), the purpose of the first step is to collect essential information about the company and the value chain. This includes mapping the company's market and surroundings, as well as the company's strategy and business model. The result of step 1 is a shared understanding of the company's market and strategy. Then, a project plan is formed with goals, a common understanding of the problem, a hypothesis about why the problem occurs, and a presentation of methods to be used (Strandhagen et al., 2021).

Step 2: Mapping

This step aims to collect the necessary data to document, describe and visualise the current situation, AS-IS. There are many ways to map, where mapping can have an adapted structure as each company and process differs (Strandhagen et al., 2021). In the table below, there are six steps that Strandhagen et al. (2021) have created. The recipe is followed when the control model (AS-IS/TO-BE) is to be drawn. Most importantly, the facts and characteristic features must be described and illustrated. Examples of areas to map include material and information flow, processes, actors, inventory, performance etc. It is crucial to describe the factors that affect production and logistics the most, specific to the company and its operation, and the market and products (Strandhagen et al., 2021). An interpretation and understanding must be included to avoid simply being a reproduction of facts. Step two should result in a broad understanding of the company's operations and current control model, identifying the characteristic features and which areas should be analysed further (Strandhagen et al., 2021).

Table 3: The six steps to draw the control model (AS-IS/TO-BE)

1	Start by drawing the company and the material flow. It is important to draw all physical processes, inventories, and the material flow between them.
2	Draw all actors with whom the company interacts. The suppliers are placed on the left side of the company, and the customers are placed on the right side.
3	Draw the material flow that connects the actors in the value chain, and note the frequency of the flow or what triggers the movement.
4	Draw the administrative processes and information flow. State the type of information being transferred and the frequency and format of the transfer.

5	Mark the control areas. There are often several. A management area can have processes with several actors.
6	Mark the CODP.

Step 3: Analysis

Step three aims to conduct various analyses of the results from step two, which will form the basis for improvements and changes in the TO-BE (Strandhagen et al., 2021). The project focuses on determining which method to use and in which area. Here the company can use different methods and tools, both quantitative and qualitative, where the results must be put in context and not interpreted in isolation (Strandhagen et al., 2021). Step three should result in a broad understanding of the operation and management of the company, allowing the proposal of areas for improvement following the company's business strategy (Strandhagen et al., 2021).

Step 4: Design

Step four aims to develop specific solutions in a TO-BE control model based on the identified improvement areas found in stage three (Strandhagen et al., 2021). The next step is to create the TO-BE; the same steps are followed as with the drawing of the AS-IS. A discussion about the consequences of the improvement proposals should be included. Here it should be seen how the improvements affect the operation and how they solve the issues (Strandhagen et al., 2021). The result of step four is a description and outline of TO-BE. TO-BE should be more adapted to the company than AS-IS (Strandhagen et al., 2021).

Step 5: Implementation

Step five aims to implement the changes identified in step four. This is a more practical step and involves introducing the proposed changes from previous steps (Strandhagen et al., 2021).

Step 6: Project Management

The sixth step aims to handle the process of mapping, analysis, identifying areas for improvement and designing and implementing new solutions. This step is carried out in parallel with the previous steps, resulting in the project plan, identification of milestones, delegation of responsibility and management of changes (Strandhagen et al., 2021).

4.3. Flowchart Methodology

A flowchart is a visual representation method used for visualising processes' flow sequentially and designing complex processes (Jirasukprasert et al., 2014; Shakil et al., 2013). Aguilar-Savén (2004) defines a flowchart "as a formalised graphic representation of a program logic sequence, work or manufacturing process, organisation chart, or similar formalised structure". Since the flowchart uses a sequential flow of actions, it does not support a breakdown of the activities. The flowchart methodology is possibly the first process notation method, as it has been used for many years, and there is no exact date or owner for its origin (Aguilar-Savén, 2004).

The flowchart is a simple and time-efficient mapping tool that shows a process in an easily readable and communitive form. The flowchart methodology is flexible, where a process can be described in many different ways, and it is up to the designer how the diagram should be depicted (Aguilar-Savén, 2004; Jirasukprasert et al., 2014). During the 1960s, the American National Standards Institute (ANSI) created a symbol standard in the flowchart methodology. Further, the International Organization for Standardization (ISO) adopted the symbols in 1970 (Chapin, 1970).

The standard consists of a series of boxes or graphic outlines, categorised into three groups: the basic, the additional, and the specialised. The basic and the additional symbols are enough to draw a flowchart, but the specialised ones can be used if necessary, as long as the use follows the standard. A description of the basic symbols follows:

- Terminal: Symbolises the diagram's start or end, or sub-process. It might also symbolise stop, halt, delay or interrupt (Robson, 2015), and is visualised in a stadium shape.
- Process: Any processing function; or defined operations causing a change in value, form or location of information (Robson, 2015), visualised as a rectangle.
- Decision: A decision or conditional operation determining which of alternative paths are followed (Robson, 2015), and is visualised as a rhombus.
- Input/Output: The input/output contour indicates an input or output operation or input or output data. It is defined for use regardless of media, format, equipment and timing (Chapin, 1970), and is visualised as a rhomboid.

- Predefined Process: One or more named operations or program steps specified in a subroutine or another set of flowcharts (Robson, 2015), and is visualised as a rectangle with double-struck vertical edges.
- Flowline: an arrow of any length that connects consecutive other symbols to indicate the sequence of operations or data. It also indicates the order in which the other contours should be read (Chapin, 1970), and is visualised as an arrow between the other symbols.

There are many different types of flowcharts, which have a repertoire of boxes and notational conventions (Jirasukprasert et al., 2014). Two of these commonly used to map processes will be explained.

Event-driven Process Chain (EPC) is a type of flowchart, and the method's goal is to gain a complete insight into the process being modelled. Introduced in 1992, EPC is targeted to describe processes at a business level and is thus easy to understand and use by business people. The name comes from the fact that the control flow structure of the process is shown as a chain of events and functions (Aalst, 1999; Amjad et al., 2018).

The EPC method consists of the following elements:

- Functions are the basic building blocks of the method and correspond to an activity (task/process step) that must be performed (Aalst, 1999).
- Events describe a situation before and/or after a function is performed. EPC starts and ends with an event, and events link a function. An event can correspond to the post-state of a function and act as a prerequisite for another function (Aalst, 1999; Amjad et al., 2018).
- Logical connectors connect activities and events, thus specifying the control flow. There are three types of connectors: and, exclusive or, and or (Aalst, 1999).

It is possible to model three views of EPC: entities (things in the real world), business objects (data), and organisational units. Making a visualisation of the EPC consists of three steps. The first step is to collect the business requirements. In the second step, the requirements are modelled. The third step consists of verifying and analysing the model to validate its correctness according to the business requirements. If an error is detected at step three, one must return to step two to correct it. (Amjad, Azam, Anwar, Butt, & Rashid, 2018).

Business Process Model and Notation (BPMN) is a standard for business process modelling that provides a graphical notation for specifying business processes. BPMN was developed by an industry consortium called Business Process Management Institute (BPMI). They focused on standardising business-oriented techniques to visually represent process components and align the notation with an executable procedural language. The method's goal is to represent complex process semantics intuitively, thus bridging the communication gap between business process design and implementation. (Rosing et al., 2015).

A specification document was developed that separates the BPMN constructs into a set of core graphical elements, which are grouped into four basic categories: Flow Objects, Connecting Objects, Swimlanes and Artefacts (Muehlen & Recker, 2013).

- Flow objects are the most basic elements of the model. Flow objects include events, activities and gateways (Muehlen & Recker, 2013).
- Connector objects connect flow objects through different types of arrows (Muehlen & Recker, 2013).
- Swim lanes group activities into separate categories for different functional capabilities or responsibilities (e.g., different roles or organisational departments) (Muehlen & Recker, 2013).
- Artefacts can be added to a model where displaying additional related information, such as processed data or other comments, is deemed appropriate (Muehlen & Recker, 2013).

4.4. Comparison

This sub-chapter consists of a comparison of the various mapping methodologies that were found in the literature study. The comparison is divided into three tables with three focus areas. The first table shows the complexity, the level of detail, and whether the method is time-consuming. The level of detail is divided into three aspects on how good the method is at mapping the time aspect, the activities and roles. The comparison is shown in the table below.

Table 4: Comparison of the mapping methodologies on complexity, level of detail and time intensity.

Method	Complexity	Level of detail			Time-intensity
		Time	Activities	Roles	
Value Stream Mapping	Average	High	Low	Low	High
Control Model	Average	Low	High	Average	High
Flowchart	Low	Low	Optional	Low	Low
EPC	Low	Low	Optional	High	Low
BPMN	Low	Low	Optional	Optional	Low

The second table shows a comparison based on what kind of flow the method shows, to what extent the method shows areas for improvement, and whether the method uses specific language and symbols.

Table 5: Comparison of the mapping methodologies on flow, visualisation of areas for improvement and language.

Method	Flow	Visualisation of areas for improvement	Language
Value Stream Mapping	Materials and Information	Good	Common
Control Model	Materials, Activities and Information	Average	Not standardised
Flowchart	Activities	Good	Common
EPC	Activities	Low	Common
BPMN	Activities	Low	Standardised

The third and last table shows additional strengths and weaknesses of the various methods not included in the previous tables.

Table 6: Additional strengths and weaknesses of the mapping methodologies.

Method	Additional Strengths	Additional Weaknesses
Value Stream Mapping	• Easy to understand • Includes a timeline • Flexible in mapping	• Presence of subjective data • Low consideration of human factors • Not suitable for all processes
Control Model	• Visualises the process from a larger perspective • Flexible in both methods and mapping	• Includes many factors • It might be tough to understand • Often becomes large and unmanageable
Flowchart	• Easy to understand • Flexible	• Do not have sub-layers • No overview • Often becomes large and unmanageable • Different notation
EPC	• Easy to understand • Suitable for processes with parallel activities and decision points • Logical connectors	• Syntax and semantics are not formally defined • Do not support time
BPMN	• Easy to understand • Large selection of symbols	

5. Case study

This section focuses on the case company for this thesis, Overhalla Hus. After the company's products and markets are explained, there will be a short explanation of the company's ETO environment. Afterwards, the company's design, modelling and preparation phase will briefly be explained. The following is a more detailed description of the production phase, where the element line will be particularly focused. Next follows a mapping of the case company's element production line using the Value Stream Mapping methodology. Finally, various technologies that can be used to create a digitalised VSM will be presented.

5.1. Products and Markets

Overhalla Hus has two market segments: one aimed at the market for private individuals (private market) and one aimed at the professional market (pro-market). Overhalla Hus is changing their focus from previously being a supplier of prefabricated houses in the private market to a supplier of wood elements for the pro market. The new division between the two segments will now be 70% in the pro market and 30% in the private market. The change of focus means that there will be an increase in more time-consuming and complex wood elements. Overhalla Hus, however, aims not to let the change influence their yearly production. The two market segments are described further, as well as the product characteristics for the markets.

Private market

Overhalla Hus offers standard models and custom-built solutions for the private market. Their website has a selection of standard models of detached houses and cabins. Examples are illustrated in the figure below. Even though the models are standardised, changes can still be made at the customer's request. The standard models are adapted for production, and the company has experience in making them, which makes production more efficient. Overhalla Hus can produce a move-in ready house for a standard project within 80 days, where the completion time and price will increase with the product's complexity. With a custom-built solution, the architects of Overhalla Hus can design the building the customer requests. Additionally, Overhalla Hus cooperates with several suppliers offering products like doors, windows, cladding, ventilation, kitchen furniture, etc., to deliver a complete house.

Figure 4: Examples of a standard house and cabin from Overhalla Hus's website (Overhalla Hus, 2022)

Professional market

For the pro-market, Overhalla Hus offers roof trusses, external wall facades and facade elements for all types of buildings. They also have standardised products, and their website has a selection of student housing, terraced houses and smaller apartment buildings for which they supply carrier systems, roofs and facades. Like the private market, the standard models can be changed at the customer's request. The product's complexity determines the completion time and price.

The elements for the pro-market are often more complex to produce. Firstly, the elements can be significant and do not necessarily fit into some of the machines in the production. Which means they have to be created in the manual production stations. Secondly, the facades of the buildings can have different shapes to give the buildings a unique character, which is more time-consuming and complex for the operators. In addition, the different shapes of the elements make it difficult to pass on experience from one project to the next since each project is unique. At the same time, it takes time for the company to get used to and gain experience in producing the elements for the pro-market. The venture into this market is a relatively new direction for them.

On the other hand, the deliveries only consist of elements, making it easier for the project manager since fewer suppliers are involved. An example of a complex project is "Blått bygg", a new university building at Nord University on the campus of Bodø. Overhalla Hus delivered the building's façade elements, as seen in the picture below. The project had several curved elements, while a traditional element is usually flat.

Figure 5: «Blått bygg», an example of a project for the pro-market (Overhalla Proff Treelementer, 2023)

5.2. Engineer-to-order environment

In the autumn of 2022, the candidate wrote a specialisation project for Overhalla Hus, where one of the objectives of the thesis was to look at the extent to which the case company operates in an engineer-to-order environment. Overhalla Hus produces customised products for specific customers, decoupled at the start of the production process, making the customer influence the process from the design phase. The products are produced through projects that can have a great degree of complexity. The volume of finished goods is low, no products are identical, and the engineering work can be pretty complex.

Nevertheless, Overhalla Hus is an example of the debate regarding the definition of ETO, as mentioned in *Chapter 3.2., Engineer To Order*. Gosling and Naim (2009) raise the question of the degree to which products must be developed and innovative to be categorised as ETO. This becomes a question of interpretation, a house is not necessarily innovative, but Overhalla Hus has the resources to contribute to an innovative building project. The specialisation project, however, concludes that Overhalla Hus operates in an ETO environment.

5.3. Design, Modelling and Preparing Phase

As mentioned, Overhalla Hus operates with projects. The finished product is complicated to produce, involves activities from several departments and consists of several manufactured components, resulting in the products being produced in projects. Projects are divided into the following four phases: design and modelling, preparation for production, production and transport, and delivery. The most time-consuming phases of a project are preparing for production, design, and modelling. According to the company, 79% of the time used to finish a standard project is used here. This section will briefly explain the activities carried out in this part of the project.

Design and Modelling phase

Overhalla Hus comprises sixty employees distributed into five departments: sales advisors, administration, assembly, project management and technical. The customer's first contact with the company is through a sales advisor. The sales advisor's main task is to sell a project to the customer, which involves gathering information and advising the customer. The sales advisor will then involve the project's architect, who draws the technical illustrations of the project. The sales advisor will also include an estimator in calculating the project's price. When the contract is signed, the sales advisor conducts a registration meeting where the responsibility of the project is transferred to a project manager. With the registration meeting, the sales advisor part of the project is completed, marking the end of the design and modelling phase.

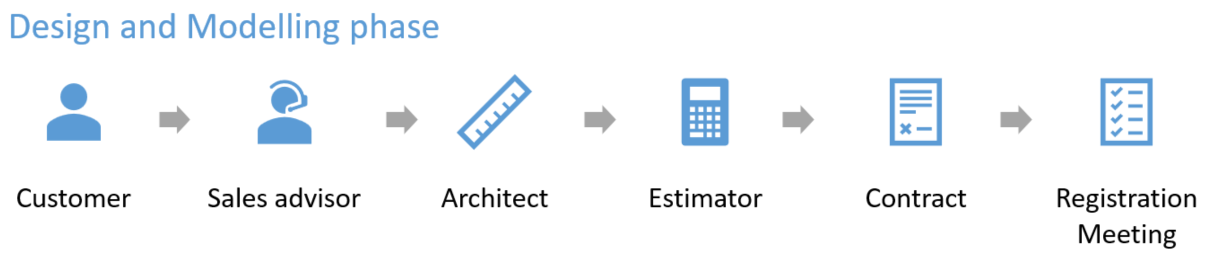

Figure 6: Process flow of the design and modelling phase.

Preparing for production phase

The second phase is the preparation for production. The project manager is responsible for this phase, where the primary task is to guarantee the delivery of the project. This involves ensuring that the project's activities are effectively completed and communicating the correct information to all agents.

This phase is critical as one activity must be completed before the next can start, effectively affecting each other. Preparing the technical solutions comprises the first activity of this phase and is accomplished by the construction engineers. This is because technical solutions may apply to construction, materials and substrates. The following step is to calculate the expenses of the materials for the project, which the estimator does. This is delivered to purchasing, where the inventory is confirmed, and the needed materials are ordered. The project manager will receive the ordered goods and ensure the project is ready for production, which marks the end of the preparing for the production phase.

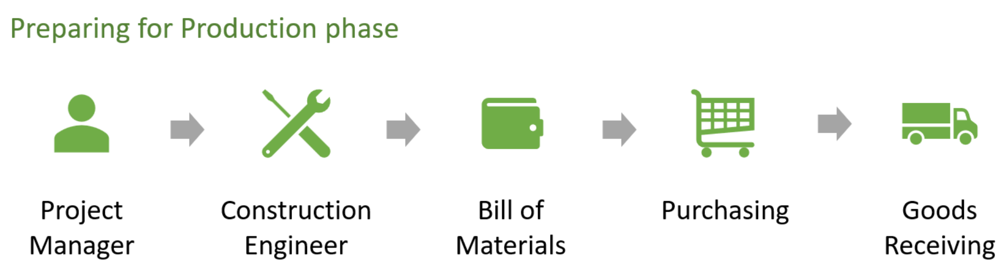

Figure 7: Process flow of the preparation for the production phase.

5.4. The Production Process

After the completion of the preparation phase, the production starts. Overhalla Hus's production consists of four units: the element line, the manual line, roof trusses and pre-cut. As requested by the case company, this thesis focuses on the element line. Therefore, the focus of this subchapter will be on explaining the element line's steps and supportive units.

The figure below is an overview of the production floor plan with the four units and the direction of the material flow. It is intended as an illustration and not to be studied in detail.

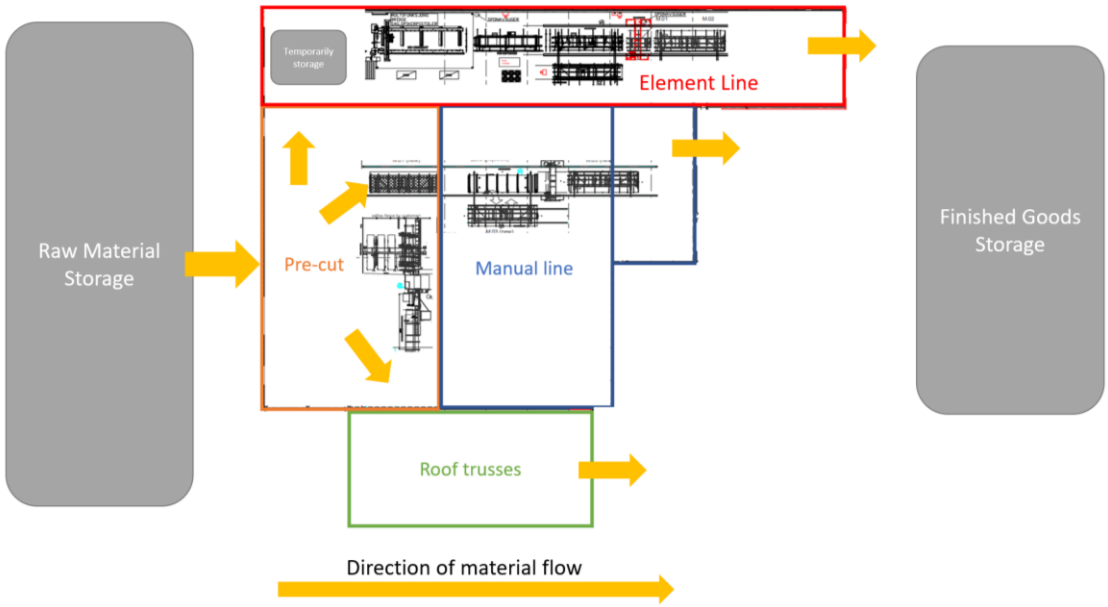

Figure 8: Floor plan of production.

Production manager

The project is positioned in the production plan fifteen weeks before the production date. The production manager oversees the production plan created in Microsoft Excel. Because of unforeseen events, the production date of projects may have to change, which is done manually in Microsoft Excel. The production manager decides the complexity of the project and the estimated production time. Operators in the production team have a meeting with the production manager every morning. At this meeting, they discuss the goals for the day and the outcome of the previous day.

Pre-cut

Pre-cut is the first stage of the production process, in which the raw materials are cut and prepared for the three production units. Pre-cut works according to the production plan; the goal is to be one project ahead of production. On big projects with many elements, typically for the pro-market, materials will be attempted to be processed a day in advance. At the morning meeting, the pre-cut team are updated on the part of the project the rest of the production is working on and plan their day accordingly.

Pre-cut consists of one automatic and one semi-automatic saw, which two operators manage. At the saws, the materials are cut, numbered, and sorted in the assembly order. The automatic saw only needs an input of raw materials and will deliver finished processed wood. A forklift delivers the raw materials from the storage to pre-cut at the request of the operators. Although the processing time to cut the materials for one element typically takes between three to five minutes, the processing time can be longer if the raw materials have different dimensions or challenging cutouts. Finally, the materials are transported by trolley to the next unit of production, where they are stored temporarily.

Element line

The element line consists of five stations, two of which have a Weinmann WEK 120 machine (WEK 120). According to its datasheet (Appendix A), "WEK 120 is a combination of framing station and multifunction bridge". The production line is semi-automatic, meaning the operators must still do various tasks even though the machines are automatic. The operators usually rotate working stations, but demanding projects require the operators to stay put. The figure below illustrates the floor plan and the stations of the element line. Furthermore, an explanation of the activities at the various stations follows in the table below.

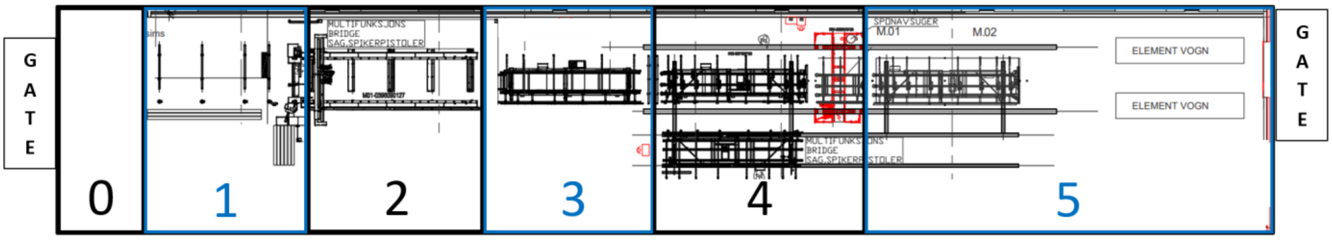

Figure 9: Floor plan of the element line and its stations.

Table 7: The activities at the stations at the element line

0 Station zero consists of a table and some free space. The table is sometimes used for carpentry and to make particular elements that do not fit into the WEK 120. The free space temporarily stores materials from pre-cut and raw material storage. A gate at the left side of this station leads to the raw material storage.
1 Station one forms the wood element's foundation with the frame's assembly. One operator is operating both stations one and two. The operator starts by studying the engineer's drawings of the element. The operator then picks up the finished processed materials from the temporary storage at station zero. The materials are placed in the WEK 120, which fastens and nails them into a frame. Then the operator adds more materials, where the machine fastens and nails. This process continues until the completion of the frame. The machine automatically measures the distance between the various studs based on the element drawings, which means that the only thing the operator needs to focus on is to add the materials evenly. Then the operator transports the frame to the next station.
2 At station two, plasterboards and house wrap are installed on the element. The operator will complete a checklist to ensure the frame has the correct measurements. In case of deviations, the production cannot continue until corrected. Next to the station is a pile of plasterboards with which the operator covers one side of the element. The operator will then attach the plates with some nails before the WEK 120 nails the rest. Then the machine will then saw away excess plasterboard and room for a window if the element is to have one. The operators then remove the cut-off parts before fitting the house wrap. The WEK 120 then marks the housing cover where to mount studs at the next station. Lastly, the operator transports the frame to the next station.

3 At station three is the mounting of windows and studs. Two operators work at this station, but there are two available operators. Here, the operators continue on the same checklist to ensure the element has the correct measurements. The studs are cut into pieces and placed on the element according to the markings made at the previous station. If the element is to have a window, it is mounted at this station. The window is lifted and placed in the element using a crane. The operators must be extra careful not to break the window, so usually, three operators usually mount it. The element will be transported to the next station if station four is free. If not, the operators will put cladding on this station. The cladding will not be nailed and cut until the next station.
4 At station four, cladding and window frames are attached to the element. Two operators work at this station, but there are two available operators. Here, the operators continue on the same checklist to ensure the element has the correct measurements. The operators then place cladding on the studs. If smaller pieces of the cladding are needed, the available operators usually use an external saw to cut them. WEK 120 then nails the cladding to the element and cuts off the excess cladding to fit it to the element. The operators remove the leftover pieces and double-check the nails to ensure they were properly nailed. The element is then entirely manufactured, and the next step is the packaging. The operators attach protective planks to the element to secure it during transport, as elements are transported together in packages. If the element is the first element in this package, the next step is to cover it in plastic sheeting. Finally, a crane will lift the element, place it on a trolley, and transport it to the final station.
5 Station five is the packing of the element. Two operators work at this station. The challenge with this station is to pack the elements together carefully. It can be difficult when the package consists of roof trusses and elements with windows. The operators must also consider the order of the items to match the order in which they are unpacked. The next step is to treat the plastic cover with heath to protect the elements from moisture. Lastly, the package is marked and transported to the finished goods warehouse through the gate.

5.5. Mapping of the case company's element production line

One of this thesis's aims is to execute a mapping of the element line at Overhalla Hus. The methodology Value Stream Mapping, explained in *Chapter 4.1., Value Stream Mapping*, was selected as the mapping method. Since the goal is not to analyse, only the first two steps were conducted.

The mapping was executed during a company visit on the 27th – 29th of March, 2023. The first day involved a *gemba walk* to get an overview of the production hall, a sense of flow and the four production units. During the day, a meeting was held with the production manager, where the plan for the mapping was reviewed.

To map the current state of a company, the first step comprises selecting a product family. However, no product family was selected due to Overhalla Hus operating within an ETO environment. Matt (2014) conducted a case study to identify the best practice guidelines for adapting and using VSM in the design of lean ETO manufacturing systems. The study emphasises the difficulty of choosing a product family in ETO environments. Firstly, the products are a result of a project. Second, each product is unique because it is designed and manufactured according to customer orders (Matt, 2014). Other ways of classifying must therefore be used.

The solution was to map the process of a relatively standard wood element, meaning it was flat, rectangular, without windows and doors and with one type of cladding. This was to try and map a situation as generally as possible where the element does not need additional processing due to special requirements. The original plan was to map several elements and thus obtain a more reliable data basis. Due to the time frame of the visit, there was only time for the mapping of one element.

The following day, the mapping of the CSM started. Delivery to the finished goods storage was chosen as the endpoint, as it marks the finish of the production. The element's next steps are transportation to the construction site and assembly, which is out of this thesis's scope. Demand can thus be calculated based on the company's desired amount of square meters per hour per man, which is $1.73 \frac{\mathrm{m}^2}{\mathrm{hrs}}$. This number is based on the total square meters the company must produce to achieve its production goal, divided by available time and operators.

Based on the fact that elements are approx. $12m^2$, and there are eight operators, the demand becomes:

$$Demand: \frac{1.73\frac{m^2}{hrs} * 8}{12m^2} \approx 1{,}2 \text{ elements per hour.}$$

The calculated takt time is:

$$Takt\ time: \frac{450\ min}{1{,}2\ elements\ pr\ hour * 7{,}5\ hours} = 50\ min.$$

This is not far from the company's previous measurements, which was 55 minutes.

The production processes were then mapped as visualised in the figure below. Here, the movement of the element implies the process. The first process is the pre-cut. This step was completed before the start of the mapping, and the cycle time (C/T) of five minutes is based on the company's measurements. According to the production manager, the time the materials are in intermediate storage between finishing cutting and assembly of the frame varies between one and two days. According to Rother and Shook (1999), one should choose the most extended time in the case of several choices. Thus, the intermediate storage time is two days.

C/T and uptime (U/T) are measured using a stopwatch for the following processes. The stopwatch was started at the start of the process. In the case of U/T, the time was noted when the machine started and ended. When the element moved on to the following process, the stopwatch was stopped, and the time was noted. The activities carried out during the process were also noted. The U/T percentage was calculated by dividing the minutes the machine was up and running by the process C/T. The number of operators at each station was also noted down. As illustrated, there is a push arrow between the processes, meaning that each process pushes the element to the following process.

Concerning station three, the reason for the frequent time intervals, as shown in the figure below, is because the WEK 120 machine's nailing function broke down several times.

The raw material warehouse was chosen as the starting point. The raw materials are sporadically delivered to the warehouse, as some goods have a delivery time of several months, which makes it challenging to map. Some raw materials are stored in the production hall, while the rest must be transported from the warehouse to the production hall with a forklift. The goods are temporarily stored in the production hall, while some are used immediately.

Most information flow between production control and the various stations is oral and occurs daily in the morning meeting. The exception is the finished goods warehouse, contacted digitally weekly, and the raw material warehouse, contacted verbally daily.

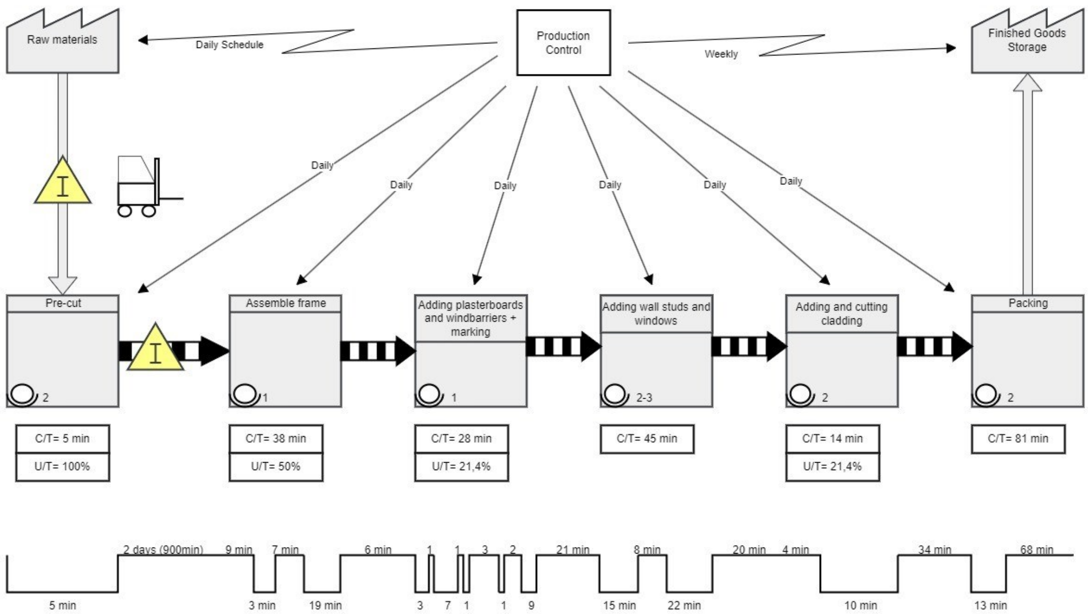

Figure 10: Current-state map of Overhalla Hus element line

The final step of the mapping is the timeline at the bottom. This symbolises the production lead time and is divided between value-added time (VA/T), the lower part of the timeline, and non-value-added time (NVA/T), the upper part. Finally, process cycle efficiency (PCE) was calculated, which is the percentage of value-added time of the total process time.

$$PCE\colon \frac{108{,}0\ min}{1192{,}0\ min} * 100\% = 9{,}1\%$$

Table 8: Data table of the current-state map

Demand	1,2 elements per hour
Takt time	50 min
Lead time	1192 min
Value-added time	108 min
Non-value-added time	1084 min
Process cycle efficiency	9,1%

5.6. Digitalised value stream mapping

One of the goals of this thesis is to look at the possibilities of collecting real-time data on the element line of Overhalla Hus. Since a mapping was carried out using VSM, examining how a digitalised VSM can be introduced to the element line is natural. This sub-chapter looks at various technologies that can be used to create a digitalised VSM. The technologies should be able to be implemented in an SME and are therefore less resource-intensive and do not require high expertise.

Weinmann WEK 120

According to the Weinmann WEK 120 data sheet (Appendix A), the machines in the element line have built-in software. The software called Power Control includes several programs, some that are standard and some that are add-ons. Still, it is unclear which features are standard and which are not. One of the standard programs shows the machine status, any errors, and how errors can be resolved. Another program called Schuler MDE, which is uncertain whether there is an add-on or not offers a data storage function. The following data can be analysed with a complete package:

- Process times of machine
- User degree and cycle time
- Production quantities
- Error times & error reason
- Actual service condition
- Necessary service requirements

Overhalla Hus has confirmed that they use Wup-Works, which works for file transfer of a computer-aided design system. It has yet to be confirmed if they have more software. This opens up the possibility that the company can either collect data via the existing program or contact Weinmann to obtain an extended version with data collection. It may seem that Power Control can collect data a lot of valuable data from the machines and visualise it. Both the machines' process time, quantities, cycle time and errors would be helpful for Overhalla Hus to collect and thus get an overview of the element line. Whether Power Control can be connected to an external ERP system or MES has not been investigated.

RFID

A technology that can be used to create a digitalised VSM is radio frequency identification (RFID). According to Weinstein (2005), RFID is a small tag that can be attached to or embedded in objects. An RFID system involves goods marked with tags containing transponders that send out messages that specialised readers can read. Usually, the RFID tags store an identification number, which the readers read and connect to a database. RFID tags can also contain a writable memory, where information can be stored and transferred to readers. There are two categories of RFID tags, active and passive, which depend on the power source. Active RFID tags contain their own power source, while passive tags receive power from the signal from an external reader. Active tags send a stronger signal over greater distances (Weinstein, 2005).

The use of RFID in a digital VSM has been done previously, for example, by Phuong and Guidat (2018), who created an RFID-based sustainable value stream mapping in an apparel manufacturer. The aim of using RFID was to get real-time data on the number of goods in production and their location. They placed a passive RFID tag in each product unit. At the start and end of each process, they placed a tunnel to read the RFID tag. The operators had a portable reading device that they used to scan. The information from the tags was sent to a computer, which made the data collected more readable via an ERP system. It passed the information on to a visual information board, which made the data from the goods in progress visible to everyone in the factory (Phuong & Guidat, 2018).

(Liu et al., 2012) have looked at how an RFID-enabled real-time production management system can be designed for a motorcycle assembly line. They present three reasons for using an RFID system to collect data:

1. "Tag identification is automatic and contactless and does not require manual intervention, easing the workload of busy operators".
2. The RFID system is resistant to dirty environments such as dust or oil. There is a lot of wood dust in a wooden element factory.
3. "The RFID system allows the detection of multiple items simultaneously".

A similar system as Phuong and Guidat (2018) present can be introduced at the element line to Overhalla Hus. The RFID tag can be attached to the element while assembling the frame to start measurements. The tag contains the product's critical information. Readers can be placed at the start and end of each station. As the element works its way through the element line, various readers will receive the information about where the element is and pass it on. The company will then know how the cycle time of the element at each station. Thus, the system can also measure the number of goods in work. A handheld reader can be included to break down the station's cycle time into the cycle time of the various activities performed at each station. However, it requires an ERP system or MES to process the data collected from the tags. It will also require the purchase of RFID tags, antennas, readers and possibly scanners.

Smart Devices

Another technology that can be used for data collection is smart devices. According to Guerreiro et al. (2017), smart devices are electronic equipment that is wireless, mobile, network-connected and comes with various sensors. Examples of smart devices are smartphones, tablets and smart wearables etc. Integrating smart devices into production processes will motivate workers by providing information and handling instructions everywhere at all times (Guerreiro et al., 2017). Lenz et al. (2023) argue that introducing smart device-enabled applications in the industry remains a significant and interdisciplinary challenge, especially for small and medium-sized enterprises (SMEs). This is due to a lack of capacity and experience, and it is essential to choose smart devices suitable for the intended use case.

One way to integrate smart devices into the element line can be by using smartphones, tablets or a wearable scanner. By tagging the element with barcodes or QR codes, operators can scan it and collect cycle times as the element works its way down the process. Identifications are then exchanged to generate context with a specific process station, a unique part number or the identification of an operator. Thus, the system can also measure the number of goods in work. Another method is using a manual input by having, e.g., tablets at each station on the element line. The collected data can be acquired by pressing start at the start of a process and then stopping at the end to measure cycle times. Or the operator can measure the time and fill it in. Both methods require an ERP system or MES to process the data collected.

Sensors

The last method presented for collecting data is the use of sensors. According to Javaid et al. (2021), “a sensor is a device that detects input stimulus, which can be any quantity, property, or condition from the physical environment and responds to a measurable digital signal". Examples of input stimuli include pressure, force, flow, light, heat, movement, or moisture. The response output is usually an electrical signal and can be voltage, current, capacitance, resistance, frequency, etc. The response is converted to a readable display or transmitted electronically over a network. Sensors can be classified based on different factors, such as goals and areas of use (Javaid et al., 2021).

The supply chain industry needs monitoring solutions and technology for streamlined supply lines, where sensors can be used for process and condition monitoring. Sensors can capture and analyse data to make effective decisions, and self-optimisation is possible for automation in production lines (Javaid et al., 2021). Syafrudin et al. (2018) undertook a performance analysis of a sensor system, among other things, for a real-time monitoring system in car production. In their presented system, sensors are attached to desks at a workstation in the assembly line. The sensors consist of temperature, humidity, accelerometer and gyroscope sensors. The data from the sensors is transmitted wirelessly to a cloud server where the data processing system is installed. After processing, sensor data such as temperature, humidity, accelerometer and gyroscope are presented to the manager in real-time via a web-based monitoring system (Syafrudin et al., 2018).

Sensors that react to movement can be used to install a sensor system at the element line of Overhalla Hus. The sensors can be attached to measure movement at various points along the line. Examples could be to measure the cycle time at each station by attaching the sensors to the start and end of each station. Thus, the system can also measure the number of goods in work. A sensor system requires a data processing program to process the data obtained from the sensors and transform it into a visual presentation. However, the sensors must be connected in a secured area so they do not collect data for other movements or are affected by vibrations.

6. Discussion

The following section aims to answer the study's research objectives. First, RQ1 will be answered, and the advantages and disadvantages of the presented mapping methods will be discussed. Then, RQ2 will be answered and a discussion about which data should be prioritised for real-time data collection. Finally, RQ3 will be answered where the technology is available to create real-time data collection and the advantages and disadvantages of the various technologies.

6.1. Advantages and disadvantages of the mapping methods

This sub-chapter aims to answer research question 1, which reads as follows:

> *To form a basis for real-time data collection, what are the advantages and disadvantages of the presented mapping methods?*

A literature study was conducted to find methods for mapping a production line. The study found several mapping methods, presented in *Chapter 4, Literature Review.* The methods are part of the methodologies, Value Stream Mapping, Control Model and Flowchart. Furthermore, this section will discuss the advantages and disadvantages of the methods regarding forming the foundation for real-time data collection.

Value Stream Mapping

As a mapping method, VSM is convenient, inexpensive and fast. The method is relatively easy to understand and implement, and it is cost-effective, as, in theory, you only need pen and paper, and the time spent depends on the lead time for the process. On the other hand, these factors affect the accuracy of the mapping. The method allows a broad perspective, including the entire value stream and looking at the process as a whole rather than individual activities. VSM thus visualises areas for improvement in the process, which helps to determine which parts of the process should be prioritised for improvement and where data should be collected in real-time. Inventories, transport and information flow, are also included in the mapping, which can be factors worth including in the real-time data collection. On the other hand, the mapping is not detailed enough to point out which part of the process should be focused on, which may mean that several more detailed mappings of the activities in the process must be done.

Using standard symbols also makes it easy for others to understand the process. So that it can be used in group work when preparing the real-time data system. It is an advantage that the mapping itself includes data collection, as this gives a clearer picture of the situation. The kind of data to be recorded during the process mapping is optional so the company can decide on the focus area. The method nevertheless presents common measurements that can be useful to measure in real-time. The method creates and shows an understanding of the flow of materials and information in the process. In productions where many products are produced, VSM has a disadvantage. It is only possible to draw the map with one product family at a time because it becomes too complex when drawing several processes. Therefore, for several product families, several maps must be drawn. The method is also not suitable for mapping all types of processes.

Control Model

Strandhagen et al. (2021) point out that the control model is adaptable since it involves different methods, principles and systems. The company itself chooses what the goal is for the mapping and how this is to be achieved. The method forms a broad overview, including suppliers, customers, administrative processes, transport, information, and material flow. Not all of these factors are necessary to find processes and activities to be measured in real-time. The fact that so much is included in the mapping means that the map becomes more complex and, thus, less intuitive. The actual material flow and activities are accurately mapped, which is an advantage when choosing measurement points. It is also advantageous that inventory and transport are included, as they can be an essential part of data collection.

The control model itself does not involve any form of data collection. Data can provide a clue as to which activities should be prioritized when collecting data. The method can nevertheless be well combined with data collection, but the company must find methods for this themselves. The mapping is so precise that it takes some time to complete. It also requires the company to familiarise itself with the methodology and implementation methods. The mapping requires some sort of software, as it can quickly become too complicated to draw by hand. It is also not as intuitive to understand which processes should be improved.

Flowchart

A flowchart is a simple, time-efficient mapping tool that is intuitive. The method requires the company to become familiar with the use of symbols, as they have special meanings. The method is flexible, and there are many ways to describe a process. It is up to the company to decide what the mapping should look like as long as the standard is followed. Since the method is so flexible, it can be challenging to set limits on what to map, and the diagram can quickly become too large and unmanageable. According to Aguilar-Savén (2004), flowcharts are best used for detailed processes and are less efficient at providing a broad overview. It is up to the company to decide which processes are to be mapped and the level of detail. There are additional packages with figures should the usual ones not cover the need.

The main and sub-activities are not specified, and there is no description to elaborate on the process and activities. Aguilar-Savén (2004) also points out that flowcharts can quickly identify bottlenecks or areas for improvement. This is an advantage as these factors should be prioritised in real-time data collection. The method does not include any data collection form, meaning the company must find methods for it. In turn, the method does not visualise the flow of materials.

Various flowcharts, such as EPC, go more in-depth on processes. The advantage of EPC is that it is intuitive for businesspeople. It is also suitable for processes with parallel activities and decision points. Another example is BPMN, which is good at describing complicated business processes and making them intuitive.

6.2. Which data to prioritise collecting

This sub-chapter aims to answer research question 2, which reads as follows:

> *To create a real-time data collection, which data should be prioritised collecting, particularly regarding the case company?*

Through a literature search, information on real-time data collection was acquired. Regarding what kind of data should be measured with this system concerns production to a greater extent than technical aspects. The essential technological aspect is that it is technically possible to collect the necessary data. With the introduction of digitisation and Industry 4.0. technology has come a long way. Technology, on the other hand, is an aid to obtain desired data, visualise it and, in some cases, make decisions. Companies still have to determine which data to obtain and, in most cases, decide what it will be used for. Thus, the kind of data that should be measured depends on the purpose of the data collection.

Regarding production, several possible data collection points are described in *Chapter 3.1. Lean Manufacturing*. One focus could be to minimise non-value-adding activities. By mapping out which activities are value-adding and which are not, the company can focus on measuring the time the non-value-adding activities use. Thus, the company can record whether measures for reducing the non-value-adding activities work. Another focus is bottleneck operations. Since they affect the lead time for the process, bottleneck operations should be prioritised in real-time data collection. Another focus can be different measurements, for example, the cycle time of processes, especially those where the cycle time is to be improved. Minimising the lead time as much as possible is vital and can be an essential measuring point. Uptime is another example that can be measured and prioritised, especially for machines that keep the entire production process going. It can also demonstrate the degree of utilisation of the machine. These are, nevertheless, only examples of measurements presented in this thesis, and the focus for real-time data collection should be determined by either vital machines and activities, improvement operations or measuring the capacity of the process.

Regarding Overhalla Hus, a VSM of their element line was carried out. In the mapping, several measurements were done, presented in *Table 7*. An important point is that the data collection was only carried out for a standard element within one project. This means that the measurements show a snapshot of the capacity of the production. Production measurements should have been made over a more extended period and with several projects to obtain a better data basis. However, since the company operates in an ETO environment, obtaining a complete overview of the capacity will still be challenging, as factors always influence the data.

The data collected shows that the lowest U/T is at stations two and four. Both have a U/T of 21.4%, which is poor utilisation of WEK 120. Overhalla Hus should aim to increase the U/T on the machines, and then the time on the manual activities should be shortened. During the semi-interview conducted by the operators, several answered that these were the most time-consuming stations with many steps to be fulfilled. Thus, the company should collect C/T data in real-time on the activities that do not involve WEK 120 during various improvement measures. A data collection will illustrate which measures work and which do not. U/T can also show how often the machine has downtime, which happened several times with the nail function during mapping.

Regarding time, station 5, which involves packing, has the highest C/T, and the company would be able to focus on reducing time here. For example, the operators can measure the waiting time for this station. The total time of the non-value-added activities in the process is 184 minutes if one disregards the waiting time of two days in intermediate storage. The total time of the non-value-added is higher than the total time for value-added activities of 108 minutes. Here the company can aim to reduce the time spent on non-value-added activities, thereby increasing PCE. To manage this, the time spent on non-value-added activities should be measured to quality check measures taken to reduce it. The company stated that they desire to reduce the lead time on production and can place measurements at the start and end of the element line to measure this. It also indicates the line's capacity, which is essential to know several aspects of the overall process. For example, when selling the project, the seller can use more real numbers to ensure delivery or the production manager can plan production based on accurate data. Data collection can and is used to give feedback to the construction engineers on which aspects of the production of the elements are more time-consuming than others.

6.3. The technology available to create a real-time data collection

This sub-chapter aims to answer research question 3, which reads as follows:

> *To create a real-time data collection, what technologies are available, and what are the advantages and disadvantages of implementing them in the case company?*

Chapter 5.6. Digitialised value stream mapping introduced three technologies to create real-time data collection. The three technologies are RFID, smart devices and sensors. An RFID system consists of attaching RFID tags to materials in production, measured by readers that can transmit position and time. Smart devices can scan QR codes or barcodes to collect time data. Smart devices can and are used to enter data. Sensors can detect an input stimulus and respond by sending an output sensed by software. Industry 4.0. includes several technologies, but due to the limitations of the task, only three were introduced. The presented technologies cannot be included alone and must have software such as ERP or MES in the background.

Related to Overhalla Hus, it was introduced how the three technologies and WEK 120's software could be implemented in a digitalised value stream mapping. The advantages and disadvantages of the four solutions will be further assessed.

WEK 120's software Power Control

Since the company already uses, this software is an advantage as they do not need to introduce something new. Another advantage of Power Control is that they comply with WEK 120 and can collect data on process time, cycle time, production quantity and errors. The solution does not involve additional work for the operators. As the company already uses the system, one can assume that the implementation price is low. It is still a question of how good the software is and whether it meets the requirements for creating real-time data collection. It also creates no data collection on the stations that do not have WEK 120 or the time on the activities that do not include the machines. It is also unknown whether the software can be connected to an external ERP or MES for possible cooperation with another data collection system.

RFID

RFID tags have become more common and are thus relatively inexpensive. Overhalla Hus must nevertheless invest in purchasing RFID tags, antennas, readers and possibly scanners, resulting in medium implementation costs. The system involves little extra work for the operators, attaching tags. With hand-held scanners, however, the workload is more significant. RFID tags can measure the cycle time of the stations or the various activities at the stations, production quantity and the goods in progress. An identification system of the element that can be connected to RFID, the chip, must also be included.

Smart devices

Smart devices have become more common and, thus, relatively inexpensive to buy. The system will mean more work for the operators, who must operate a smart device and use it to scan. An identification system for the element must also be included, either by QR code or barcode. Filling in data manually on a smart device is believed to be the most time-consuming. Nevertheless, smart devices can motivate workers, as they can avoid manual paperwork, such as filling in checklists, or through applications that can assist in production. Smart devices can be connected to computer-aided design systems, giving a better overview of the element, for example, a modelling program that can show the element in 3D. The system of smart devices can collect cycle time for stations and activities and record production quantity and goods in progress.

Sensors

Creating a sensor system has a high implementation cost. In addition to the sensor equipment, a data processing program is needed to process the data obtained from the sensors and transform it into a visual presentation. The sensor system can collect the cycle time of stations, production quantity and goods in progress. The system does not include additional work for the operators. Sensors are sensitive, and whether they can withstand the vibrations in the element line is questionable. This can result in incorrect data. Dust and other dirt that occurs in production can also affect the sensors. There is also a risk of error sources if the sensor reacts to movements other than the movement of elements.

Combining

It is also possible for Overhalla Hus to combine several of the technologies into a shared measurement system. For example, Power Control can be well combined with the other systems in that Power Control measures the stations with machines, while the other methods measure other production activities. Table 9 shows a summary of the advantages and disadvantages of the introduction of the various systems.

Table 9: Summary of the advantages and disadvantages of implementing the proposed technology to the element line

Technology	Advantages	Disadvantages
Power Control	- Already owned by the company - Comply with WEK 120 - Can collect process time, cycle time, production quantity and errors - Possibly low implementation price - Do not include additional work for the operators	- Unsure of how good the performance is - Only collect data from the activities of WEK 120 - Unknown whether it can be connected with other software
RFID	- Do not include additional work for the operators - Can collect cycle time, production quantity and goods in progress - RFID tags are cheap	- Medium equipment expense - With hand scanners, some extra work for the operators - Need an identification system
Smart devices	- Motivate operators - Can collect cycle time for stations and activities, production quantity and goods in progress - Smart devices can connect to other supporting applications - Low implementation price	- Extra work for the operators - Need an identification system
Sensors	- Can collect cycle time of stations, production quantity and goods in progress - Do not include additional work for the operators	- High implementation cost - Need to be connected to a reception system - Possibility of data errors - Uncertain whether the sensors can withstand the vibrations and dust that are in the production facility

7. Conclusion

This section presents a summary of the findings from the research, limitations of the research, and suggestions for further work.

Summary of findings

This thesis aimed to determine how real-time data collection can be introduced in small and medium enterprises in the manufacturing industry. This was illustrated through a case study of an SME within the prefabricated wooden element production industry. A literature study provided three methods which could be used for mapping a production process. A mapping of the selected production line within the case company was conducted, contributing to collecting production data. Through the literature study, technology was found, resulting in four ways to introduce real-time data collection for the case company.

Three mapping methods were presented as a result of a literature study to form a basis for real-time data collection. The methods were assessed, resulting in the findings of their advantages and disadvantages. Value Stream Mapping as a mapping method is flexible, convenient, and efficient, includes the entire value stream and is good at collecting data in time that indicates which processes should be measured. It is still inaccurate enough to form a complete mapping for real-time data collection and is unsuitable for all processes. As a mapping method, the control model visualises the process from a significant perspective and is precise and flexible in choosing methods. It can still be large and difficult to understand and handle, does not include any form of data collection, and is relatively time-consuming. The flowchart mapping method is simple, time-efficient, intuitive, flexible, and available in different variants, some of which go more in-depth on processes. The method can still be significant and unmanageable, is better for detailed processes, does not include data collection and lacks a process description.

Which data to prioritise collecting with real-time data collection depends on the purpose of the data collection. The essential technical aspect is that it's technically possible to collect the data. With a production aspect, data can offer control, confirm the need for improvement measures or confirm that the measures are working. Several elements that can be measured were presented, such as minimising non-value-adding activities, lead time, cycle times and uptime. Regarding the case company, the VSM of the element line contributed with several measurements, which the company can collect by implementing real-time data collection. Measuring the U/T of WEK 120, the C/T of the activities in the process, the non-value-added processes, or the lead time of the whole process are all possible targets. To determine which measurement to aim for, the company should analyse which will give the wanted outcome.

As a result of the literature study, three technologies which can be used to create real-time data collection in an SME were presented. The technologies found were RFID, smart devices and sensors, all of which need the support of an ERP system or an MES to be implemented. Suggestions of how the three technologies could be implemented in the case company were presented, along with an assessment of the WEK 120's software. The technologies were assessed, resulting in the findings of the advantages and disadvantages of implementing them in the case company. WEK 120’s software is already in the company’s obsession, can collect valuable measurements with a possibly low implementation price and does not include additional work. However, there is uncertainty about its performance, whether it can be connected to other software and the fact that it only measures 120 WEK. RFID does not include additional work, can collect valuable measurements, and has a possibly low implementation price. With hand scanners, there may still be extra work and an identification system is needed. Smart devices can motivate the operators, collect valuable data, connect with other supporting applications and has a low implementation price. The system needs an identification system and includes extra work. Sensors can collect valuable data and do not include additional work. However, the implementation cost might be high, and a reception system is needed, the possibility of data errors might occur, and there is uncertainty about whether it's suited for the production environment.

Results from this assignment contribute to knowledge about how SMEs can introduce Industry 4.0 by implementing real-time data collection. The assignment focuses on a company in the prefabricated wooden element production industry but may apply to companies and industries operating in similar environments. For the case company, Overhalla Hus, the assignment has contributed insight into how they can introduce Industry 4.0 technology.

7.1. Limitations

The most important limitation of this thesis is the lack of data material. Data collection was carried out, but only for one element. Many external factors can affect the data, which only apply to the one time the measurement was carried out. With further measurements, these factors become less important. This means that the results are not 100% accurate for Overhalla Hus, but it is still relevant enough to illustrate a realistic scenario. In addition, the candidate collects the data physically, creating more sources of error. The assignment is limited to a single case study. Several case companies could have been acquired to reinforce the real issues further.

The results are conceptual and based on case-specific inputs, meaning that the data produced may not be relevant, but the findings and implications of the data may be applicable. A bias in the assignment may have arisen in the literature study. Here, the candidate's subjective opinions may have influenced the selected articles, and relevant articles may have been excluded.

The project has a time limit since the study must be delivered by June. Geographical distance from the case company is a limitation of the project. The geographical distance is so significant that several visits to collect data were made difficult. It can have an impact on the quality of the product. It also makes working directly with the company in question more complicated.

7.2. Further work

This thesis proposes three technologies that can be used to create real-time data collection in an SME. An analysis of the detailed implementation of the three technologies can be performed. A systematic literature review can be carried out by looking at which industry 4.0 technology has been implemented in SMEs and what effects they have.

In Overhalla Hus's case, an element line analysis should be conducted to assess which areas should be improved. Then an analysis of how data should be collected for the specific area can be conducted.

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Appendix

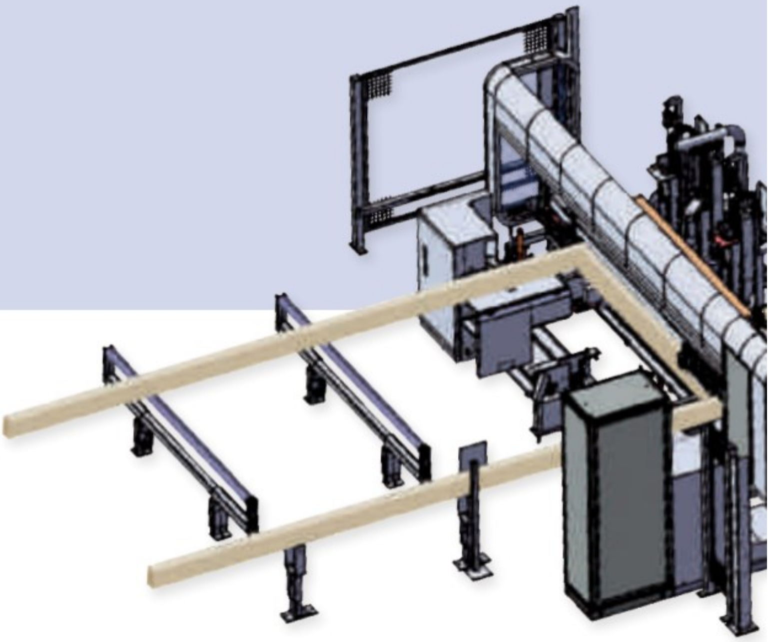
Appendix A – Data Sheet Combi Wall System WEK 120

WEINMANN

Combi Wall System WEK 120

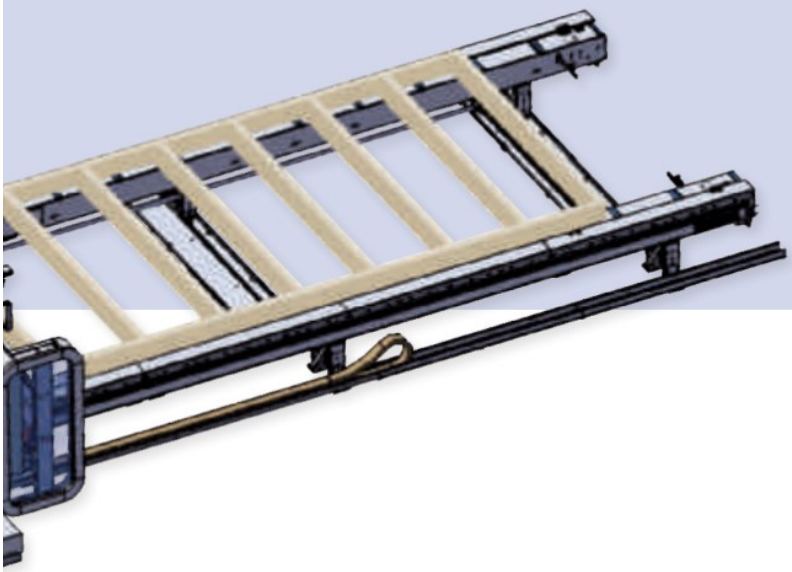
WEK 120 - The combination

Highlight:
1 operator



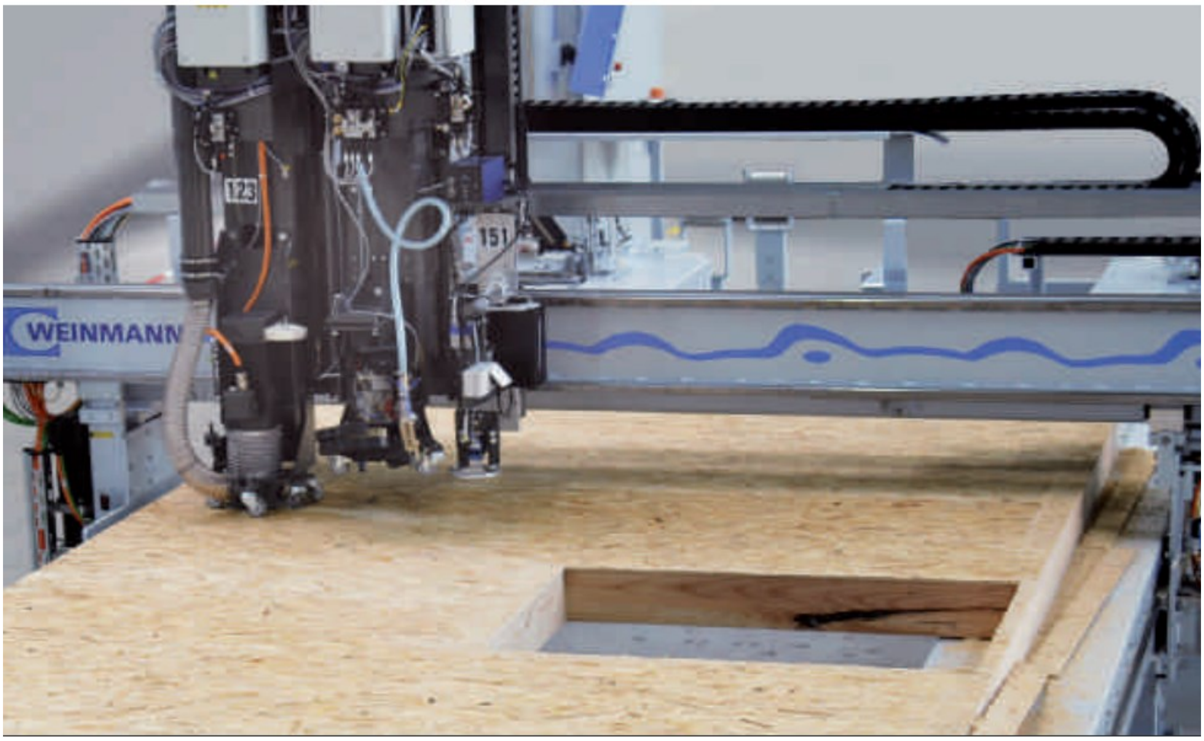
The WEK 120 is a combination of framing station and multifunction bridge.
The frame work assembly and element sheeting takes place at one work station.
A system for the production of wall and gable elements using one single machine.
Developed especially for small and medium-sized manufacturers of wooden houses with limited factory space.
Framework with sheeting one side can be produced at a high level of quality and flexibility by only one operator.

that's its characteristic



Highlight:
Less space but more performance

Function:
The framework is adjusted, clamped and fastened automatically by the well proven Weinmann stop alignment system. The stud positioning is also automatic by means of the CNC-driven outfeed system. The positioning of the sheeting on the rectangular clamped framework is done manually. A CNC-driven multi-function bridge mounted on the outfeed gripper, can automatically travel across the element to fasten the sheeting in a high speed operation.



Combi wall system WEK 120

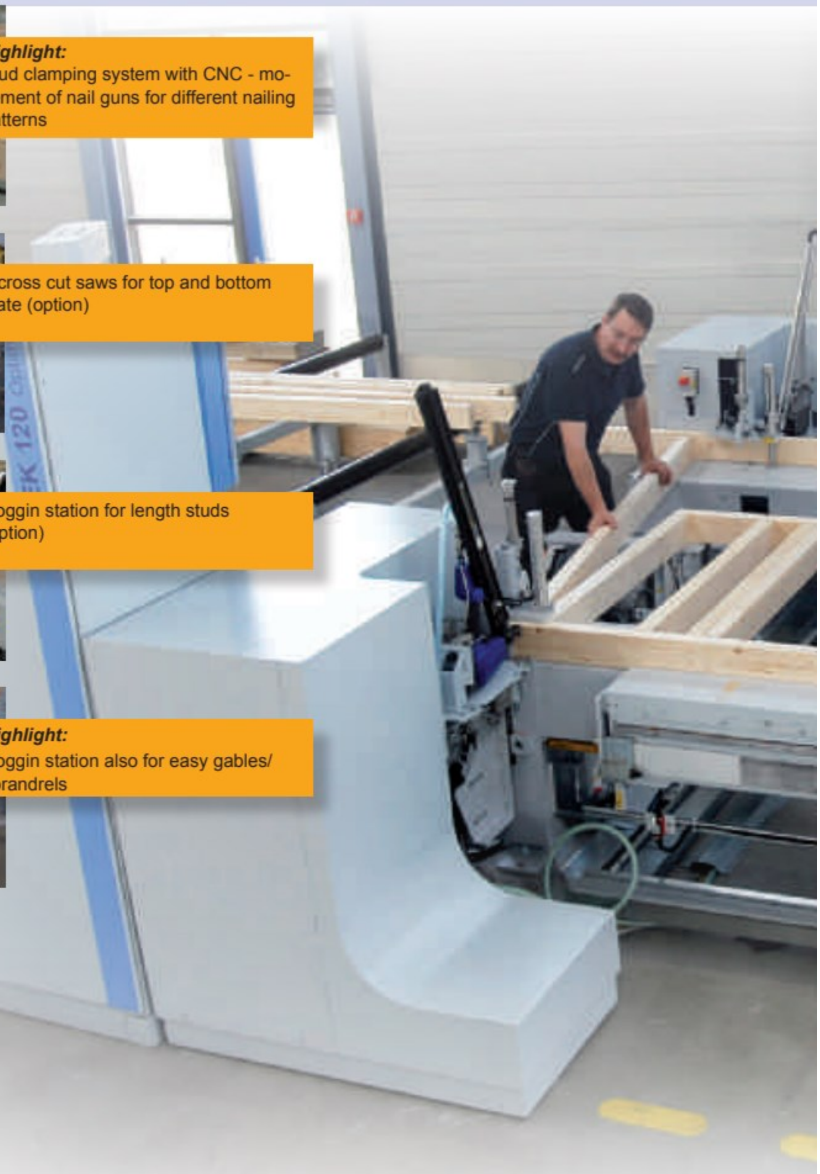
Highlight:
Automatic width adjustment

Highlight:
Stud clamping system with CNC - movement of nail guns for different nailing patterns

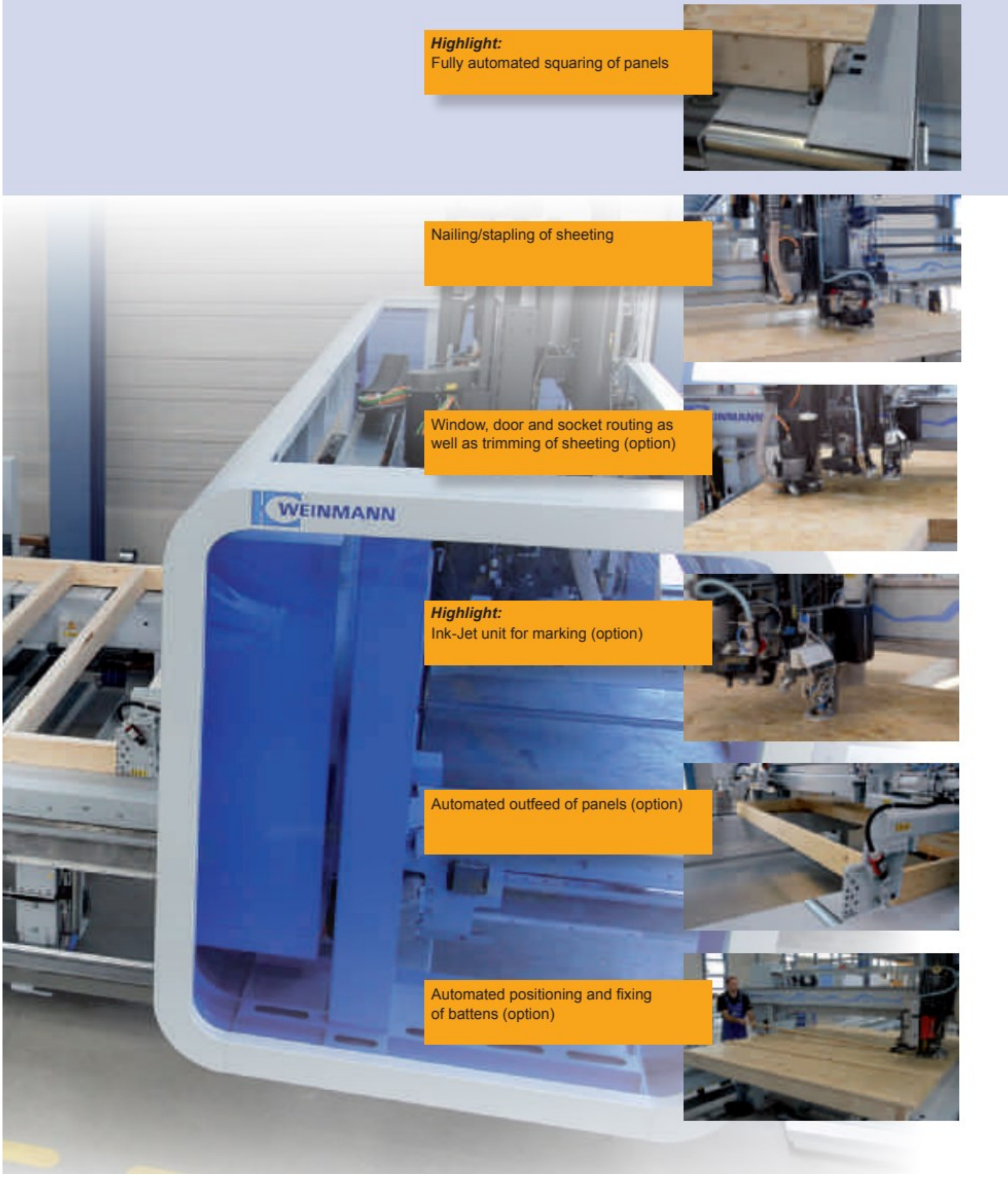
2 cross cut saws for top and bottom plate (option)

Noggin station for length studs (option)

Highlight:
Noggin station also for easy gables/ sprandrels

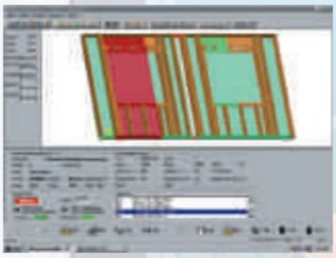


11 jobs = 1 machine



Software / Service

The new software generation with new Power control
The great advantage of our new software, running under Windows, is not only simple operation, but also it provides a common interface across all Weinmann machines. This minimises time consuming training and familiarisation, particularly when your system is expanded and complemented by further Weinmann machines.

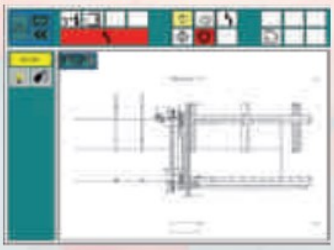


The Power Control with an online connection and integrated remote diagnosis (contact plan and diagnosis by telephone) are important and efficient features. They save the customer having to pay the technician's costly travel expenses. Of course, it is also possible to run the machine by CAD/CAM link.

The following software programs are included as standard in the scope of the Power Control:

- **Wup-Works**
- **Wup-View**
- **Wood-Scout I**
- **Schuler MDE Basic**

Wood-Scout I (Optional II)
Wood-Scout is a multimedia diagnosis system for display of faults and machine status. This allows systematic trouble-shooting and reduces machine break-downs.
Wood-Scout II provides the possibility to save data (e.g. to a specific fault) with your own comments. If the same fault happens again this comment pops up automatically. The integrated machine documentation opens automatically at the right position showing how to eliminate the fault.
All these software systems are very user-friendly - you may eliminate many faults on your own without needing the help of our service team.



Service

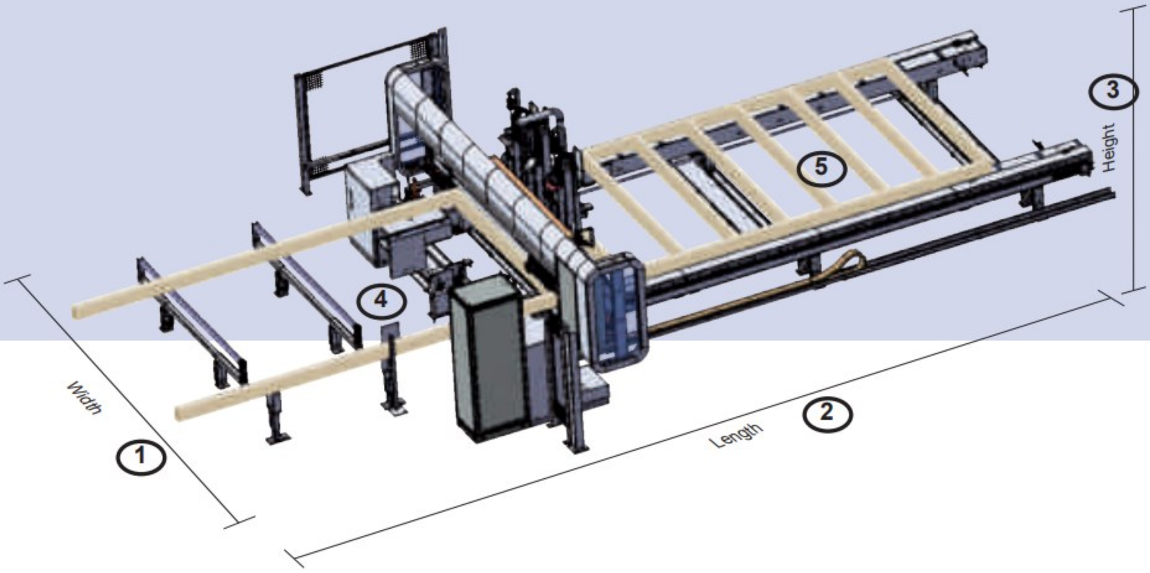
MDE
Schuler MDE Basic + Professional (Option). With the machine data entry you can save important data and use for yourself the relevant information.
The following data can be analysed:

- Process times of machine
- User degree and cycle time
- Production quantities
- Error times & error reason
- Actual service condition
- Necessary service requirements

This way Schuler MDE Professional makes your production transparent and helps you, to cover up gaps and weak positions in the production.
Schuler MDE basic is installed for free on every machine as a standard software.

Efficient remote diagnosis
Possible causes for faults are detected, isolated and in most cases eliminated at once by the time and cost saving remote diagnosis of our service center.

Technical data



Machine dimensions	WEK 120	
Width in mm (1)	7 900	8 500
Length in mm (2)	16 500 / 20 500 / 24 500 / 28 500	
Height in mm (3)	3200	
Weight in t	3,0	

Product dimensions	WEK 120	
	Standard	**Option**
Wall height in mm	1200 - 3200	3800
Wall length in mm	6 000 / 8 000 / 10 000 / 12 000	
Frame work width in mm	75 - 200	300
Timber thickness in mm	35 - 80	-
Performance	0,5 -1,0 m/min	
Width of the element in mm	max. 250	max. 350

Machine equipment	WEK 120
Safety	extensive safety concept per CE-Norm with safety light barrier, safety fence.
Control	Power Control PC 85
Software	
Wup-Works	for files transfer of a CAD-System e.g. Sema, HSB, CAD-Work, Dietrichs, Bocad, Keymark, S+S, Mitek, Eleco, Sitestream etc.
Wup-View	for visualization of data files
Wood-Scout I	the multimedia - based diagnostic system - faults displayed in words
Wood-Scout II (optional)	the multimedia - based diagnostic system - faults displayed in pictures (Possibility of adding own comments)
Schuler MDE Basic	for automated data entry and analysis of operating data
Wup Edit (optional)	for processing and simple changes of data files
Wup Client (optional)	for communication between production control system and machine (Server/client)

Working options	WEK 120	
	Frame work assembly (4)	**Element sheeting** (5)
Fastening	yes	yes
Nailing (NC axes)	yes	yes
Sawing	option	option
Routing	-	option
Marking	-	option

Connected loads	WEK 120
Power supply	18 kW
Compressed air consumption per aggregate	1500 Nl/min
Pneumatic pressure	8 bar
Customized aggregates (Fastening tools are not part of our supply)	Bea, Duofast, Haubold, Max, Paslode, Senco, etc. (Fastening tools are not part of our supply)

WEK 120 · E 02/02.10 · Subject to technical modifications

A company of the Homag Group

WEINMANN

Weinmann
Holzbausystemtechnik GmbH
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